Tutorials in Diagnostic Radiology for Medical Students

Ciaran E. Redmond
Michael Lee
Editors

Springer

Tutorials in Diagnostic Radiology for Medical Students

Ciaran E. Redmond · Michael Lee
Editors

Tutorials in Diagnostic Radiology for Medical Students

Springer

Editors
Ciaran E. Redmond
Academic Department of Radiology
Royal College of Surgeons in Ireland
Dublin, Ireland

Michael Lee
Academic Department of Radiology
Royal College of Surgeons in Ireland
Dublin, Ireland

ISBN 978-3-030-31892-5 ISBN 978-3-030-31893-2 (eBook)
https://doi.org/10.1007/978-3-030-31893-2

© Springer Nature Switzerland AG 2020
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

We are pleased to introduce this book for students interested in diagnostic radiology. Radiology is a core component of hospital medicine and few patients attending hospital do not have an imaging test to aid diagnosis. The importance of radiology in the diagnostic pathway is increasing year on year. However, the teaching of radiology to undergraduate medical students is often haphazard. In our opinion, it is best taught by a dedicated period of clinical attachment to an imaging department and is inherently suited to small group tutorial sessions rather than through the study of conventionally structured textbooks.

We have applied our experience in undergraduate radiology education to provide a book composed of 16 practical and case-based chapters with each chapter serving as a separate “tutorial”. Our goal is that the book can serve as both an adjunct to students completing their radiology rotation and as a self-directed learning resource. We believe that the book will also assist radiologists involved in medical student education and prove a useful aid to the planning and delivery of tutorials. The guiding principle throughout the production of this book was to strive for text that was easy to read, interesting, and enriched with high-quality radiological images. The content is delivered in succinct bullet point format with text boxes containing “Radiologist’s tips” to help clarify key concepts.

Diagnostic radiology is a constantly evolving medical speciality and with this in mind, we have included topics at the cutting edge of the speciality in addition to the more traditional areas taught in undergraduate radiology education. The book covers contemporary imaging pathways in acute stroke, advanced cardiac imaging, and a chapter dedicated to emerging imaging technologies such as artificial intelligence.

We are indebted to the expertise and hard work of the authors who contributed to this book. Our hope is that this book successfully conveys the authors’ passion for both radiology and education. We hope you too will find it useful in your studies.

Dublin, Ireland

Ciaran E. Redmond
Michael Lee

Contents

Tutorial 1: Introduction to Radiology

Marian Hanley, Roisin O'Cearbhaill and Ciaran E. Redmond

Aims and Guidance for Tutors

Radiology plays a vital role in patient care in both hospital and community settings. It is a multi-disciplined speciality that functions in a dynamic and exciting working environment. The aim of this chapter is to provide students with a basic introduction to the role of the radiologist and important practical concepts applicable in a radiology department. Fundamental terminology for describing each modality are outlined to help the student acquire basic "radiological" fluency.

Radiological Modalities

- A typical radiology department is comprised of a number of health care professionals. These include; radiographers, radiologists, nurses, physicists, health care assistants, administrative staff and porters. Each member has a unique role that contributes to the smooth running of the radiology department.
- There are a number of different radiological modalities, including; general radiography, computed tomography (CT) or older terminology CAT scans, (computerised axial tomography), magnetic resonance imaging (MRI), ultrasound, fluoroscopy, nuclear medicine and positron emission tomography (PET scans). Some modalities are also frequently used in combination, such as PET/CT.
- The modalities differ in terms of the method used to acquire the images, the use of ionising radiation or non-ionising radiation and length of time they take.

M. Hanley · R. O'Cearbhaill
Beaumont Hospital, Dublin, Ireland

C. E. Redmond (✉)
Academic Department of Radiology, Royal College of Surgeons in Ireland, Dublin, Ireland
e-mail: ciaranredmond1@gmail.com

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_1

X-rays

- The discovery of X-rays was by Wilhelm Röntgen, a professor of physics, in 1895. The first X-ray taken was that of an X-ray of his wife's hand and he was awarded the Nobel Prize in Physics in 1901.
- The process of creating radiological images is a multistep process. Electromagnetic energy is a spectrum of energies, ranging from radiofrequency waves to highly energetic gamma rays. X-rays are also a form of electromagnetic energy and are produced within an X-ray tube. X-rays are passed through the patient in a controlled manner. Some of the energy is attenuated by the soft tissues, organs and bones of the patient and some passes through the patient hitting a detector. This difference in what is passed through and what is absorbed is the main basis for forming an image.
- Plain radiographs, also known as X-rays, are a 2D representation of a 3D structure. They are commonly used to assess for bone fractures, signs of infection on chest-rays and can be used to assess the position of radio-opaque tubing, such as a nasogastric tube or ureteric stent.

Computed tomography

- CT imaging generates images by acquiring multiple X-rays at different angles around the patient to form 3D cross-sectional image through the patient. The first clinical CT scan was performed on the 1st of October 1971 at Atkinson Morley's Hospital, London and took five minutes to acquire the CT brain scan. The same scan today takes less than 10 seconds to acquire.
- CT became widely available in the 1980s. As technology developed so did the complexity and capability of CT. Originally conventional CT was a 'step and shoot' phenomenon, whereby the X-ray tube would take a slice image through the patient in one rotation and then acquire the next slice through the patient by moving the table in an incremental manner.
- The next important development was that of helical CT, whereby a rotational movement of the X-ray tube was in a helical path with continuous simultaneous movement of the patient through the gantry. Helical scanning is quicker than conventional imaging so there is a reduced likelihood of patient movement during the scan that would produce a blurred image, otherwise known as motion artefact. It also means that the images can be taken in a single breath hold and it allows more optimal use of IV contrast enhancement.
- To acquire a CT image, a planning image is acquired, called a topogram. This allows the radiographer to set the scan range based on the patient's anatomy and any other pertinent relative findings seen on the topogram.
- Once the scan range is selected the appropriate protocol is chosen and the images are acquired.
- A cross sectional CT image of a patient is made up of a range of different shades of grey. Attenuation values are determined by the constituents of the

Fig. 1 Axial CT image of the upper abdomen

patient and the penetrability of the X-rays. The values are mathematically assigned Hounsfield Units (HU) for each voxel of tissue (Fig. 1).

- The range of HU values for different structures allows the identification of pathology and normal anatomy. Water is used as a reference point in terms of HU, and is assigned a value of zero. See radiologist's tip box on terminology for further typical HU values.

Nuclear medicine

- Nuclear medicine uses the administration of radioactive substances to form images.
- The radioactive substances are called radiotracers or radiopharmaceuticals and are combination of the radioactive substance plus an attached pharmaceutical to allow the radioactive substance to accumulate in a specific target region of interest within the body.
- Radiotracers are injected intravenously. The most common radiotracer is technetium-99m. For more discussion on nuclear medicine, see Chap. 14 for further discussion.

Ultrasound

- Ultrasound (US) uses mechanical sound waves transferred from an US probe and into the patient. The sound waves, when used appropriately does not cause DNA or cellular changes and is thus a preferable modality in pregnant patients and the paediatric population.
- The sound waves use frequencies outside the range of audible sound and are generated in an US transducer probe by mechanical stimulation of a set of

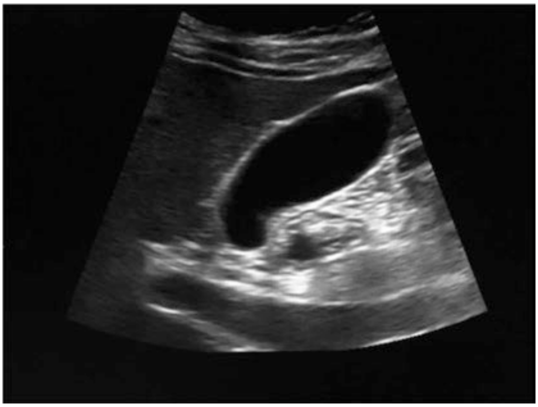


Fig. 2 US image of a healthy gallbladder in longitudinal plane. The gallbladder is filled with hypoechoic fluid (bile) and thus appears dark on B-mode image

piezocrystals. They are transferred from the US transducer probe across a layer of US gel beyond the skin and thorough the tissues of the patient.
- The sound waves are reflected back after striking structures and these reflected waves are detected by the US transducer probe to form an image.
- B-mode (brightness) is the most common US images created. The intensity of the returning echo is represented as a level of brightness on the monitor.
- US is useful for assessing the solid organs of the abdomen—liver, gallbladder, kidneys and spleen (Fig. 2). A high frequency probe is also useful to assess more superficial structures, such as lymph nodes and the thyroid gland.
- US is also used to guide interventional procedures, such as a peripherally inserted central catheter placement and breast biopsies.

Magnetic resonance imaging

- MRI, like US, produces diagnostic images without the use of non-ionising radiation and relies on a powerful magnetic field to manipulate spinning protons within hydrogen atoms. The patient lies within the magnetic bore, protons are manipulated in terms of their spinning speed and orientation. The protons relax back to their original state and it is this relaxation process that creates the MRI image.
- The most common sequences are T1 weighted and T2 weighted imaging. T1 weighted images are distinguished from T2 weighted images by the intensity signal of fluid. Fluid is hyperintense, i.e. bright, on T2 weighted images and dark on T1 weighted. Cerebrospinal fluid is often used as the reference to assess whether an image is T1 weighted or T2 weighted (Fig. 3).
- MRI is used to assess many structures and systems but is particularly useful for neurological, musculoskeletal hepatobiliary and prostate imaging.
- The magnetic field strengths in clinical practice today range between 1.5 and 3 T (Tesla), that is, approximately 50,000 times stronger than the earth's magnetic field. These acting forces are proportional to the increasing proximity to the central magnetic bore, where the magnet is it's strongest.
- While MRI does not cause radiation related harm to patients, it poses it's own risks, related to the potential projectile effects of ferromagnetic objects coming in proximity to the magnetic field.

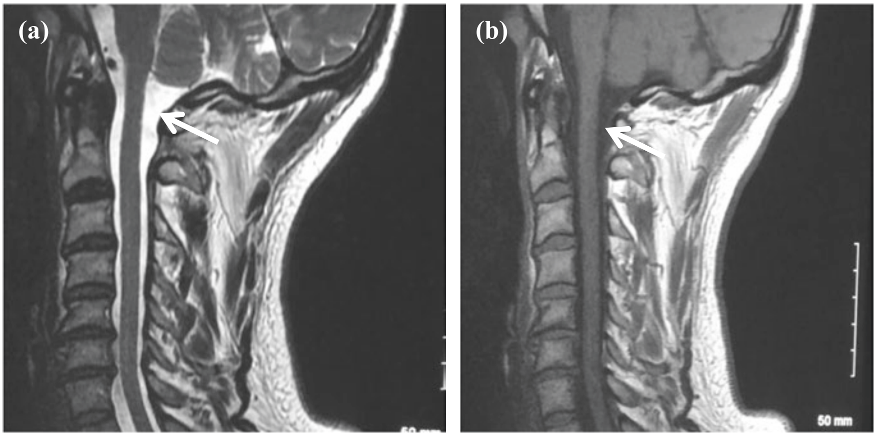


Fig. 3 MRI sagittal images of the cervical spine. The white arrows demonstrating the differences in the signal intensity of the cerebrospinal fluid in the spinal canal. This fluid is bright in image **a** (T2 weighted) and dark in image **b** (T1 weighted)

- Objects made from ferromagnetic metals will be propelled towards the magnetic field, often at high speeds, causing potentially life threatening injuries. As such, there are multiple precautions taken to ensure the safety of patients and staff.
- A cornerstone strategy of MRI safety, is the use of a screening MRI safety questionnaire. This is a mandatory questionnaire to be completed prior to carrying out an MRI study. It contains a series of questions that highlights any metallic objects that are on or implanted in a patient and that could pose a safety risk.
  - A high proportion of medical devices are now being designed to be MRI compatible.

Radiologist's tips: Terminology for describing structures based on modality

Radiographs:

- **Density**
- Opacification (bright structures) or luceny (dark structures).

CT:

- **Attenuation**
- Hyperattenuating (bright structures) or hypoattenuating (dark structures).
- Water is used as a reference value for the units used to measure attenuation, Hounsfield Units (HU).

- Water: 0 HU.
- Fat: −50.
- Bone: 700–3,000.

Ultrasound:

- **Echogenicity**
- Hyperechoic (bright structures) or hypoechoic (dark structures).

MRI:

- **Signal intensity**
- Hyperintense (bright structures) or hypointense (dark structures).
- Similar signal intensity as the surrounding muscle is an isointense structure.

PET/nuclear medicine:

- **Uptake/metabolic activity**
- Increased uptake/high metabolic activity or low uptake/reduced metabolic activity.

Role of a Radiologist

- The role of a radiologist involves integrating general medical knowledge and training with specialist training in radiology (Fig. 4).
- Radiologists use their expertise to:
  - Help decide what the most appropriate imaging modality or imaging protocol is in order to answer the clinical question at hand.
  - Decide on the appropriateness and urgency of an examination.
  - Interpret radiological images, in context with the patients' history and examination to guide clinical treatment.
  - Communicate findings with the requesting doctor and formulate a report.
  - Perform image guided procedures.

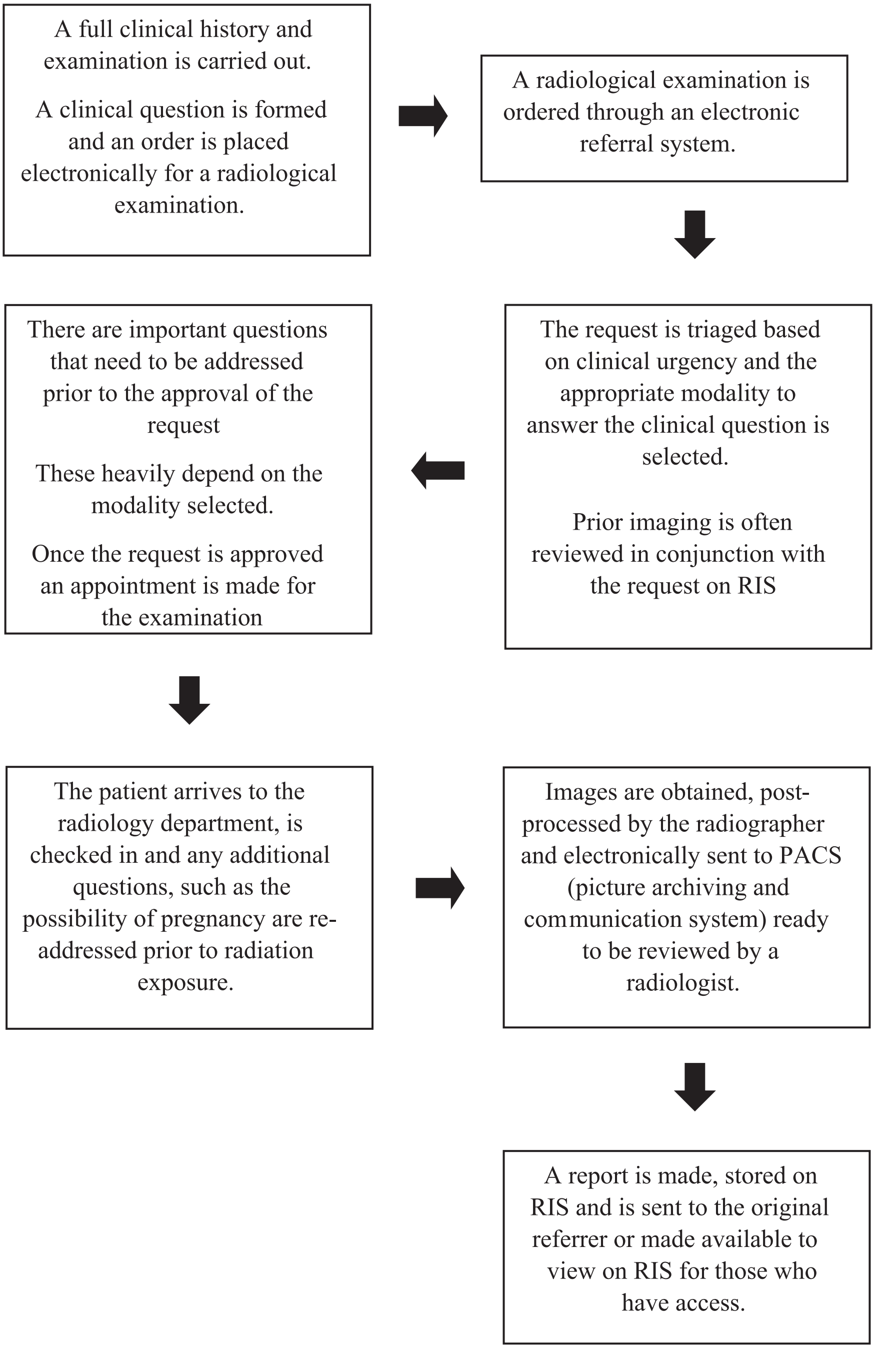
- Continually maintain and improve imaging protocols to provide high quality imaging and improved workflow.
- Mitigate the risks associated with unnecessary investigations, specifically those involving ionising radiation.

Picture archive and communication system

- An essential tool for a radiologist is an appropriate workstation and a fast, efficient integrated computer system. PACS (picture archive and communication system) is a medical imaging technology used in healthcare organisations to securely store and transfer images and the reports.
- PACs eliminates the need for hard copies of images and allows remote access for viewing images. It has its roots in DICOM (Digital Imaging and Communications in Medicine) which allows the integration of medical devices, workstations, printers and PACS regardless of the manufacturer and is often used in conjunction with RIS (radiological information system).
- The RIS is the platform used to view study requests, workflow, scheduling of studies and reports.

A typical step by step account of the process involved in performing a radiological investigation:

Fig. 4 Typical signage seen in a radiology department, indicating controlled area


A full clinical history and examination is carried out.
A clinical question is formed and an order is placed electronically for a radiological examination.
A radiological examination is ordered through an electronic referral system.
The request is triaged based on clinical urgency and the appropriate modality to answer the clinical question is selected.
Prior imaging is often reviewed in conjunction with the request on RIS
There are important questions that need to be addressed prior to the approval of the request
These heavily depend on the modality selected.
Once the request is approved an appointment is made for the examination
The patient arrives to the radiology department, is checked in and any additional questions, such as the possibility of pregnancy are re-addressed prior to radiation exposure.
Images are obtained, post-processed by the radiographer and electronically sent to PACS (picture archiving and communication system) ready to be reviewed by a radiologist.
A report is made, stored on RIS and is sent to the original referrer or made available to view on RIS for those who have access.

Contrast Media

- Contrast media are agents administered to the patient in order to evaluate structures that are not clearly identified or characterised on non-contrast imaging.
- The type of contrast media used depends on what kind of imaging is being performed and varies for US, CT, MRI and fluoroscopy.
- There are also different methods of administering contrast depending on the organs of interest. The most common method of administration of contrast is intravenously but it can also be administered orally, intrathecally and by other methods.

Intravenous Contrast Agents

Iodine based contrast agents

- Iodine based contrast agents are the most frequently encountered contrast agents. They contain molecules of iodine which prevent X-rays penetrating through. High concentration of iodine appears bright on the final image.
- These agents are relatively safe although not totally risk free.
- Allergic-like reactions are rare and can range from mild symptoms such as urticaria, pruritus to bronchospasm, to full anaphylactic reactions.
- Patients at high risk for an allergic-like reaction include:
  - Patients who have had an allergic-like reaction to contrast medium previously
  - Patients with a history of asthma
  - Patients with other severe allergies or reactions
- When treating a patient who is at high risk for an allergic-like reaction, consideration should be given to other imaging modalities, non-contrast imaging or premedication with corticosteroids. The regimen for premedication varies across different institutions and usually involves multiple doses of oral corticosteroids starting at least 12 hours before administration of iodinated contrast.
- Physiologic reactions can also occur such as flushing, nausea, syncope, headache or mild self-limiting hypertension.
- Particular caution should be taken in patients with untreated hyperthyroidism as there is a risk of inducing thyrotoxicosis. Furthermore, use of iodinated contrast agents should be avoided before planned radioactive iodine ablation as it can interfere with the treatment.
- Another consideration in all forms of intravenous contrast administration is the risk of contrast extravasation. This occurs when contrast infiltrates the interstitial tissues from the vascular lumen. Extravasation can be avoided with

a catheter gauge appropriate for the flow rates used. A 20-gauge cannula is appropriate for most CT studies and at least an 18-gauge cannula for angiographic phases, where higher flow rates are required.

Contrast induced nephropathy

- Contrast induced nephropathy is defined as sudden deterioration in renal function observed in patients who have recently been administered intravascular iodinated contrast medium. Deterioration of renal function can be quantified as:
  - Absolute serum creatinine increase of greater or equal to >26.4 μmol/L (0.3 mg/dl)
  - Increase in serum creatinine by 50% or greater
  - Urine output less than or equal to 0.5 ml/kg/hour for at least 6 hours
- The risk of contrast induced nephropathy (CIN) is thought to have previously been overestimated. The risk of CIN in the general population is now considered very low, but not zero.
- The most important risk factor for CIN is pre-existing severe renal insufficiency, defined as an estimated glomerular filtration rate (eGFR) of <30 ml/min/1.73 m^2.
- In patients who are at increased risk of CIN:
  - Perform a risk benefit analysis and consider alternative imaging modalities such as ultrasound and non-contrast MRI.
  - Volume expansion should be considered if appropriate, which usually involves isotonic fluids administered intravenously. Depending on the patient and clinical circumstances 100 ml/hour starting 6–12 hours before and continuing 4–12 hours after contrast administration is a reasonable regimen.
  - Evidence for renal protective agents such as NAC, sodium bicarbonate and diuretics is weak and is not routine practice.
- Metformin is a medication used in diabetes management which is predominantly renally excreted. Lactic acidosis is a rare but serious side effect of the medication metformin.
- Patients are at increased risk of developing lactic acidosis if they have pre-existing severe renal insufficiency and receive iodinated contrast medium.
  - In patients with eGFR >30 there is no need to discontinue metformin
  - In patients with eGFR <30 it is recommended that metformin is discontinued 48 hours after giving iodinated contrast and restarted only when renal function has been re-evaluated and has not been compromised.

Gadolinium based contrast agents

- Gadolinium based contrast agents (GBCAs) are used in MR imaging. Structures with a high concentration of gadolinium appear bright on T1 weighted imaging.

- GBCAs are usually well tolerated with a low incidence of adverse reactions.
- In recent years, evidence of gadolinium accumulation has been noted in the brains of patients who undergo numerous contrast enhanced studies. Currently, the potential significance of this with regards to adverse effects is unknown and under investigation.

Nephrogenic systemic fibrosis

- Nephrogenic systemic fibrosis (NSF) is a disease predominantly of the skin and subcutaneous tissues but can involve other organs such as the lungs, liver, heart and skeletal muscle.
- NSF is a disease process which occurs exclusively in patients who have received GBCAs.
- Although it is rare, nephrogenic systemic sclerosis can be debilitating and in some cases fatal.
- The main risk factor for developing NSF is advanced renal failure—stage 4 or stage 5 chronic kidney disease or significant acute kidney injury.
- Doses higher than the recommended 0.1 nmol/kg and repeated doses are also a risk factor.
- In patients at high risk of developing NSF:
  - Consider alternative imaging such as CT or ultrasonography.
  - Consider whether non-contrast MR imaging is suitable.
  - Consider dialysis post administration.
  - Use as a low a dose as possible.
  - Avoid repeat doses of GBCAs for 1 week.

Enteric contrast agents

- Enteric contrast agents are administered orally or rectally to delineated to gastrointestinal tract.
- Barium sulphate is the most commonly used agent in fluoroscopy for studies such as barium swallow and barium enema.
- Barium is relatively safe, however, extravasation into the mediastinum or peritoneum can cause mediastinitis or peritonitis which carry high mortality rates. Therefore, water soluble iodine based contrast agents are used if perforation is suspected.
- Water soluble iodine base contrast agents are used as oral contrast in CT studies.

Other

- There are many different methods of contrast administration depending on what is being examined. A few such examples of alternative methods of contrast administration include:

– Intraarticular contrast to assess the joint spaces with fluoroscopy or MR imaging.
– Contrast may administered directly into a sinus or fistula or into percutaneously placed feeding tubes followed by imaging with fluoroscopy or CT.
– CT myelography involves injection of contrast into the cerebrospinal fluid prior to CT imaging.

Radiation Safety

- Ionising radiation is used in the majority of imaging modalities e.g. conventional X-ray, computed tomography, fluoroscopy and nuclear medicine.
- However, there are harmful effects of radiation. These can be divided into stochastic and deterministic effects:
  – Stochastic effects are effects that occur by chance. The probability of a stochastic effect occurring is more likely with increasing doses but the severity of the effect is not. The main stochastic effects are cancer and radiation induced hereditary effects.
  – Deterministic effects are a direct effect of radiation. There is a threshold radiation dose below which the effect is not seen. Beyond this threshold the severity of the effect increases with increasing dose. Examples of deterministic effects include; skin burn, hair loss, visual impairment and sterility.
- It is therefore important to protect patients, staff members and the public from the harmful effects of radiation as much possible. There are three main principles of radiation protection—justification, optimisation and dose limitation:
  – **Justification**: A patient should only be exposed to radiation if it will provide more benefit to the patient's care than the risks incurred. In practise this means that performing an examination using ionising radiation that will make an impact on the patient's management. Additionally, alternative imaging modalities that don't involve ionising radiation should always be considered, such as ultrasonography and MRI.
  – **Optimisation**: This is also known as the "ALARA" principle, meaning that radiation dose should be kept as low as reasonably achievable in order to obtain a diagnostic image.
  – **Dose limitation**: Dose limits are set for staff member who are exposed to ionising radiation. These limits don't apply to patients as it is assumed that the benefit will outweigh the risk.

Imaging in paediatric patients

- Children are more sensitive to the harmful effects of radiation than adults. They have a longer life expectancy and therefore are at greater risk of developing radiation related cancer during their lifetime.

- Particular attention should be paid to the principle of justification. In many cases the correct diagnosis can be made in children using ultrasonography or plain film radiography which incur relatively low radiation doses compared to CT imaging.
- The radiologists and radiographers also employ a number of technical strategies to further reduce the dose to the child. Multiple images are generally avoided and the exposed area is reduced as much as possible. Additionally gonadal and breast shields can be applied as these tissues are particularly radiosensitive.

Imaging in pregnancy

- The foetus is highly sensitive to the effects of radiation. Sufficiently high doses can result in childhood cancer, mental retardation, growth retardation or foetal death.
- In any female patient of child bearing age it is important to:
  - Make enquiries regarding pregnancy status and last menstrual period.
  - If pregnancy cannot be out-ruled, the patient is treated as potentially pregnant.
- In patients who are pregnant or patients in whom pregnancy cannot be out-ruled:
  - Review justification for exam, consider alternative imaging or consider deferring exam.
  - In some cases, such as emergencies, it is necessary to proceed with an examination involving ionising radiation in a pregnant patient. In these cases dose is reduced as much as possible while also obtaining an image of sufficient quality to make an accurate diagnosis.

Radiologist's tips: Requesting a radiological investigation

- **Patient**
  - Ensure the request is for the correct patient
- **Clinical information**
  - Brief history of presenting complaint and examination findings.
  - Investigations to date such as blood results and other imaging performed.
  - Working diagnosis or differential diagnosis
  - Explain how imaging might change patient management
- **Background**
  - Risk factors for CIN or NSF
  - Previous allergy
  - Contraindications e.g. metallic implants for MRI, pregnancy or breast feeding
  - Relevant medications e.g. metformin

- **Mode of transport to the radiology department**
- **Risk groups status**
- **Referrer details and contact information**

Protection of staff

- Staff members who are exposed to ionising radiation may be subjected to high levels of radiation over the course of their career. Protective measures are taken to reduce their exposure and prevent harm from radiation.
- The main principles of radiation protection are summarised as time, distance and shielding.
  - **Time**: Time spent in areas where there is likely to be exposure to ionising radiation should be limited as much as is practical.
  - When working in fluoroscopy or interventional radiology, long exposures and unnecessary repeated exposures should be avoided.
  - During procedures using ionising radiation only those required to assist should be in the room. All other staff member should remain behind a lead reinforced division.
  - **Distance**: Increasing distance from the source of ionising radiation is the most effective method of reducing radiation dose.
  - For example, when performing portable chest radiograph, staff members who maintain a distance of at least 6 feet incur a negligible dose of radiation.
  - **Shielding**: Radiosensitive organs can be protected from ionising radiation by wearing protective garments containing lead, such as lead aprons, thyroid shields and lead glasses.
  - Additional shielding can be provided in the intervention suite by ceiling suspended shielding, mobile screen shields and table skirts.
  - Within the radiology department walls, doors and observation windows are reinforced with lead to prevent ionising radiation passing through.
- Supervised and controlled areas are areas where exposure to ionising radiation is likely to occur and are clearly demarcated in the radiology department. Areas where very high doses are likely to occur are termed controlled areas. Controlled areas are restricted to authorised personnel only and are physically segregated (Fig. 4).

Suggested Reading

- Do C. Intravenous contrast: friend or foe? A review on contrast-induced nephropathy. Adv Chronic Kidney Dis. 2017;24(3):147–9. https://doi.org/10.1053/j.ackd.2017.03.003.
- Luk L, Steinman J, Newhouse JH. Intravenous contrast-induced nephropathy-the rise and fall of a threatening idea. Adv Chronic Kidney Dis. 2017;24(3):169–75. https://doi.org/10.1053/j.ackd.2017.03.001.
- Ramalho J, Semelka RC, Ramalho M, Nunes RH, AlObaidy M, Castillo M. Gadolinium-based contrast agent accumulation and toxicity: an update. Am J Neuroradiol. 2016;37(7):1192–8. https://doi.org/10.3174/ajnr.A4615.
- Beckett KR, Moriarity AK, Langer JM. Safe use of contrast media: what the radiologist needs to know. Radiographics. 2015;35(6):1738–50. https://doi.org/10.1148/rg.2015150033.
- Don S, Macdougall R, Strauss K, Moore QT, Goske MJ, Cohen M, Herrmann T, John SD, Noble L, Morrison G, Lehman L, Whiting BR. Image gently campaign back to basics initiative: ten steps to help manage radiation dose in pediatric digital radiography. Am J Roentgenol. 2013;200(5):W431–6. https://doi.org/10.2214/ajr.12.9895.
- American College of Radiologists. ACR manual on contrast version 10.3. 2018.
- Role and value of the clinical radiologist: recognising the value and responding to the challenges. Position statement. The Royal Australian and New Zealand College of Radiologists; 2014.

Tutorial 2: Imaging of Head Trauma

Ciaran E. Redmond and Michael Lee

Aims and Guidance for Tutors

In the emergency setting, accurate clinical assessment in combination with appropriate imaging is key to the identification of patients that would benefit from urgent surgical intervention. This chapter aims to familiarise students with the role of imaging for patients with head trauma. It is important that students understand the basic concepts and patterns of traumatic intracranial haemorrhage. After completion of this tutorial students should be able to describe the key CT appearances of traumatic intracranial haemorrhage and associated mass effect.

Introduction

- Traumatic brain injuries (TBI) are a major cause of morbidity and mortality in the injured patient.
- Injury occurs due to primary and secondary mechanisms.
- Primary injury occurs as direct mechanical consequence of the trauma.
  - Skull fracture, acute haemorrhage.
- Secondary injury occurs as a result of the pathological processes initiated by the initial traumatic insult.
  - Cerebral oedema, intracranial hypertension, cerebral hypoxia.
- In conjugation with clinical assessment, diagnostic imaging plays a fundamental role in the evaluation of patients with a suspected TBI in the emergency setting.

C. E. Redmond (✉) · M. Lee
Academic Department of Radiology, Royal College of Surgeons in Ireland, Dublin, Ireland
e-mail: ciaranredmond1@gmail.com

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_2

- The Glasgow coma scale is the scoring system used to describe a patient's level of consciousness following head trauma
  - This is scored between 3 and 15. A score of 8 or less implies severe injury.
- All patients with severe head injury should be transferred to a dedicated neurosurgical centre.
- Imaging also has an important role in the triage of patients sustaining minor head injuries to identify those who can safely be discharged.
- There is increasing evidence that for patients presenting with traumatic intracranial haemorrhage, features on the CT brain scan can predict long term outcome:
  - Findings such as haemorrhage site and size, presence of intraventricular haemorrhage, presence of mass effect.

Radiological Modalities Utilised

Non-contrast CT brain

- The initial investigation of choice. It is widely available and can be performed rapidly. It is a sensitive study for the identification of:
  - Acute intracranial haemorrhage
  - Evidence of mass effect
  - Bony injuries

  CT is also a useful study for the follow-up of patients with known TBI to assess response to treatment, haemorrhage stability and the development of complications. Imaging with CT will be the focus of this tutorial.
- We do not administer intravenous contrast media in patients with head trauma as contrast media is hyperdense and can look like haemorrhage.

MRI brain

- In comparison with CT, there are several practical reasons that MRI is less suited for use in the emergency setting:
  - Longer imaging time required
  - Sensitivity to patient motion
  - Possible incompatibilities with indwelling medical devices or foreign bodies
  - Not as widely available on-call
- MRI is superior to CT for the identification of non-haemorrhagic injuries of the brain parenchyma such as contusions, oedema and diffuse axonal injury. MRI can also detect acute ischemia associated with TBI.

Skull radiography

- The use of skull radiography for trauma has been largely replaced by CT. Of historical interest, before the advent of CT an abnormal position of the calcified pineal gland on frontal skull radiograph was used to diagnosis midline shift.

Indications for Imaging

- The need for imaging is dictated by clinical assessment.
- Patients who have sustained trauma and are considered at moderate or high risk for TBI require urgent CT brain.
- It can be more challenging in deciding which patients that have sustained a minor head trauma require imaging. For these patients clinical assessment will help decide if imaging is required. A number of criteria and guidelines have been published to assist clinicians in this decision. These criteria are based on clinical risk factors such as:
  - Glasgow coma scale
  - Vomiting
  - Anticoagulation treatment
  - Presence of amnesia
  - Dangerous mechanism of injury
  - Seizures

Radiologist's tips: Acute haemorrhage on CT

- Acute haemorrhage on CT is high in density/attenuation
  - It appears bright (between 50 and 70 Hounsfield units)
- Intracranial haemorrhage can be classified as extra-axial or intra-axial:
  - **Extra-axial haemorrhage** is blood inside the skull but outside the brain parenchyma. This includes extradural, subdural, subarachnoid and intra-ventricular haemorrhages.
  - **Intra-axial haemorrhage** is blood within the brain parenchyma
- If the patient's mechanism of injury is unclear, carefully examine the subcutaneous soft tissues overlying the skull on the CT. The presence small superficial haematoma often marks the point of impact.

Review of Relevant Radiological Anatomy: CT Brain

See Figs. 1, 2, and 3.

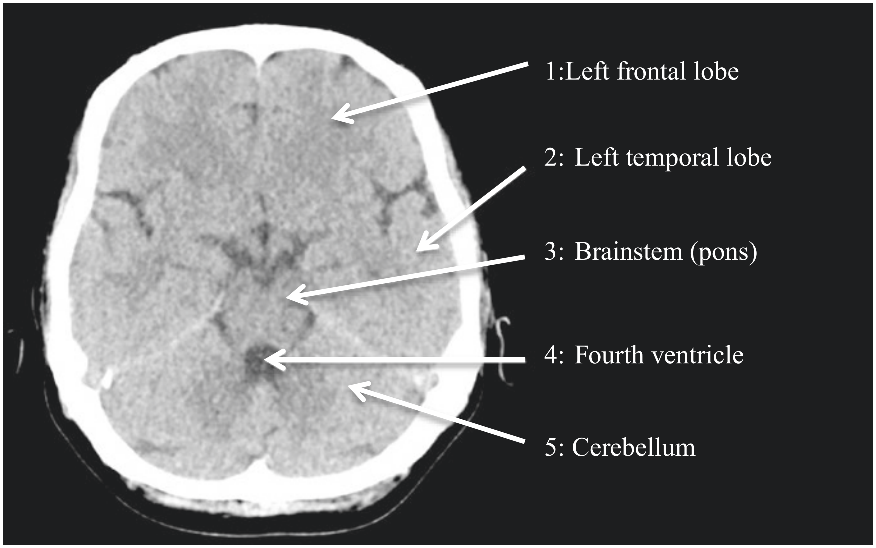


Fig. 1 Axial non-contrast CT brain

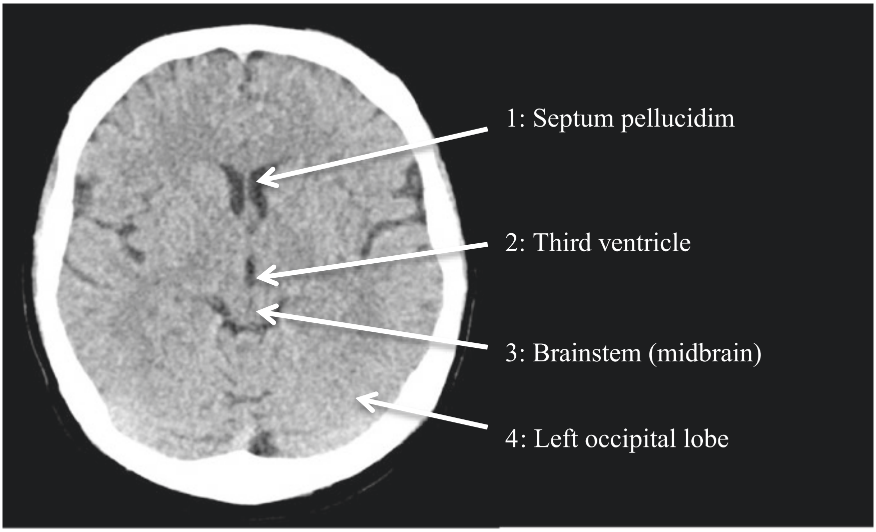


Fig. 2 Axial non-contrast CT brain

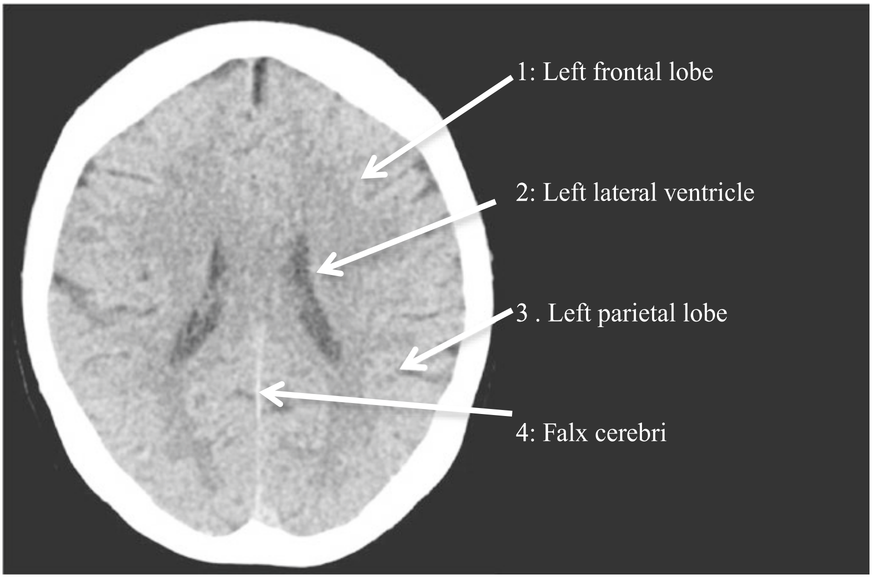


Fig. 3 Axial non-contrast CT brain

Extra-axial Lesions

Extradural haemorrhage

- Also known as epidural haemorrhage
- Involves blood located between the dura and the inner table of the skull. The site of haemorrhage usually occurs at the site of impact, in most cases this is in the temporal region and bleeding is due to laceration of the middle meningeal artery.
- Over 90% of cases have an overlying skull fracture.

Clinical features

– The classically described lucid interval followed by neurological deterioration is only present in a minority of patients with extradural haemorrhage.
– As the haematoma expands, patients develop features of herniation.

Key imaging appearances

– Hyperdense, biconvex (or lens-shaped) collection on CT
– The haemorrhage does not cross suture lines
– Underlying skull fracture (Fig. 4).

Subdural haemorrhage

- This is due to tearing of bridging cortical veins crossing the subdural space, usually as a result of acceleration/deceleration injuries.
- Subdural haemorrhages can be diagnosed at the acute, subacute or chronic stages. Chronic subdural haemorrhages are associated with anticoagulation use, alcoholism and epilepsy.

Clinical features

– Chronic subdural haemorrhages can have a vague/indolent clinical presentation and mimic other intracranial pathologies
– Consider chronic subdural haemorrhage as a cause of cognitive dysfunction in elderly patients (pseudodementia). Pay close attention to those on anticoagulant medication.

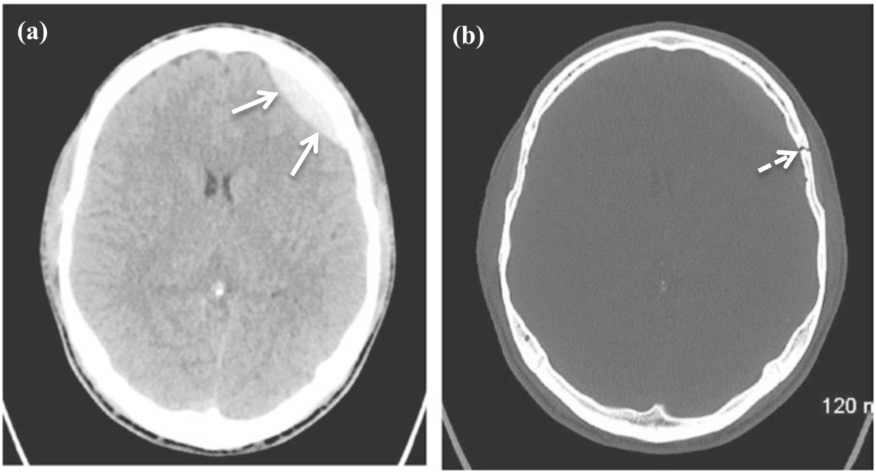


Fig. 4 A 30 year old man sustained a head injury after falling from a height. He complained of a headache on presentation (GCS 15) but after a short period became confused became drowsy (GCS 13). An emergency CT brain was performed. This demonstrates a biconvex hyperdense extra-axial collection adjacent to the left frontal lobe which obeys the suture lines **(a)**. This is an acute extradural haemorrhage. On the bone reconstruction image **(b)**, there is a non-displaced fracture of the left frontal bone. The patient underwent emergency surgical decompression of the haematoma

Key imaging appearances

– Crescentic collection spread diffusely over affected cerebral hemisphere
– Crosses suture lines
– The density of the haematoma on CT depicts the acuity:

  - Hyperdense: Acute (<1 week)
  - Isodense: Subacute (1 week to 1 month)
  - Hypodense: Chronic (>1 month) (Fig. 5).

Subarachnoid haemorrhage

- Haemorrhage in the subarachnoid space which can be traumatic or non-traumatic in origin (trauma being more common)
- CT has a very high sensitivity if performed within 6 hours of trauma.
- The main non-traumatic causes are ruptured aneurysms (older patients) and vascular malformations (younger patients). *For further reading on non-traumatic subarachnoid haemorrhage, see non-traumatic neurological emergencies chapter*.

Key imaging appearances

– Curvilinear hyperdensity within the sulci, sylvian fissures and basal cisterns
– Crosses suture lines
– Acute blood around the circle of Willis forms a five pointed star.

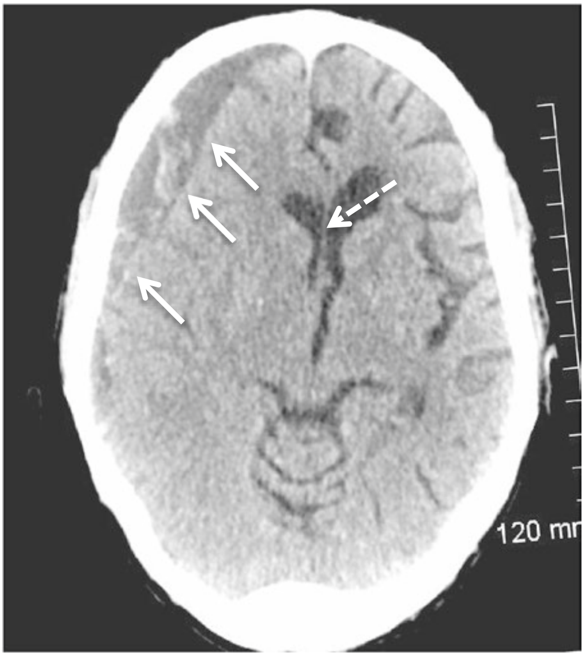


Fig. 5 A 45 year old man with a history of alcohol addiction is brought to the Emergency Department with increasing confusion. He reports a history of multiple recent falls. A non-contrast CT brain is performed. This axial image demonstrates a crescentic extra-axial collection (solid arrow) overlying the right cerebral hemisphere consistent with a subdural haematoma. This collection is predominantly of low density but contains areas of high density, this is an acute-on-chronic subdural haematoma. Note also the midline shift due to associated mass effect- the midline structures are displaced to the left (labeled with dashed arrow)

Intraventricular haemorrhage

- Acute haemorrhage within the ventricular system can be primary—as a resulting from tearing of vessels lining the ventricular wall
- Secondary intraventricular haemorrhage is more commonly encountered, resulting from extension from large intraparenchymal or subarachnoid haemorrhages
- Intraventricular hemorrhage can obstruct the flow of CSF causing hydrocephalus (Fig. 6).

Radiologist's tips: mimics of intracranial haemorrhage

- Beware of several structures within the brain which can normally calcify and be mistaken for acute haemorrhage:
  - Pineal gland
  - Choroid plexus with in the lateral ventricles

Intra-axial Lesions

Cortical contusion

- Bruising of the brain surface as a result of blunt injury. When contusions contain foci of haemorrhage, the term haemorrhagic contusion is used.

Fig. 6 An axial image of a non-contrast CT brain demonstrating normal calcification of the choroid plexuses (dashed arrows) and pineal gland (solid arrow). This normal finding can be mistaken for acute haemorrhage

- It occurs most frequently in the frontal and temporal lobes.
- Contusion can occur as a coup injury (at the site of cranial impact) and as a contrecoup injury (occurring opposite the site of cranial impact).

Intraparenchymal haemorrhage

- Traumatic intraparenchymal haemorrhage is on the same spectrum of injury as haemorrhagic contusion.
- Intraparenchymal haemorrhages are often multiple and usually located in the frontal and temporal lobes.
- Large intraparenchymal haematomas cause surrounding cerebral oedema, exacerbating the associated mass effect (Fig. 7).

Diffuse Axonal Injury (DAI)

- This is due to a high velocity deceleration or rotational forces resulting in shearing of axons.

Fig. 7 A 72 year old man on warfarin presented after a fall at home. On presentation to the Emergency Department, he had left sided weakness and a reduced level of consciousness (GCS of 12). A non-contrast CT brain was performed. This axial image demonstrates a large acute intra-parenchymal haemorrhage (white areas on the right side of the brain). The mass effect of the haemorrhage is causing subfalcine herniation—this is a form of herniation where part of the right side of the brain is pushed medially and below the falx cerebri (dashed arrow). There is resultant hydrocephalus of the left lateral ventricle (dashed arrow) due to compression of the third ventricle

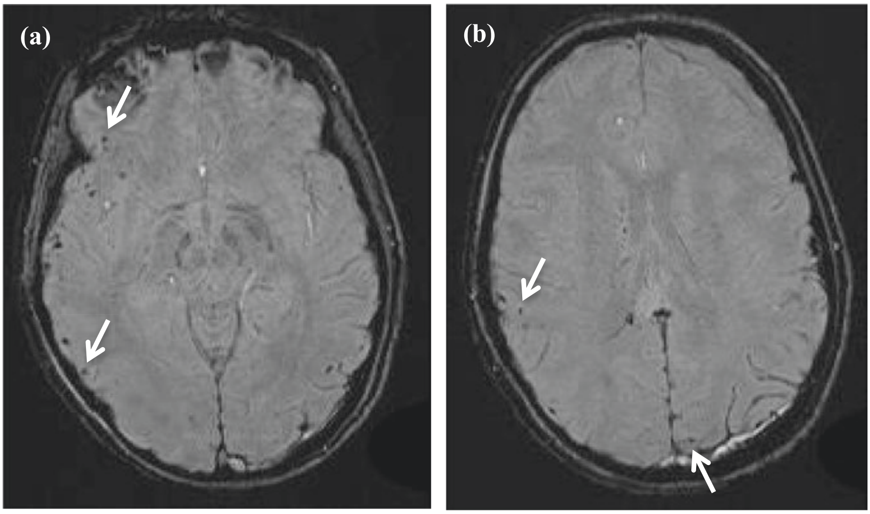


Fig. 8 A 46 year old woman sustained head trauma in a road traffic accident. On presentation she was comatose (GCS 7). A CT scan showed a shallow subdural haematoma. Her GCS remained low and an MRI was performed for further evaluation. These MRI susceptibility weighted images (a sequence which is sensitive to haemorrhage) show numerous small foci of low signal (black dots, several of which are labeled with arrows) at the grey-white matter junction, characteristic of diffuse axonal injury

- This should be clinically suspected in patients with a persistent vegetative state following trauma (GCS <8). DAI is associated with high levels of morbidity and mortality in patients sustaining head trauma.
- It is characterised by multiple small lesions at the grey–white matter junction, corpus callosum and brainstem. These lesions are often haemorrhagic.
- MRI is the key imaging modality to demonstrate these microbleeds.
- CT has poor sensitivity for DAI. Consider DAI in patients post head trauma with a low level of consciousness despite a reassuring CT brain (Fig. 8).

Mass Effect and Herniation

- The mass effect resulting from haematoma cause elevation in intracranial pressure and can lead to herniation.
- The Monro–Kellie doctrine, proposed two centuries ago remains a useful hypothesis. This states that the cranial cavity is a structure with a fixed volume containing brain, CSF and blood. If the volume of blood increases, displacement of CSF and brain will result to maintain the fixed volume.
- Herniation is the displacement of brain parenchyma from one compartment to another. It is one of the leading causes of mortality in patients who sustain head trauma.

- The early recognition of mass effect and herniation is essential as these patients will benefit from emergency decompressive surgery.

Herniation syndromes

– Subfalcine herniation:

  - This is the most common type of herniation and involves displacement of the cingulate gyrus under the falx cerebri
  - Clinically patients usually develop headache and contralateral limb weakness (motor cortex compression).
  - Often associated with contralateral hydrocephalus due to obstruction of the foramen of Monro.

– Uncal herniation:

  - This involves herniation of the medial aspect of the temporal lobe (the uncus) across the tentorium cerebelli.
  - Uncal herniation can cause compression of the adjacent third cranial nerve, resulting in palsy (fixed, dilated pupil)
  - With uncal herniation, the contralateral cerebral peduncle can also be compressed leading to ipsilateral hemiparesis. This false localising sign is known as Kernohan's notch.

– Tonsillar herniation:

  - The most serious herniation syndrome where the cerebellar tonsils herniate through the foramen magnum. When this occurs there is compression of the medulla, resulting in respiratory arrest.

Radiologist's tips: recognising mass effect

- Compare the side without haemorrhage to the side with hemorrhage. On the side of the haemorrhage, look for displacement of CSF from the cortical sulci—this is called **sulcal effacement** ie pressure forces the fluid out of the sulci.
- On the side of the haemorrhage, look at the lateral ventricle, when this appears compressed or smaller when compared to the opposite lateral ventricle **ventricular effacement** is present indicating mass effect.
- Observe the midline structures, such as the falx cerebri. These should be centrally located. With increasing intracranial pressure, there is displacement of the midline structures away from the side of the haemorrhage. This is called **midline shift**.

Skull Fractures

- Skull fractures are classified anatomically:
  - Skull vault fractures
  - Skull base fractures

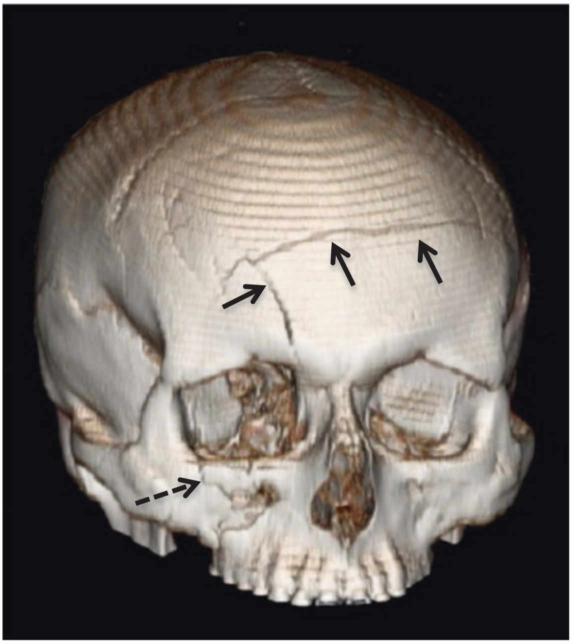


Fig. 9 A 3D reconstruction of a CT performed for a patient with a comminuted frontal bone fracture (solid arrows). There is also a fracture of the right maxilla (dashed arrow)

- 3D reconstruction of CT images is helpful in the evaluation of skull fractures.
- Skull fractures can be linear or compound, depressed or elevated and open or closed.
- Depressed fractures are often treated surgically.
- While patients who sustain trauma and have skull fractures are more likely to have intracranial haemorrhage than patients without skull fractures, the presence of a skull fracture in itself does not correlate with severity of brain injury.
- There are several important clinical signs that suggest a skull base fracture:
  - "Panda eyes"—periorbital bruising
  - Battle sign—bruising over the mastoid process
  - CSF rhinorrhoea—leakage of CSF into the paranasal sinuses.
- Base of skull fractures that involve the temporal bone are of particular concern as the inner ear structures can be disrupted resulting in hearing loss and leakage of CSF from the ears (Fig. 9).

Suggested Reading

- Lolli V, Pezzullo M, Delpierre I, Sadeghi N. MDCT imaging of traumatic brain injury. Br J Radiol. 2016;89:20150849.
- Kidwell CS, Wintermark M. Imaging of intracranial haemorrhage. Lancet Neurol. 2008;7(3):256–67.

- Mutch CA, Talbott JF, Gean A. Imaging evaluation of acute traumatic brain injury. Neurosurg Clin N Am. 2016;27(4):409–39.
- Provenzale JM. Imaging of traumatic brain injury: a review of the recent medical literature. AJR Am J Roentgenol. 2010;194(1):16–9.
- Currie S, Saleem N, Straiton JA, Macmullen-Price J, Warren DJ, Craven IJ. Imaging assessment of traumatic brain injury. Postgrad Med J. 2016;92(1083):41–50.
- Yao S, Song J, Li S, Cao C, Fang L, Wang C, Xu G. Helsinki computed tomography scoring system can independently predict long-term outcome in traumatic brain injury. World Neurosurg. 2017.

Tutorial 3: Spinal Trauma

Damien O'Neill and Mark Given

Aims and Guidance for Tutors

In the emergency setting, accurate clinical assessment in combination with appropriate imaging is key to the identification of patients with or at risk of neurological deficit. This chapter aims to familiarise students with the role of imaging for patients with spinal trauma. The primary concern with any spinal injury is not the vertebral column but the closely related neurological elements: the spinal cord, nerve roots and cauda equina. It is important that students understand the basic concepts of imaging in the context of the clinical examination. After completion of this tutorial students should be able to describe the key imaging features of typical patterns of spinal injury.

Introduction

- Road traffic accidents (40%) and falls (35%) are the leading causes of spinal injury.
- The greater the mechanism force (e.g. higher velocity) typically the greater the associated injury
- Cervical spine is most commonly affected followed by thoracic spine and lumbar spine

D. O'Neill (✉)
Beaumont Hospital, Dublin, Ireland
e-mail: damienconeill@rcsi.com

M. Given
Department of Radiology, Beaumont Hospital, Dublin, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_3

- In any suspected spinal injury immobilisation is key so as not to worsen any existing or potential neurological deficit
- The mechanisms of injury include flexion, extension, flexion with rotation, and compression.
- The AOSpine classification system is an internationally accepted imaging classification system based on recognised spinal injury patterns.
- Common types of spinal fractures are:
  - Compression
  - Burst
  - Seat-belt associated e.g. Chance fracture
  - Fracture-dislocation

Radiological Modalities Utilised

Radiography

- Mainstay of spinal imaging. AP and lateral radiographs of the region of the spinal area affected.
- Initial investigation of choice in most cases. Radiography is widely available and can be performed rapidly and without moving the patient from their trolley if needed.
- When imaging the cervical spine it is essential to include dedicated imaging of the odontoid peg in the cervical spine and the cervicothoracic junction (C7–T1).
- Radiography allows assessment of:
  - Vertebral alignment.
  - Vertebral body height and cortical margins for fractures.
- It is important to be cognizant of the limitations of radiography for the imaging of spinal trauma: Radiography will in many cases fail to establish the full extent of spinal injury. In addition, radiography has a lower sensitivity for fracture detection when compared to CT.
  - In many trauma units, CT cervical spine has replaced radiography as the initial imaging investigation for high risk patients presenting after high velocity cervical spine injury.

CT spine or as part of body CT scan

- Often performed as part of a work-up for other associated injuries (intra-abdominal/intra-thoracic).
- Can be performed to further assess an abnormality identified on plain radiographs or as initial investigation if there is high clinical suspicion.

- CT allows detailed anatomic identification of fractures and whether fractures are stable/unstable and whether there is cord compression
- Helpful for pre-operative planning if surgical fixation is being considered.

MRI spine

- In comparison with CT, there are several practical reasons that MRI is less suited for use in the emergency setting:
  - Longer imaging time required.
  - Sensitivity to patient motion.
  - Possible incompatibilities with indwelling medical devices or foreign bodies.
- For these reasons, MRI is usually performed after CT.
- MRI is far superior to CT for the identification of neurological injuries of the spinal cord such as contusions, oedema and haematoma. MRI can also identify soft tissue abnormalities such as ligamentous injury and intervertebral disc disruption.

Radiologist's tips: limitations of radiographs

- For the majority of patients with relatively low mechanisms of injury plain radiography should be sufficient
- However in the presence of a high velocity injuries, have a low threshold for further imaging
- CT can better delineate the bony structures of the vertebral column
- MRI can better delineate the spinal cord and soft tissues around the vertebral column
- Often a patient will require CT and MRI imaging when there is a fracture with neurological deficit to determine extent of injuries and plan fixation.

Indications for Imaging

- The need for imaging is dictated by clinical assessment.
- Patients who have sustained trauma with associated tenderness should have plain films of that portion of the spine.
- If a high velocity mechanism e.g. motor vehicle accident then CT imaging should be performed, usually as part of a trauma body CT scan to look for associated injuries.
- When a neurological deficit is present then an MRI should be performed as part of the imaging work-up.

Review of Relevant Radiological Anatomy: Spinal Radiography

See Figs. 1, 2, 3.

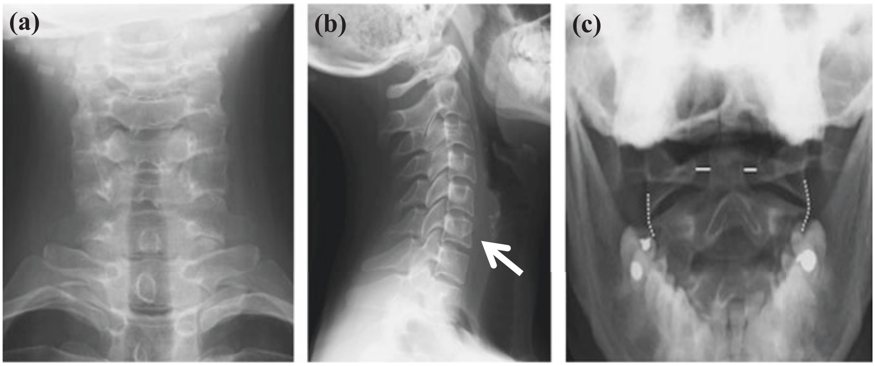


Fig. 1 Technically satisfactory AP (**a**), lateral (**b**) and open-mouth (**c**) views of the cervical spine. There are 7 cervical vertebrae: C1–C7. The AP and lateral radiographs demonstrate vertebral bodies, disc spaces, facet joints and spinous processes. Note on the lateral projection the normal shadow of the prevertebral soft tissues (arrow)—these can become swollen after cervical spine trauma. Recognition of prevertebral soft tissue thickening can help the Radiologist identify cases of significant cervical spine injury. Also appreciable on the lateral projection is the normal curvature of the cervical spine (cervical lordosis). **c** The open-mouth view demonstrates the odontoid process of C2 (also called the axis) and lateral masses of C1 (also called the atlas). The solid line between the odontoid process and lateral masses on either side should be equidistant and the dotted lines along the lateral margins of C1 and C2 should be smooth and continuous. Abnormalities of either of these lines suggests high cervical spine injury

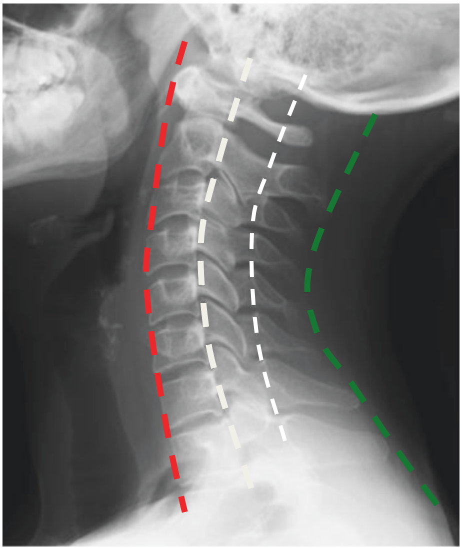


Fig. 2 Lateral radiograph of the cervical spine on which longitudinal lines are depicted. Anterior vertebral line—along the anterior margins of the vertebral bodies. Posterior vertebral line—along the posterior margins of the vertebral bodies, this delineates the anterior margin of the spinal canal. Spinolaminar line—along the junctions of the laminae and spinous processes of the vertebrae, this delineates the posterior margin of the spinal canal. Posterior spinous line—along the posterior margins of the spinous processes. Disruption of any of these lines suggests spinal injury and close examination for associated fractures should be performed

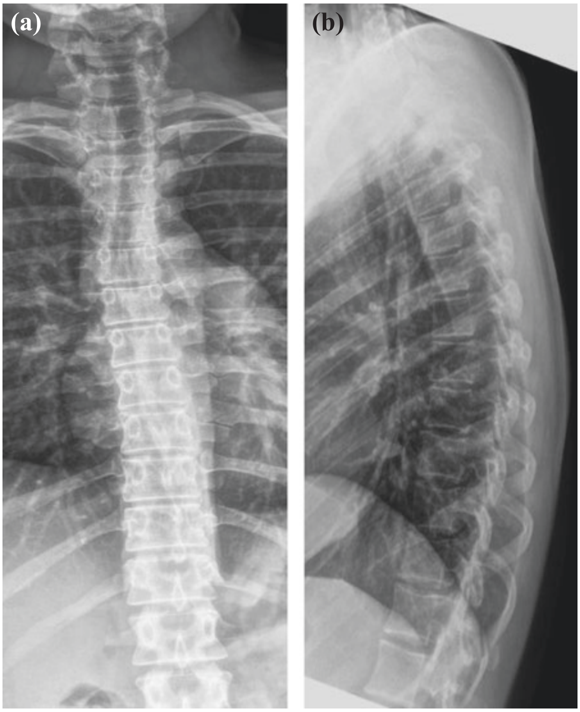


Fig. 3 AP (**a**) and lateral (**b**) radiographs of the thoracic spine. There are 12 thoracic vertebrae (T1–T12), which articulate with 12 pairs of ribs

Radiologist's tips: Spinal injury on plain films

- Assess the integrity of the spinal lines.
  – This will identify and displacement or associated soft tissue abnormality
- Trace the outline of each vertebra to identify:
  – Compression fractures: wedging of the vertebral body anteriorly
  – Burst fractures: discontinuity of the cortex of the vertebra anteriorly or posteriorly
- Check for uniformity of the disc spaces, this will help identify flexion/extension injuries

Fracture Types

Compression

- Typically result in wedge fractures due to hyperflexion injuries from axial loading.

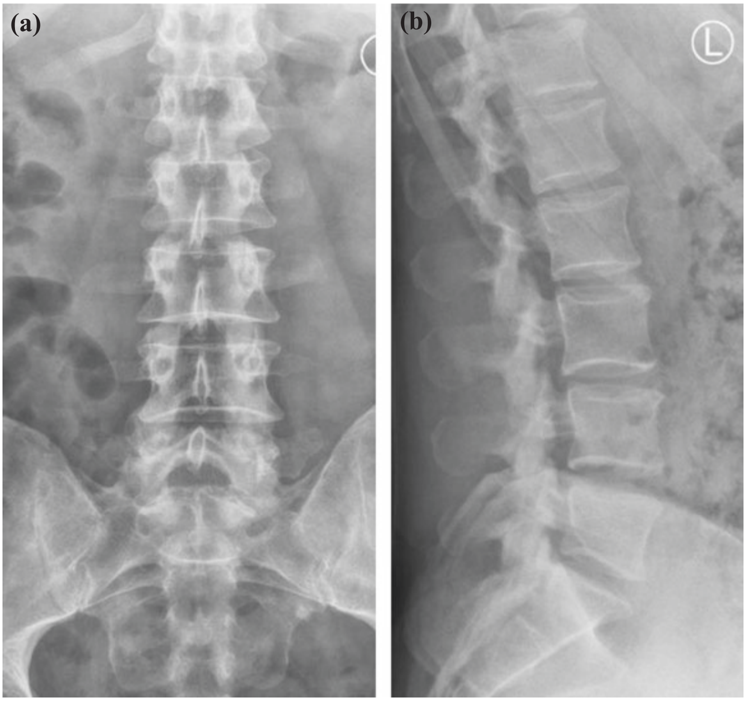


Fig. 4 AP (**a**) and lateral (**b**) radiographs of the lumbar spine. There are 5 lumbar vertebrae (L1–L5). Partially imaged upper sacrum is included

- Most commonly affecting the anterior aspect of the vertebral body in the lumbar and thoracic spine (Fig. 4).
- Risk factors include osteoporosis and can occur after minimal trauma (Fig. 5).

Burst

- These are a type of compression fracture related to high-energy axial loading spinal trauma (for example—a fall from a height in a standing position).
- The posterior vertebral body cortex is disrupted with retropulsion into the spinal canal. If the spinal cord is compressed this can result in neurological deficits below the level (Fig. 6).

Seat belt associated e.g. chance fracture

- Flexion-distraction type injuries of the spine that extend to involve the anterior and posterior elements, which may be ligamentous.
- These are unstable injuries and have a high association with intra-abdominal injuries especially in the retroperitoneum of the pancreas and duodenum (Fig. 7).

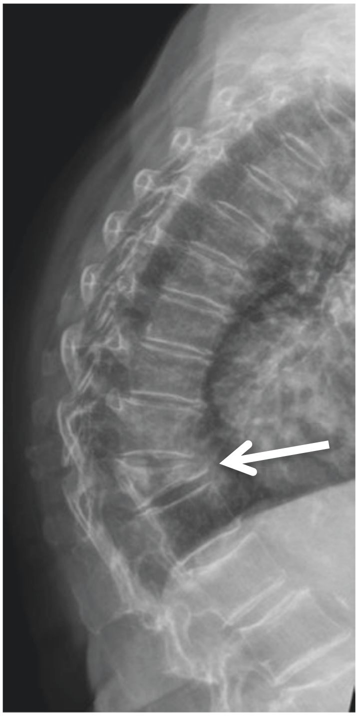


Fig. 5 Lateral radiograph of the thoracic spine of an elderly patient that demonstrates anterior wedging of T9 with approximately 50% loss of height anteriorly. There is a resultant exaggerated thoracic kyphosis

Flexion teardrop

- These result from severe axial loading with associated flexion. Most commonly occurring in the mid/lower cervical spine.
- Important to recognise as they indicate extensive underlying ligamentous injury and spinal instability. Associated spinal cord injury is common, especially anterior cervical cord syndrome and quadriplegia.
- The key finding is fracture of the anteroinferior lip of vertebral body and posterior displacement of the vertebral body often with widening of interspinous distance at that level, indicating ligamentous injury (Fig. 8).

Extension teardrop

- This injury occurs due to forced extension of the neck with resulting avulsion of the anteroinferior corner of the vertebral body, this disrupts the anterior longitudinal ligament.
- There is no vertebral body displacement. Generally not considered as severe as a flexion teardrop fracture (Fig. 9).

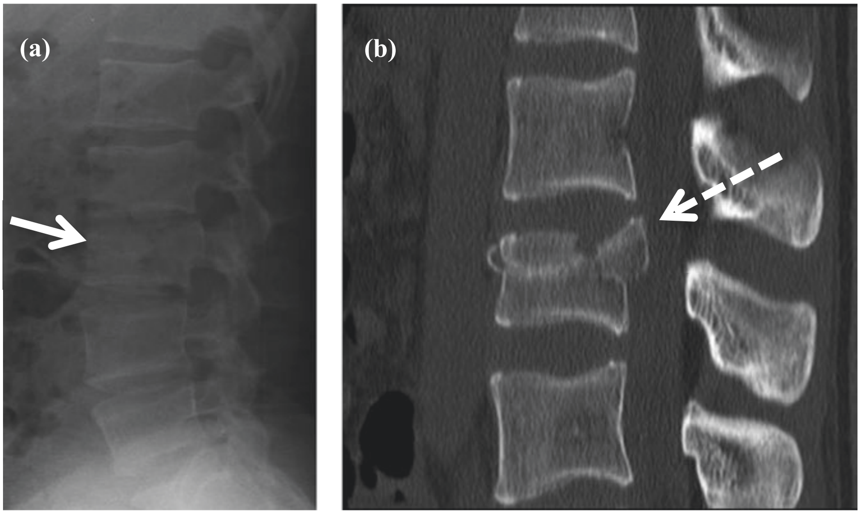


Fig. 6 **a** Lateral radiograph of the lumbar spine demonstrates some compression of L3 (arrow). There is also disruption of the posterior spinal line with retropulsion of a bone fragment into the spinal canal. **b** Sagittal CT through the lumbar spine demonstrates the burst-type fracture which extents through the anterior, superior and posterior cortices. A fragment arising posterosuperiorly is retropulsed into the spinal canal (dashed arrow), this likely causes some compression of the cauda equina nerve roots, which are not visible on CT. The posterior elements are intact

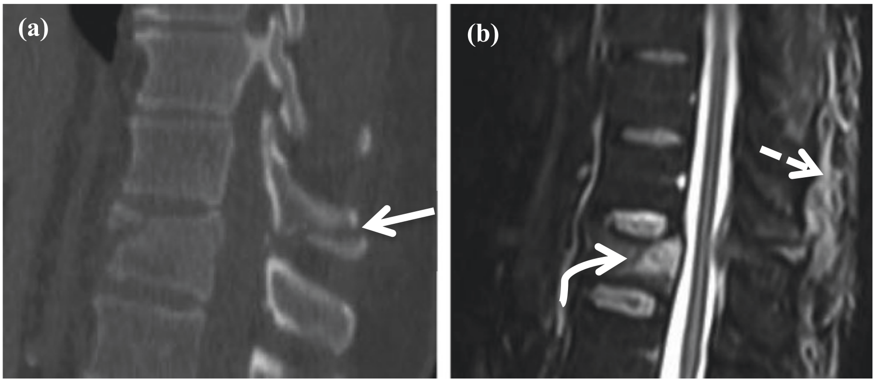


Fig. 7 **a** Sagittal CT of the thoracolumbar junction demonstrates a fracture through the L1 vertebral body, with extension of the fracture line posteriorly through the posterior elements of L1 (arrow). **b** Sagittal T2 weighted MRI demonstrates high signal with L1 vertebra (curved arrow), this is marrow oedema due to the fracture. Posteriorly injury of the spinous process of T12 and in the interspinous ligaments is evident by the increased signal (dashed arrow)

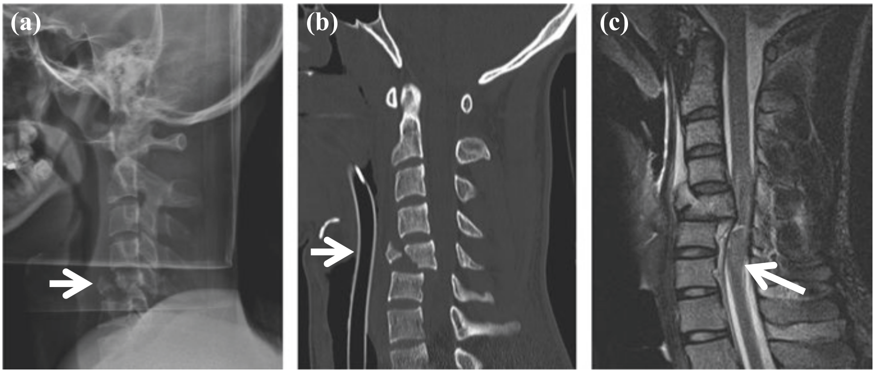


Fig. 8 Cervical spine imaging for a patient involved in a road traffic accident. **a** Lateral radiograph of the cervical spine with the patient immobilised in spinal blocks (partially visualised rectangular outline). A displaced fracture fragment is seen arising anteroinferiorly from C5 (arrow). In this case all of the longitudinal spinal lines have been disrupted—the C5 vertebral body has slipped posteriorly relative to the C6 vertebral body (this is called "retrolisthesis"). **b** Sagittal CT better depicts the fracture. Note also the presence of an endotracheal tube due to impaired respiratory function (arrow). **c** Sagittal T2 MRI again demonstrated the fracture also with disruption of the anterior longitudinal ligament and elevation of the posterior longitudinal ligament. The retrolisthesis of C5 has resulted in severe spinal canal stenosis and compression of the cervical cord. There is diffuse high signal within the cord from C4 to C6 consistent with oedema (arrow)

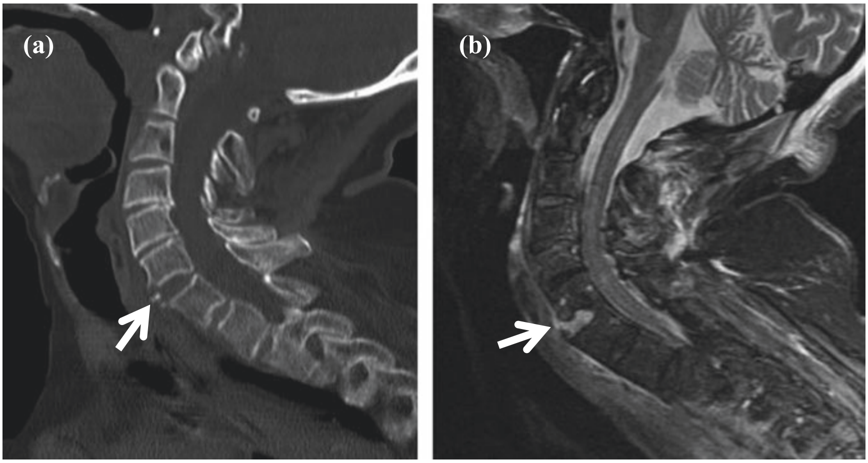


Fig. 9 **a** Sagittal CT demonstrating a small fracture fragment at the anterinferior margin of C6 (arrow) with some widening of the disc space at this level. **b** Sagittal T2 weighted MRI again demonstrates the fracture fragment, with increased signal within the C6–C7 disc and disruption of the anterior longitudinal ligament (arrow)

C-Spine Specific Fractures

There are several important fractures unique to the cervical spine. If neurological compromise results then symptoms affect both the upper and lower limbs.

Jefferson fracture

- This is a burst fracture of C1 (atlas), typically as a result of a significant axial load to the head that transmits through the occipital condyles resulting in fracture of the ring of C1 (Fig. 10).

Hangman fracture

- This results from hyperextension and distraction of the C2 vertebra (axis) with resultant bilateral fractures through the pars interarticularis of C2.

Odontoid process (peg) fracture

– Fracture involving the vertical protuberance of C2 often as a result of sudden neck flexion or extension. Elderly patients with osteoporosis are particularly at risk for sustaining this fracture. These fractures are at risk of nonunion and may require stabilisation with surgical fixation (Fig. 11).

Clay-shoveler fracture

- Fracture through the spinous processes of a lower cervical vertebra, usually C7 often with displacement.

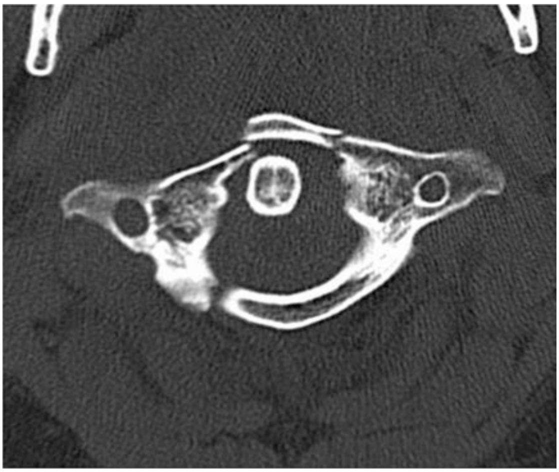


Fig. 10 Axial CT through C1 demonstrates two fracture lines within the anterior arch of C1 and a third fracture line through the posterior arch on the right

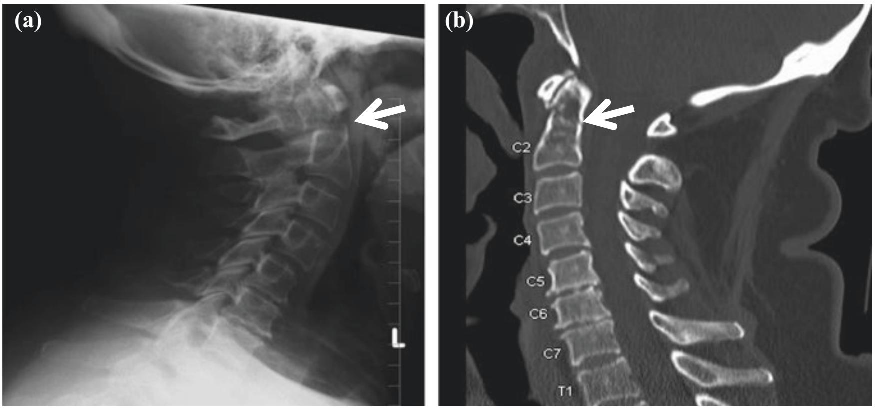


Fig. 11 **a** Lateral cervical spine radiograph demonstrating a minimally displaced fracture through the odontoid process (arrow) which is confirmed on CT (**b**)

Fig. 12 Lateral radiograph of the cervical spine that demonstrates a mildly displaced fracture of the spinous process of C7 (arrow). Note the loss of normal cervical spine curvature—this can be an indirect sign of cervical spine trauma

- This fracture was originally described in workers shovelling clay—when throwing the clay of the shovel, on occasion the clay would stick to the shovel resulting in a flexion injury to the neck and a “clay-shoveler fracture“ (Fig. 12).

Traumatic Listhesis

- Can occur either with or without associated fracture.
- In the absence of fractures then facet joint dislocation must occur:
  - Subluxed: partial uncovering of facet joint.
  - Perched: complete uncovering of facet joint.
  - Locked: occurs when the inferior articular process jumps over the superior articular process of the vertebra below and becomes locked in the position.

Cord compression

- Neurological dysfunction: The neurological level is at the most lowest segment with normal motor and sensory function
- Complete:
  - Flaccid paralysis with total loss of sensory and motor functions below that level. Autonomic dysfunction can also be present: perianal and "saddle" paraesthesia, bowel and/or bladder dysfunction
- Incomplete (mixed loss):
  - Anterior cord syndrome: Due to compression fracture of vertebral body or anterior dislocation. Anterior spinal artery compression. Loss of power, reduced pain and temperature below the lesion.
  - Posterior cord syndrome: Hyperextension injuries, Posterior vertebral body fracture, Loss of proprioception and vibration sense, Severe ataxia.
  - Central cord syndrome: Older age with degenerative cervical disc disease results from hyperextension with minor trauma. The cord is compressed by osteophytes from vertebral body against thick ligamentum flavum. Damages the central cervical tract. UMN lesion to legs (spastic). LMN to arms (flaccid paralysis).
  - Brown sequard's syndrome: Hemisection of the cord, usually as a result of stab injury and lateral mass fractures. The uninjured side has good power but absent pinprick and temperature. This is because the spinothalamic tracts cross to opposite side of the cord three segments below.

Suggested Reading

- Parizel PM, van der Zijden T, Gaudino S et-al. Trauma of the spine and spinal cord: imaging strategies. Eur Spine J. 2010;19 Suppl 1(S1):S8–17.
- Munera F, Rivas LA, Nunez DB et al. Imaging evaluation of adult spinal injuries: emphasis on multidetector CT in cervical spine trauma. Radiology. 2012;263(3):645–60. https://doi.org/10.1148/radiol.12110526.

- Kim KS, Chen HH, Russell EJ et-al. Flexion teardrop fracture of the cervical spine: radiographic characteristics. Am J Roentgenol. 1989;152(2):319–26. https://doi.org/10.2214/ajr.152.2.319.
- Looby S, Flanders A. Spine trauma. Radiol Clin North Am. 2011;49:129–63.
- Gamanagatti S, Rathinam D, Rangarajan K, Kumar A, Farooque K, Sharma V. Imaging evaluation of traumatic thoracolumbar spine injuries: radiological review. World J Radiol. 2015;7(9):253–65.

Tutorial 4: Body Trauma

Gerard M. Healy and Colin P. Cantwell

Aims and Guidance for Tutors

Radiology plays a vital role in the management of patients with thoracic and abdominal trauma. The objective of this tutorial is to familiarise medical students with the basic principles of body trauma imaging and the common patterns of injury. The therapeutic role of Interventional Radiology is briefly reviewed.

Introduction

- Radiology plays an important role in the assessment and management of patients who have suffered major trauma. The goal is rapid identification of life threatening conditions such as pneumothorax, haemothorax, aortic injury or laceration of an intraabdominal solid organ.
- Trauma can be divided into blunt (approx. 80% of total cases) or penetrating. This chapter focuses upon blunt trauma.
- The Advanced trauma life support (ATLS) program from the American College of Surgeons defines two stages of assessment in trauma; the primary survey and later the secondary survey.

G. M. Healy (✉) · C. P. Cantwell
Department of Radiology, St. Vincent's University Hospital, Dublin, Ireland
e-mail: ger.healy@svuh.ie

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_4

Radiological Modalities Utilised

Plain radiography (X-ray)

- Rapid and non-invasive. Can be performed in the Emergency Department (ED) resuscitation room as an adjunct to the primary survey.
- Exposes the patient to low dose of ionizing radiation.
- A standard 'trauma series' performed in the emergency department includes anterior-posterior (AP) and lateral radiographs of the cervical spine, AP chest and AP pelvis.
- Haemodynamically unstable patients will usually go directly to advanced imaging (CT) without plain radiography.

Ultrasound

- A portable ultrasound (US) machine can be used at the time of primary survey in the trauma area to see if the patient has cardiac haemopericardium or free fluid with the abdominal or pleural space (may be due to bleeding or bowel perforation) using gel and an ultrasound probe on the skin. This is called a Focused Assessment with Sonography for Trauma (FAST) scan.
- Does not expose the patient to ionizing radiation.
- The results of an US scan are limited by operator skill and patient factors such as bowel gas and obesity.
- Good at detecting free abdominal fluid, but cannot outrule bleeding or organ damage.

Computed tomography (CT)

- CT is the standard of care for imaging of the major trauma patient. A whole body CT (from top of head to mid-thigh) is recommended by the National Institute for Health and Care Excellence (NICE) for all adults with major blunt trauma, where multiples injuries are suspected.
- ATLS considered CT to be an adjunct to the secondary survey.
- Rapid and non-invasive.
- Generally not portable (except in very specialist centres).
- Exposes patient to moderate dose of ionizing radiation.
- Multiplanar reconstruction (axial, coronal and sagittal) improves accuracy of reporting.
- Intravenous contrast should be administered to improve sensitivity of the test for solid organ injury and vessel injury. Typically, a chest trauma CT is

acquired in non-contrast and then arterial phase contrast to assess for aortic injury, while an abdomen trauma CT is acquired in the venous phase, to assess for solid organ injury. Another option is a split bolus technique, which provides a porto-venous and arterial phase CT abdomen simultaneously.
- Multiphasic imaging may be performed if active haemorrhage is suspected. This may include all or some of the following phases: non-contrast, arterial, portal venous. A 5–10 min delayed urographic phase can be performed if urinary tract injury is suspected clinically.

Interventional radiology (IR)

- Uses ultrasound and fluoroscopy (real time radiography) to guide minimally invasive treatments to stop bleeding.
- IR can manage major haemorrhage, by blocking the bleeding artery (embolization) or by using a covered metal stent to control the ruptured vessel.

Image Interpretation

- Following a structured approach to image interpretation in emergencies is advised by international guidelines, such as from the Royal college of Radiologists (see 'Further reading').
- Trauma centres will often have proformas for the primary imaging survey of severely injured patients, using which any life-threatening diagnosis can be rapidly and clearly communicated to the trauma team leader.

Radiologist's tips

- CT is the imaging procedure of choice in evaluating the major trauma patient.
- Initial assessment should focus upon identification and prompt communication of life-threatening conditions to the trauma team leader. Reporting should adhere to the ATLS protocol (primary survey, secondary survey).

Review of Relevant Radiological Anatomy

See Figs. 1 and 2.

Fig. 1 Axial contrast-enhanced CT of the chest presented in lung windows

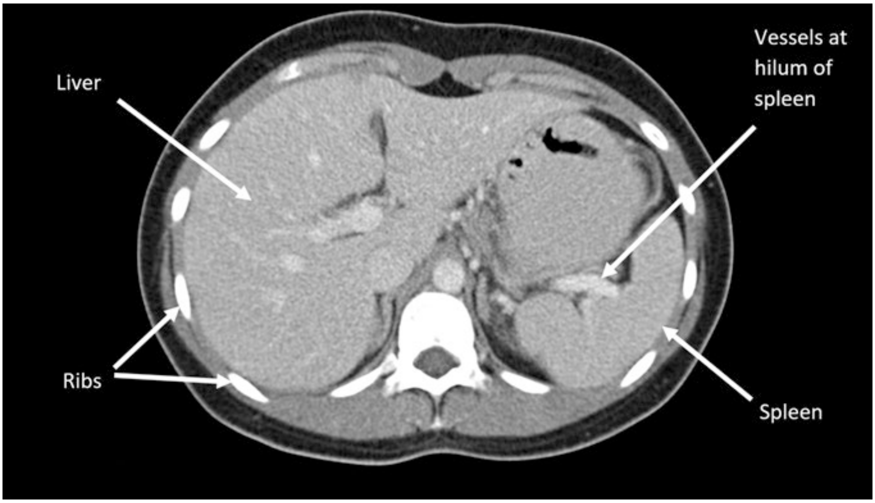


Fig. 2 Axial contrast-enhanced CT of the abdomen presented in soft tissue windows at the level of the splenic and hepatic hila

Common Patterns of Trauma: Chest

Pneumothorax

- Air within the pleural cavity. This may be caused by an injury to the lung parenchyma, airways or chest wall. The lung then collapses reducing the capacity of the respiratory system to oxygenate blood.
- In some cases a pneumothorax can enlarge and become pressurized called a tension pneumothorax. This will push the mediastinal structures including the heart and other lung away, compromising blood flow. This condition can be rapidly fatal if not identified and corrected with a chest drain.
- A large or tension pneumothorax is usually clinically apparent during the primary survey and can be treated with chest drain insertion without the need for imaging.

Pneumothorax: Key imaging features

- Identification of the edge of the lung separate from the chest wall (Fig. 3).
- The deep sulcus sign occurs in patients who are X-rayed supine and it appears as a unilateral 'deep' costophrenic sulcus.

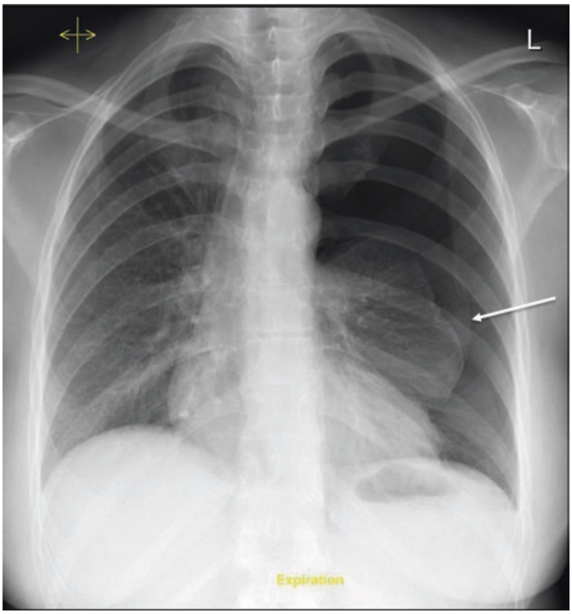


Fig. 3 Erect chest radiograph in a patient following blunt chest trauma. There is a large left-sided pneumothorax and the mediastinum has shifted to the right side, consistent with tension pneumothorax. The edge of the collapsed lung is highlighted with the white arrow

- The position of the mediastinum must be assessed in every case of pneumothorax, in order to assess for tension.
- Check for associated features: haemothorax, rib or sternal fractures or pneumomediastinum.

Haemothorax

- Bleeding into the chest cavity. May be from the chest wall, lung parenchyma or great vessels.
- Defined as massive if greater than 1,500 ml.
- The potential capacity of the thoracic cavity is significant, therefore a patient can lose a high volume of blood into the chest quickly, leading to hypovolemic shock and pulmonary compromise.

Haemothorax: Key imaging features

- Indisguisable from pleural effusion on chest radiograph. Blunting of costophrenic angles (if erect radiograph) or diffuse haze overlying hemithorax (if supine)
- Haemorrhage can be distinguished from simple effusion on CT by measuring the attenuation of the fluid. >30 Hounsfield units typically indicates blood products.

Aortic injury

- This can be rapidly fatal. Patients with a less severe injury such as mural haematoma or laceration are more likely to survive to hospital
- The thoracic aorta is relatively fixed at the isthmus, which is just distal to the left subclavian artery. There is a risk of transection at this point with a deceleration injury.

Aortic injury: Key imaging features

- Widened mediastinum on chest radiograph is a nonspecific sign with low sensitivity. Nonetheless it is important to assess for this, since almost all patients will have a chest radiograph as part of their primary survey.
- Haemorrhage tracking up along the left subclavian artery is called the apical cap sign on chest radiograph.
- Left sided haemothorax and/or depression of the left main bronchus.
- On CT, there may be an obvious injury but it may be a subtle irregularity of the aortic wall. Secondary signs include mediastinal haematoma.

Flail chest

- This is defined as two or more adjacent ribs fractured in at least two places.

- The rigid thoracic cage normally facilitates respiration. The result of a flail chest is a segment of chest wall which moves inwards (paradoxically) with inspiration, thus reducing air exchange in the lungs and causing significant pain.

Flail chest: Key imaging features

- Displaced rib fractures are usually obvious on chest radiograph (Fig. 4), however undisplaced fractures may be difficult to see.
- If a CT is obtained, look for associated injuries such as pneumothorax, pulmonary laceration (tear) or pulmonary contusion (which looks like lung infection, however the alveoli are filled with blood rather than inflammatory fluid—Fig. 5).
- 3D reconstruction of chest CT can be helpful in visualizing the ribs and identifying fail chest (Fig. 6).

Diaphragm injury

- Uncommon injury. Occurs in approximately 5% of major trauma cases
- More common on the left side, which may be due to the presence of the liver on the right.
- Abdominal contents may herniate into the thorax and reduce the functional capacity of the lung. The herniated abdominal organs are at risk of ischaemia.
- This can be a difficult diagnosis to make, even with advanced imaging such as CT. Some patients will therefore have a delayed diagnosis.

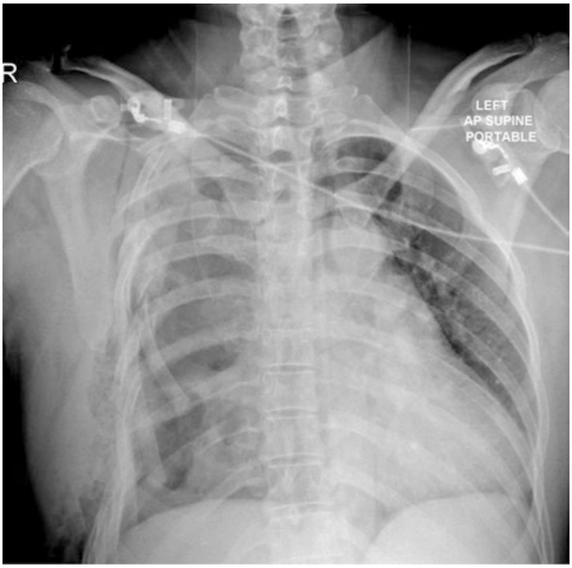


Fig. 4 Supine chest radiograph in a patient who fell from a horse. Multiple right-sided rib fractures, with at least two adjacent ribs fractured in two places, consistent with flail chest. Subcutaneous emphysema in the adjacent chest wall. Asymmetrical opacification of the entire right hemithorax suggests effusion/haemothorax (remember that this patient is lying flat, so fluid will not accumulate in the costophrenic angle as it would in an erect radiograph). The mediastinum is shifted to the left

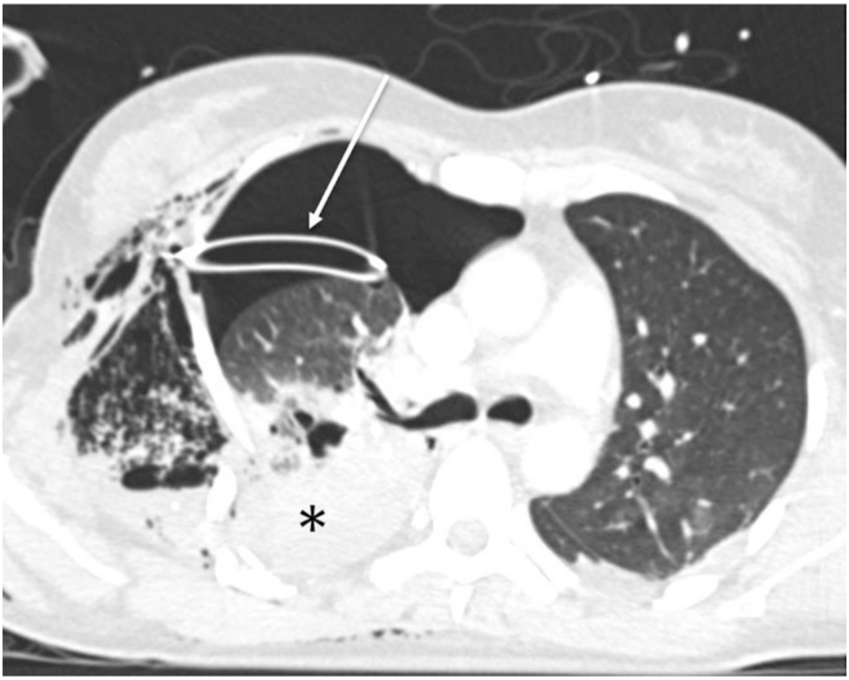
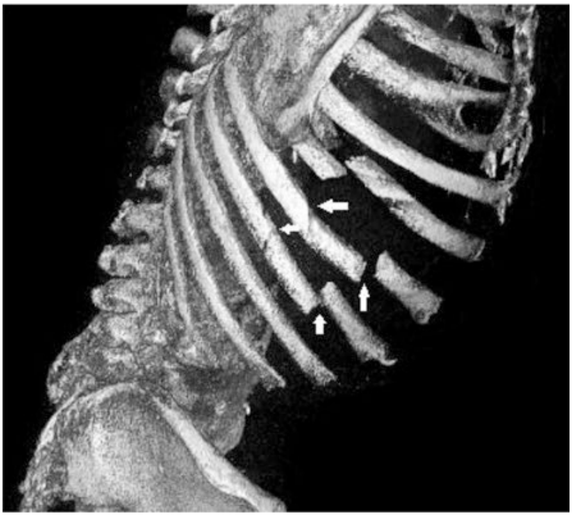


Fig. 5 Axial CT chest in the same patient as Fig. 4. This demonstrates a pneumothorax with a wide bore chest drain in situ (white arrow), collapsed lung with contusion (*) and displaced right sided rib fractures

Fig. 6 3D reconstruction of a chest CT in a patient with flail chest. There is a displaced fracture of the right 7th rib and there are two fractures in each of the 8th and 9th ribs (arrows)



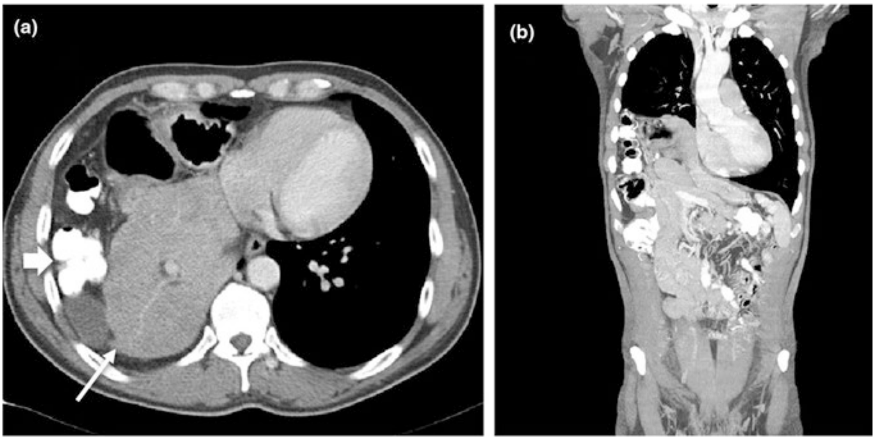


Fig. 7 Axial (**a**) and coronal (**b**) CT images from a patient with right sided diaphragm rupture. **a** With herniation of liver (thin arrow) and colon (thick arrow) into the thorax. The liver (thin arrow) has compressed and displaced the lung in the right costophrenic space and now appears to lie on the posterior ribs (the dependent viscera sign) **b** The right hemidiaphragm appears to extend more cranial than the left on the coronal CT due to the tear of the right diaphragm

Diaphragm injury: Key imaging features

- It can be difficult to visualise the diaphragm on plain radiography or CT because it is so thin, however new elevation of a hemidiaphragm or abnormal position of abdominal contents within the thorax can help make the diagnosis.
- Most important sign on CT of diaphragmatic rupture is the 'dependent viscera sign', where in a supine patient the liver or spleen are in abnormal contact with the ribs when the "sling function" of the diaphragm is lost (Fig. 7).

Common Patterns of Trauma: Abdomen

Solid organs: liver, spleen and kidney

- These are the most commonly injured intra-abdominal structures in blunt abdominal trauma. Injuries can be broadly divided into parenchymal haematoma, laceration and vascular injury.
- The American Association for the Surgery of Trauma (AAST) has published injury severity scores for multiple chest and abdominal organs, which are available freely online. The most widely used are for the liver and spleen (Table 1). The AAST system is useful when describing these complex injuries.
- Injuries to the renal tracts can be identified with delayed 'urographic' phase imaging. This is the phase during which intravenous contrast is being excreted by the kidneys, opacifying each ureter. Leakage of contrast during this phase signifies injury of the collecting system.

Table 1 American association for the surgery of trauma (AAST) classification for liver injury

Grade		
I	Haematoma	Subcapsular, <10% surface area
	Laceration	Capsular tear, <1 cm parenchymal depth
II	Haematoma	Subcapsular, 10–50% surface area intraparenchymal, <10 cm in diameter
	Laceration	Capsular tear, 1–3 cm parenchymal depth, <10 cm in length
III	Hematoma	Subcapsular, >50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma >10 cm or expanding
	Laceration	>3 cm parenchymal depth
IV	Laceration	Parenchymal disruption involving 25–75% hepatic lobe or 1–3 Couinaud's segments
V	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud's segments within a single lobe
	Vascular	Juxtahepatic venous injuries; i.e. retrohepatic vena cava/central major hepatic veins
VI	Vascular	Hepatic avulsion

Table reproduced with permission
[a]Advance one grade for multiple injuries up to grade III

Key imaging features on CT

- Peri-splenic/peri-hepatic/peri-nephric haematoma.
- Intra-parenchymal haematoma.
- A laceration appears as a low attenuation region within the organ, usually extending to the organ capsule (Figs. 8 and 9).
- Vascular injury, which may range from complete avulsion of the organ hilum with active bleeding, to pseudoaneurysm or subtle vessel wall irregularity (Fig. 10 and Table 1).

Bowel Injury

- Intestinal injury typically occurs at a site of attachment to the mesentery, where an enteric structure is relatively fixed.
- Injury to bowel can be subtle on imaging and therefore is sometimes missed. This can have grave consequences if peritonitis occurs.
- Duodenal haematoma is commonly caused by blunt trauma to the epigastrium, such as from the handle bars of a bike. Pancreatic injury should also be suspected from this mechanism of injury.

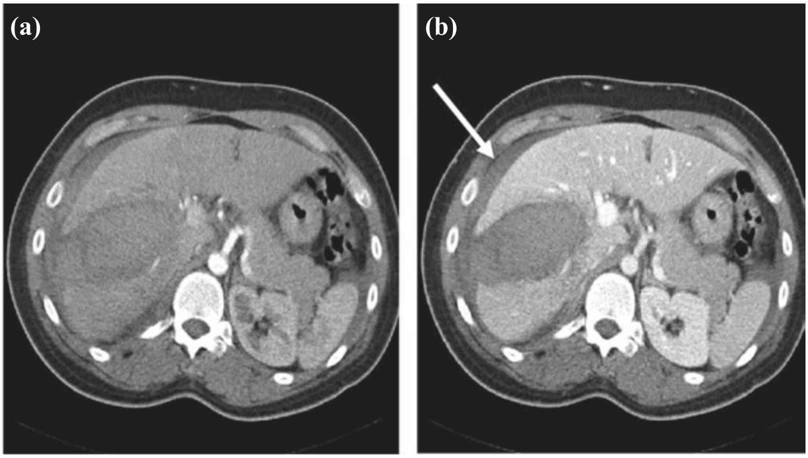


Fig. 8 Axial multiphasic CT liver (arterial and venous phases) of a patient following blunt trauma in a cycling accident. This is classified as AAST grade IV (laceration involving 25–75% of hepatic lobe). No active haemorrhage is demonstrated, however there is a crescent of high attenuation material surrounding the liver (see arrow), consistent with haemoperitoneum

Fig. 9 Axial CT of a patient following a fall from height. There is an AAST grade III splenic injury consisting of a parenchymal laceration (small arrow) and adjacent large subcapsular haematoma. There is also a high attenuation retroperitoneal haematoma anterior to the right kidney (long arrow)

Bowel Injury: Key imaging features

- Hemoperitoneum (often the only indication of visceral injury).
- Mesenteric fat stranding.
- Bowel wall thickening/mural haematoma.
- Free intra-abdominal air.

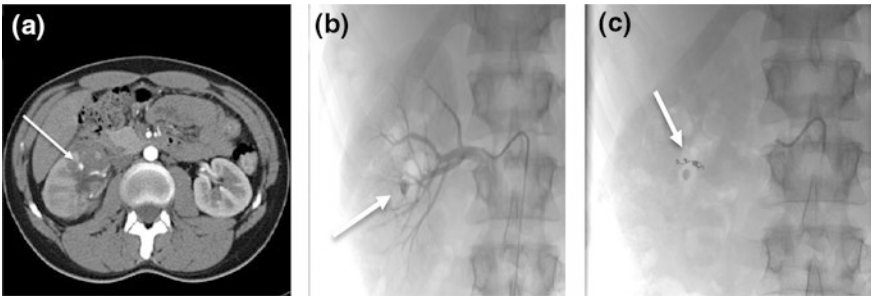


Fig. 10 **a** Right renal laceration post snowboarding injury. Image **a** is the arterial phase and **b** is the venous phase. There is an arterial enhancing structure within the site of injury (see arrow), consistent with a pseudoaneurysm (PsA). This was treated by Interventional Radiology by angiography and embolization. **b** Angiographic image from the IR embolization procedure, demonstrating the PsA (arrow). **c** Post embolization image showing metallic coils (arrow) which have been placed across the site of renal arterial branch injury

Management—The Role of Interventional Radiology

- Interventional Radiology plays an important role in the management of major haemorrhage.
- Typically patients will first undergo CT angiography in order to identify the site of haemorrhage. Patients who are acutely unstable despite resuscitation are usually managed by open surgery.
- In patients who are stable, or in those unstable patients who respond to resuscitation, haemorrhage may be managed by Interventional Radiology with embolization or stenting of a damaged artery.
- Common procedures in trauma include: Thoracic Aortic transection stent graft placement, embolic occlusion of the splenic artery for splenic laceration, selective repair of transected arteries or artery embolisation at suitable sites such as pelvic fractures, liver or renal laceration

Suggested Reading

- Gore R, Levine M. Textbook of gastrointestinal radiology, 4th ed. Elsevier; 2015.
- Major trauma: assessment and initial management. NICE guideline NG39. February 2016.
- Advanced trauma life support. Student course manual, 10th ed. 2018.
- AAST Injury Severity Scores: http://www.aast.org/library/traumatools/injury-scoringscales.aspx#spleen.
- Royal College of Radiologists (RCR) Standards of practice and guidance for trauma radiology in severely injured patients, 2nd ed. 2015.
- Soto JA, Anderson SW. Multidetector CT of blunt abdominal trauma. Radiology. 2012;265:678–93.

Tutorial 5: Fractures of the Upper and Lower Limbs

Mark Sheehan and Deirdre Duke

Aims and Guidance for Tutors

The aim of this tutorial is the review fractures and dislocations of the upper and lower limbs that a medical student might encounter during an orthopedic or emergency medicine rotation. The key principles of the imaging of fractures and dislocations are presented in this tutorial. This tutorial also aims to help students recognise fracture patterns and be familiar with the common mechanisms and clinical presentations associated with fractures/dislocations.

Introduction

- Trauma is the most common reason patients present to the emergency department.
  - the majority of injuries sustained are minor.
- Most radiographs performed for trauma will compromise of two orthogonal projections (one projection that is 90 degrees in relation to the other projection)
  - but additional special views may also be required. It is important to review all the images supplied as it is not uncommon for a fracture to be only visualised on a single projection.
- When approaching any radiological investigation a systematic approach is required.
- A basic knowledge of normal anatomy is required to be able to identify the region of interest and describe the fracture pattern.

M. Sheehan (✉) · D. Duke
Beaumont Hospital, Dublin, Ireland
e-mail: marksheehan@rcsi.ie

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_5

- In children it is important to include the joints on either side of the injury.
- Clinical history and examination are important as some injuries will not be visible on radiographs.

Radiological Modalities Utilised

- Plain radiography: The main modality for the diagnosis and observation of healing for traumatic fractures.
- CT: Often used with complex comminuted fractures for preoperative planning. CT is the imaging procedure of choice in evaluating the major trauma patient. Initial assessment should focus upon identification and prompt communication of life-threatening conditions to the trauma team leader. Reporting should adhere to the ATLS protocol (primary survey, secondary survey).
- MRI: Useful for identifying occult fractures especially on T2 and STIR (Short Tau Inversion Recovery) sequences where high signal representing odema may be the only indication of the fracture.
- Nuclear medicine: Can also be used to identify occult fractures which are seen as areas of increased radiotracer uptake.

Describing a Fracture

- Firstly identify the modality and the views that are available.
- Secondly identify the bone or region that is imaged.
- Then describe the features of the fracture that are relevant to the Clinician treatning the patient (see Radiologist‘s tips).

Radiologist's tips: Describing a fracture

- Where in the bone is the fracture located- i.e. epiphysis, metaphysis, diaphysis. Does the location of the bone have a specific name; e.g. anatomic neck of the humerus.
- Complete/Incomplete Fractures:
  - Complete: Extend across the cortex on both sides of the bone.
    Incomplete: The fracture extends only from the cortex to the medulla.
- Orientation of fracture:
  - Transverse: Fracture orientated across the short axis of the bone.
  - Oblique: Fracture is orientated diagonally across the short axis of the bone.
  - Spiral: Fracture spirals along the long axis of the bone.
- Comminuted: Multiple fracture lines.

- Alignment of the fracture:
  - Displaced: Separation of the bone fragments or the bone is pointing in the wrong direction.
  - Angulation: Usually describes the direction of the distal fragment of bone. Can be measured in degrees deviation from its normal position.
  - Impaction: The two bone fragments are impacted together.

- Intra-articular extension: The fracture extends to involve the articular surface.
- Complications of fracture: For example neurovascular compromise as seen in supracondylar fractures of the humerus (median nerve damage) or avascular necrosis in a neck of femur fracture and proximal scaphoid fracture.

Upper Limb Fractures

Finger

- Mallet finger (Fig. 1):
  - Occurs due to an injury of the extensor mechanism of the finger at the level of the distal interphalangeal joint (DIPJ).
  - Often seen in sports where the finger is forced into flexion e.g. tag rugby and basketball.

Fig. 1 Mallet finger (no avulsion fracture) sustained by a patient after playing rugby

- They can be a tendinous injury alone or occur in combination with an avulsion fracture (mallet fracture).
- Patient presents with distal phalanx held in a slightly flexed position.

- Volar plate avulsion fracture (Fig. 2):
  - The volar plate is a thick ligament that joins the phalanges. In hyperextension injury the volar ligament can be stretched and torn and may result in an avulsion fracture.
  - The avulsion fracture usually occurs at the base of the middle phalanx due to injury at the proximal interphalangeal joint (PIPJ).
  - Conservative management is usually reserved to small avulsion fragments with <30 degrees of flexion.

Hand

- Boxers fracture (Fig. 3):
  - Usually seen as a consequence of a direct blow by a closed fist resulting in impaction of the 5th metacarpal (MCP) on a hard surface.
  - The fracture is seen to transverse the 5th MCP and is often comminuted, angled and impacted.
  - Conservative management versus operative intervention depends on the degree of angulation, the degree of malrotation or articular involvement.

Fig. 2 Volar plate avulsion fracture, frequently seen in volleyball or baseball

Fig. 3 Boxers fracture

Fig. 4 Game keepers Thumb, commonly seen in skiers due to the ski pole forcefully abducting the thumb

- Gamekeeper thumb (Fig. 4):
  - Results from forced abduction of the thumb.
  - Avulsion of the ulnar collateral ligament of the thumb from its insertion into the proximal phalanx.

- Bennett's fracture (Fig. 5):
  - Fracture of the base of the 1st metacarpal bone with associated intra articular extension into the 1st CMC joint. Usually with subluxation or dislocation of the CMC.
  - Caused by a force against a partially flexed metacarpal.
- Scaphoid fracture (Fig. 6):
  - Usually due to fall on the outstretched hand.
  - If a scaphoid fracture is clinically suspected i.e. pain in the anatomical snuff-box, a repeat radiograph should be carried out in 7–10 days to ensure there is no fracture as often the fracture is not visible on the initial radiograph.
  - Complications include avascular necrosis and non-union and delayed presentation typically requires surgical intervention.
- Triquetral fracture (Fig. 7):
  - The second most common carpal bone fracture.
  - Usually the fracture occurs at the dorsal surface of the bone and results in the 'pooping duck' sign on lateral projection.

Wrist

- Colles:
  - Most common distal radius fracture. Usually due to a fall on the outstretched hand.
  - Frequently seen in patients with underlying osteoporosis.

Fig. 5 Bennetts fracture

Fig. 6 Scaphoid fracture seen 10 days after a fall on the outstretched hand

Fig. 7 Triquetral fracture are typically seen best on the lateral view

– The fracture consists of the distal radial fracture with dorsal angulation of the distal fragment without articular involvement.
– Complications of the fracture include impaction, fracture of the ulnar styloid and scapholunate dislocation.

- Smith's fractures:
  - Occurs from falling onto a flexed wrist or from direct trauma to the dorsal aspect of the wrist.
  - A reverse of a Colles fracture where there is volar angulation of the distal fragment of the radius.
  - Complications of this fracture includes narrowing of the carpal tunnel resulting median nerve compression and carpal tunnel syndrome.
- Ulnar styloid fracture:
  - Frequently occurs in association with distal radial fractures.
  - Usually an avulsion fracture and often does not require intervention.

Forearm

- Monteggia fracture dislocation (Fig. 8):
  - Consists of a fracture of the proximal third of the ulnar diaphysis and a dislocation of the radial head at the elbow.
  - Highlights the importance of having a radiograph of the elbow in the presence of a forearm fracture.

Fig. 8 Monteggia fracture dislocation

- Galeazzi fracture dislocation:
  – Fracture of the distal radius and dislocation of the ulnar at the radioulnar joint.
- Complications of forearm fractures include compartment syndrome, anterior interosseous nerve or a radial nerve palsy.
- A common mnemonic used is Manchester United: Monteggia—Ulnar fracture, Glasgow Rangers: Galeazzi—Radial Fracture.

Elbow

- Radial head and radial neck fractures (Fig. 9):
  – These fractures are usually due to indirect trauma i.e. fall on the outstretched hand with the radial head forcefully impacting the capitulum of the elbow.
  – These are often very subtle and may only be seen on one view. It is very important to look for the presence an elbow joint effusion as this may be the only clue.
  – The presence of an elbow joint effusion is recognised on lateral radiographs indirectly as elevation of the anterior fat pad which is triangular in shape and said to resemble the sail of a boat (therefore referred to as the sail sign). Also look for a posterior fat pad, this should not normally be visible on radiographs. When there is an elbow joint effusion, the posterior fat pad is displaced away from the distal humerus to become visible on lateral radiographs as a linear lucency.
  – An elbow joint effusion associated with a radial head fracture is usually caused by haemorrhage into the joint (haemarthrosis).

Fig. 9 Lateral radiograph of the right elbow demonstrating a fracture of the radial head/neck junction (solid arrow). Note the presence of an associated joint effusion- there is a sail sign (dashed arrow) and a visible posterior fat pad (arrowhead)

Fig. 10 Olecranon fracture

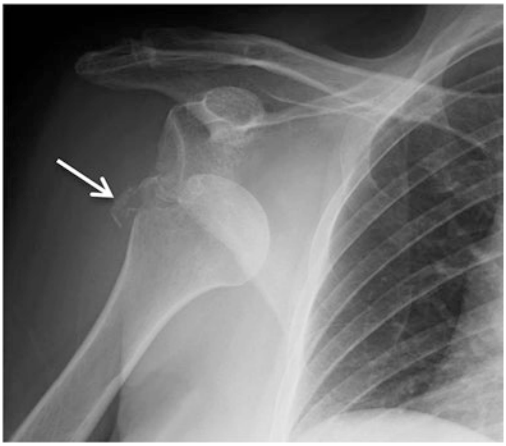


Fig. 11 Anterior dislocation with a Hill sachs deformity (arrow)

- Olecranon fracture (Fig. 10):
  - Usually a consequence of direct trauma or rarely due to a triceps avulsion.
  - All olecranon fractures are intra-articular.

Glenohumeral (shoulder) joint:

- Anterior Dislocation (Fig. 11):
  - Accounts for up to 95% of all shoulder dislocations. Usually occurs due to forced extension in the arm that is extended, abducted and externally rotated.
  - Can be associated with fractures of the humerus or scapula.
  - Dislocation can be complicated by formation of two abnormalities that may predispose to future glenohumeral instability:
  - Hills sach lesion: A compression fracture of the posterolateral aspect of the humeral head as it impacts against the glenoid during dislocation.

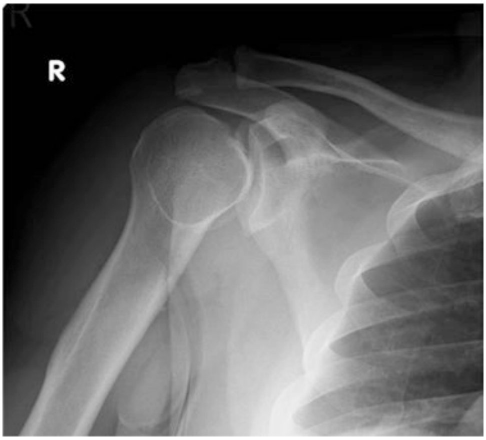


Fig. 12 Posterior dislocation with a lightbulb sign

 - Bankart lesion: This refers to an injury of the anteroinferior aspect of the glenoid labrum after a shoulder dislocation. When it is associated with a fracture of the glenoid it is known as a “bony bankart lesion”.

- Posterior Dislocation (Fig. 12):
  - Uncommon, usually seen in patients post seizure or electrocution who fall forward onto shoulder and the shoulder is forced posteriorly.
  - This dislocation can be frequently overlooked as imaging appearances may be subtle.
  - Lightbulb sign: Internal rotation of the humeral head gives it a rounded appearance.
  - An additional view to confirm may be required (axial view).

Proximal Humeral fracture:

- Most commonly seen in the older population and often associated with osteoporosis.
- Locations of the fractures include surgical neck, anatomical neck and involvement of the greater tuberosity.

Clavicle:

- Clavicle Fracture (Fig. 13):
  - Fractures usually a consequence of a direct blow or fall. These are seen frequently in contact sports such as rugby or football.
  - The fracture usually occurs in the middle 3rd of the bone and often associated with displacement and angulation.
  - Treatment is commonly conservative with just immobilization.

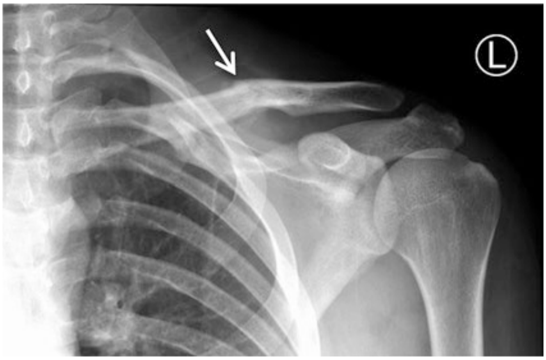


Fig. 13 Clavicular fracture

Fig. 14 Base of 5th fracture

– Important to look for associated disruption of the sternoclavicular or acromioclavicular joints.

Lower Limb Fractures

Feet:

- Base of 5th metatarsal (Fig. 14):

Fig. 15 Lisfranc fracture dislocation

- Usually a consequence of an inversion injury.
- Avulsion fracture of the insertion of peroneus brevis frequently occurs- representing approximately 90% of base of 5th fractures.
- An extra articular fracture located at the metadiaphyseal junction is known as a Jones Fracture.

- Lisfranc fracture dislocation (Fig. 15):
  - The Lisfranc joint is the relationship between the first 3 metatarsals and the cuneiform bones.
  - The Lisfranc ligament is a strong band that connects the medial cuneiform, the 2nd and 3rd metatarsal.
  - Excessive kinetic energy applied directly or indirectly to midfoot can result in ligamentous injury.
  - Lisfranc injury usually seen as a widening of the space between the first and second metatarsal with malalignment of the 2nd metatarsal and medial cuneiform. Fractures of the bases of the metatarsals can also occur.
  - Treatment is typically with internal fixation.

- Calcaneal Fractures:
  - Seen in high energy traumas such as a fall from a height or road traffic accidents.
  - It is the most commonly fractured tarsal bone.
  - Subtalar joint involvement is seen in 75% of fractures.

  – Narrowing of Böhler's angle (The angle between two tangential lines drawn along the superior surface of the calcaneus) of $<20°$ is indicatative of a calcaneal fracture.

Ankle:

- Distal Fibular fractures (Figs. 16 and 17):
  – Usually seen as a consequence of an inversion injury.
  – The Ottawa Ankle rules can be applied in the emergency department to assess who warrants investigation with plain films.
  – Classified in accordance with the Weber classification.

Fig. 16 Weber A

Fig. 17 Weber B

    - Weber A: Fracture below syndesmosis
    - Weber B: Fracture occurs at the syndesmosis
    - Weber C: Fracture occurs above the syndesmosis
  - The ankle syndesmosis is fibrous joint between the distal fibula and tibia. The joint is held together by dense connective tissue.
  - Involvement of the syndesmosis is considered unstable.

Knee:

- Tibial spine fracture:
  - Can be seen with ACL avulsion injuries as ACL attaches to the anterior aspect of the tibial spine.
  - Best seen on the AP radiographs.
  - Most commonly seen in children between 8–14 years.
  - Commonly associated with meniscal or collateral ligamentous injuries.
- Tibial Plateau fracture (Figs. 18 and 19):
  - Depressed tibial plateau fractures are more commonly seen in elderly population while splint type fractures are seen in younger patients who have had a fall from a height.
  - Previously known as a "fender fracture" as it was associated with direct blow by a car bumper.
  - A lipoheamarthrosis can be seen on the horizontal beam lateral of the knee with a fluid-fluid level (blood-fat) visible indicating an intra articular fracture.
  - CT is utilized to characterize the fracture prior to surgery.

Fig. 18 Suprapatellar lipoheamarthrosis seen in a patient with a tibial plateau fracture

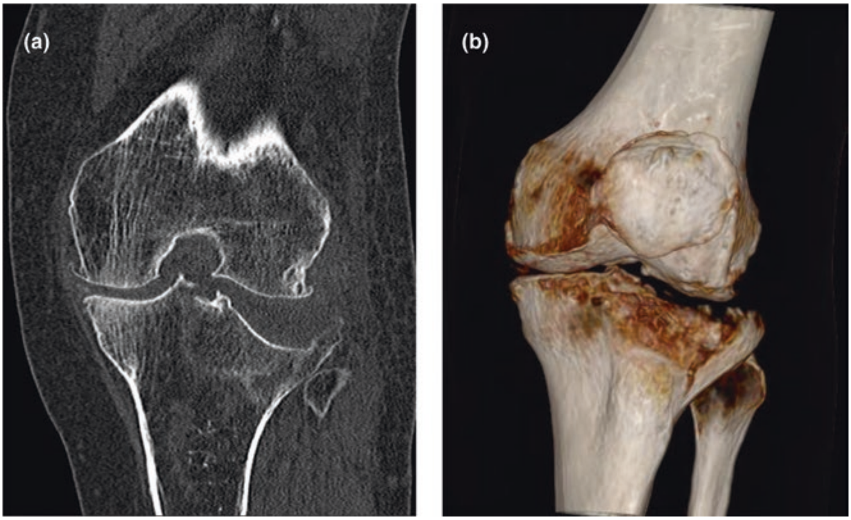
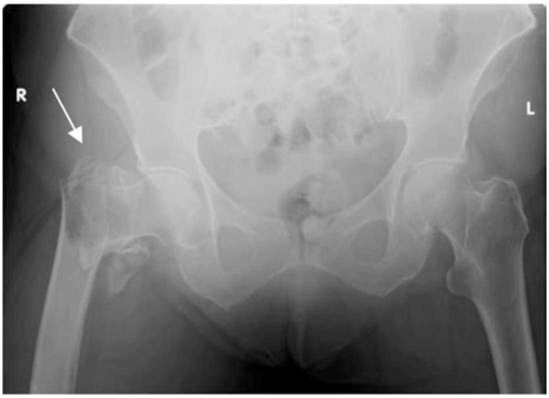


Fig. 19 Coronal CT (**a**) and a 3D (**b**) reconstruction of a depressed tibial plateau fracture

Fig. 20 Neck of femur fracture

Fig. 21 Intertrochanteric fracture



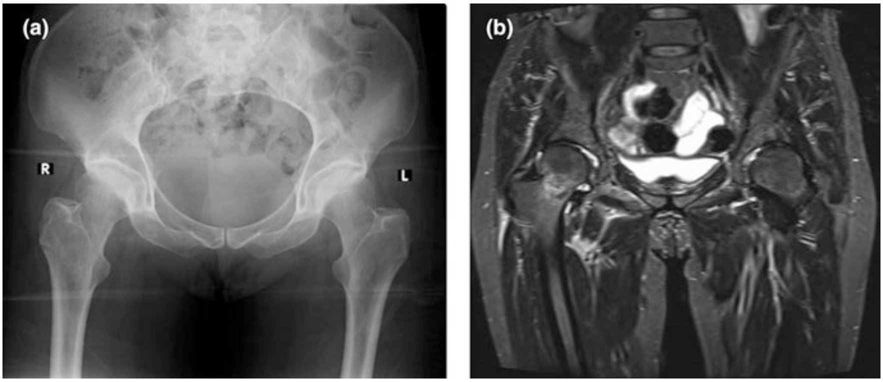


Fig. 22 Pelvic radiograph (**a**) appears normal, but MRI (**b**) shows an occult right sided neck of femur fracture

  - Fractures are classified according to the Schatzker system.
  - Serious complication includes compartment syndrome and vascular injury to the popliteal artery.

Hips:

- Femoral neck fracture (Figs. 20, 21 and 22):
  - Seen mostly in the elderly with osteoporosis and may be seen in high-energy trauma in young adults.
  - Associated with high morbidity and mortality rates in the elderly population.
  - A disruption in Shenton's line or discontinuation of trabecular markings are signs of fracture.
  - Avascular necrosis and non-union are complications that dictate the type of surgical intervention depending whether the fracture is intra or extracapsular.
  - Intracapsular fractures include fractures of the femoral neck and head fractures.
  - CT and MRI can be very useful in the diagnosis of radiographically occult fractures.
  - Occult fractures should be considered if patient is unable to weight bear despite a normal radiograph.
- Trochanteric fractures (Fig. 21):
  - Intertrochanteric and subtrochanteric are examples of extracapsular hip fractures involving the greater and/or lesser trochanters.
  - Lower risk of AVN and non-union due to rich blood supply.

Fig. 23 Pubic Ramus fracture

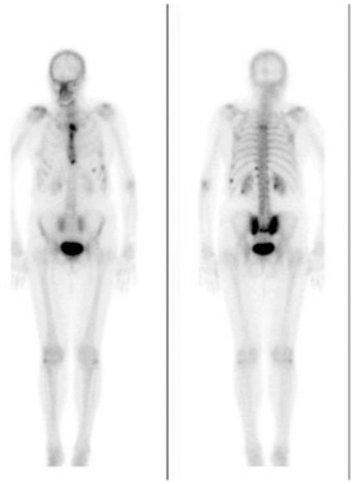


Fig. 24 Sacral insufficiency fracture displaying the Honda sign

Pelvis:

- Stable pelvic fractures:
  - Pubic ramus fracture (Fig. 23):
    - Often very subtle and can present as hip pain.
  - Sacral insufficiency fracture (Fig. 24):
    - Elderly female patients presenting with lower back pain.
    - A type of stress fracture which are usually seen in patients with weakened bones such as osteoporosis (the most common association), rheumatoid arthritis and Paget's disease.
    - Distinctive appearance on bone scan with increased uptake of radiotracer.

- Unstable pelvic fractures:
  - These fractures types are dictated by the direction of the force which has caused the fracture.
  - The most common is the open book fracture which is caused by anteroposterior compression and results in widening of the pubic symphysis and a posterior pelvic fracture injury.
  - These injuries result from high energy trauma and are frequently associated with bladder and ureteral injuries.

Suggested Reading

- Sellon E, Howlett D. Radiology for medical finals: a case-based guide, 1st ed. CRC Press;2017.
- Soto JA, Lucey B. Emergency radiology: the requisites, 2nd ed. Elsevier;2016.
- Gyftopoulos S, Chitkara M, Bencardino JT. Misses and errors in upper extremity trauma radiographs. Am J Roentgenol. 2014;203:477–491. 10.2214/AJR.14.12589.
- Cooney W. The wrist: diagnosis and operative treatment, 2nd ed. Lippincott Williams & Wilkins;2010.
- Birchard KR, Busireddy KR, Semelka RC. Critical observations in radiology for medical students, 1st ed. Wiley Blackwell;2015.
- Sandstrom CK, Kennedy SA, Gross JA. Acute shoulder trauma: what the surgeon wants to know. Radiographies. 2015;35(2).
- Sheehan SE, Shyu JY, Weaver MJ, Sodickson AD, Khurana B. Proximal femoral fractures: what the orthopedic surgeon wants to know. Radiographics 2015; 35(5).
- Egol K, Koval KJ, Zuckerman JD. Handbook of fractures, 4th ed. Lippincott Williams & Wilkin;2010.

Tutorial 6: Imaging of Non-traumatic Musculoskeletal Conditions

Damien O'Neill and Mark Given

Aims and Guidance for Tutors

The musculoskeletal system consists of the bony skeleton and joints with its supporting muscles, tendons and ligaments. Disease processes can primarily affect the musculoskeletal system or the musculoskeletal system can be secondarily involved as part of multisystem diseases. This chapter aims to familiarise students with the role of imaging for patients in non-traumatic musculoskeletal conditions. It is important that students understand the basic concepts of imaging in the context of the clinical examination. After completion of this tutorial students should be able to describe the key imaging features of typical patterns of non-traumatic musculoskeletal conditions.

Introduction

- Non-traumatic musculoskeletal conditions can be either a primary bone/joint disorder or secondarily involved as part of a systemic disorder e.g. metastases, metabolic, inflammatory.
- Joint involvement in a disease process is termed an arthropathy. When the primary pathology is inflammation then the term "arthritis" is used.
- These diseases can result in significant morbidity. Osteoarthritis is the fourth most common cause of hospitalisation in US adults.

D. O'Neill (✉)
Beaumont Hospital, Dublin, Ireland
e-mail: damienconeill@rcsi.com

M. Given
Department of Radiology, Beaumont Hospital, Dublin, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_6

- When present as part of a systemic metabolic disorders laboratory tests provide valuable additional information as to the underlying cause.

Radiological Modalities Utilised

Radiography:

- Radiographs are the mainstay of imaging of non-traumatic musculoskeletal conditions, particularly arthropathies.
- The significant difference in densities between bone and soft tissues allows excellent imaging of bony structures.
- Radiographs are the usual initial investigation of choice because they are widely available and relatively inexpensive.
- They allow the surveillance and monitoring of disease status in chronic conditions.
- Radiographs are suboptimal for the specific imaging of soft tissue structures like ligaments and tendons and articular cartilage.

CT:

- CT is of limited use in the evaluation of non-traumatic musculoskeletal conditions.
- It confers little additional information over plain radiographs, however involves significantly more radiation exposure and cost.
- Dual-energy CT has an evolving role in the identification of monosodium urate crystal depositions to assist in patients with gout.

MRI:

- MRI can provide highly detailed imaging of the musculoskeletal system, particularly of tendons, ligaments, cartilage and bone marrow.
- Its use however clinically is often not required as frequently sufficient information is available from radiographs.
- MRI is less freely available and costs significantly more than plain radiographs.

Bone Scan:

- Nuclear medicine scintigraphic study which involves the administration of methylene diphosphonate labeled with technetium 99 m.
- This can provide functional information with increased uptake in regions of increase bone turnover. Particularly useful in evaluation for metastatic disease.
- Provides little anatomic information and finding should be correlated with a plain radiograph or CT.

Indications for Imaging

- The need for imaging is dictated by clinical assessment. Initially plain radiographs are performed of the region of interest.
- Many arthropathies are monoarticular therefore typically only imaging of that joint is required.
- When an arthropathy is polyarticular then typically only imaging of the symptomatic joints is required.

Review of Relevant Radiological Findings

- Loss of joint space, in most arthropathies.
- Erosions may be present in erosive arthropathies; their positions are characteristic or differing arthritides.
- Deformity is typical a feature of late stage and often untreated arthritides e.g. Rheumatoid arthritis.
- Osteophyte formation.
- Sclerosis: increased bone density.
- Bone resorption/destruction: osteomyelitis, metastases, metabolic e.g. hyperparathyroidism.

Arthropathies

Osteoarthritis (OA):

- This is a degenerative condition, often secondary to overuse or previous trauma.
- Typically this affects larger weight-bearing joints such as the hips and knees.
- Often mono or oligoarticular.
- Characteristic imaging features- **LOSS**: L- ***l***oss of joint space, O- periarticular ***o***steophyte formation, S- ***s***ubchondral sclerosis, S- ***s***ubchondral cystic change (Fig. 1).

Rheumatoid Arthritis (RA):

- This is a multisystem disorder that has typical musculoskeletal involvement and imaging features.
- Inflammatory process that results in periarticular erosions, decreased periarticular bone density with associated symmetrical loss of joint space.
- It has preponderance in the hands for the metacarpal-phalangeal (MCP) joints, proximal inter-phalangeal (PIP) and carpal joints with sparing of the distal inter-phalangeal (DIP) joints. There may be associated ulnar deviation at the MCP joints (Fig. 2).

Fig. 1 Frontal pelvic radiograph in a 60 year old male demonstrating bilateral joint space loss at both hip joints with subchondral sclerosis (arrow) and periarticular osteophytes (dashed arrow)

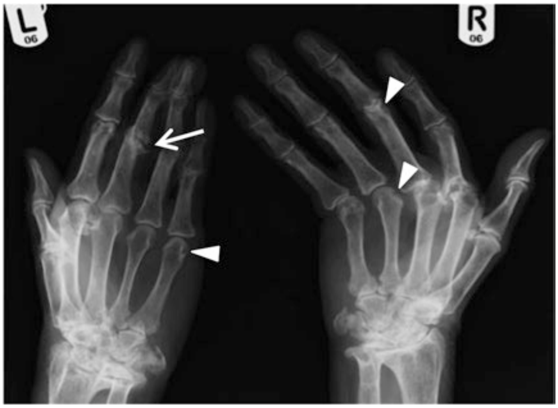


Fig. 2 Ball-catchers views of both hands that demonstrate an arthropathy predominatly affecting the carpal joints and MCP joints. Periarticular erosions are well demonstrated (arrow heads). The PIP joint of the left middle finger shows significant erosions with partial collapse of the phalangeal head (arrow). Note the presence of ulnar deviations of the digits of the right hand- this part of the "Z deformity" and can be appreciated on physical examination. Features are typical of rheumatoid arthritis

- In advanced stages boutonnière's or swan neck deformities may be seen (Fig. 3).

Gout:

- This condition results from deposition of monosodium urate crystals in joints or soft tissues.

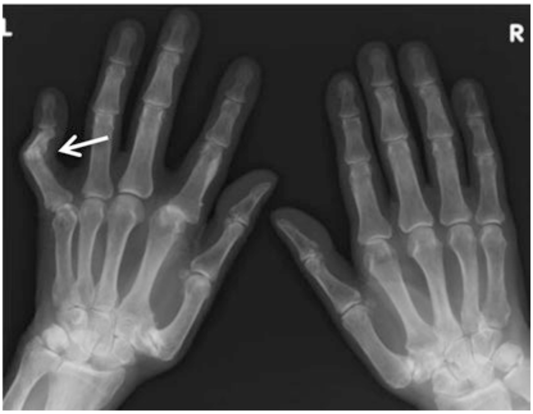


Fig. 3 PA views of another patient with rheumatoid arthritis. There is a boutonnière's deformity of the left little finger with flexion of the PIP joint and extension at the DIP joint

Fig. 4 A focused radiograph of the MTP joint of the left hallux. This shows an erosion on the metatarsal head (arrow) with increased density in the soft tissue medial to the joint (curved bracket); this is a tophus typical of gout

- Usually a monoarticular arthropathy with preponderance for the first metatarsal-phalangeal (MTP) joint.
- The characteristic imaging features are juxta-articular erosions with increased density in the overlying soft tissue (tophus) (Fig. 4).

Seronegative arthritides:

- These are usually HLA B27 positive; e.g. psoriatic (60%), Reiter's (85%), ankylosing spondylitis (90%).
- Psoriatic and Reiter's typically affect the peripheries (periostitis, enthesitis) (Fig. 5).

Fig. 5 Oblique radiograph of a left foot demonstrating an abnormality of the left fifth metatarsal head. There are erosions on the metatarsal head with a "pencil-in-cup" appearance of the fifth MTP joint

- Ankylosing spondylitis (sacroilitis, vertebral body squaring and syndesmophyte formation) typically affects the axial skeleton (Fig. 6).

Neuropathic joints/Charcot joints:

- Occur where there is decreased sensation and proprioception, most commonly in the lower limb.
- This results in a chronic degenerative and destructive arthropathy characterized by joint destruction with periarticular bone fragmentation.
- Most commonly seen in diabetics or in patients with chronic neurological dysfunction (Fig. 7).

Other Bone Disorders

Neoplasia:

- Metastatic tumor to bone is far more common (>70%) than primary bone malignancy.
- Metastases can be lytic (lung, renal), sclerotic (prostate) or a mixture of both (breast).
- The most common sites are the vertebrae, pelvis and proximal femora and humeri.

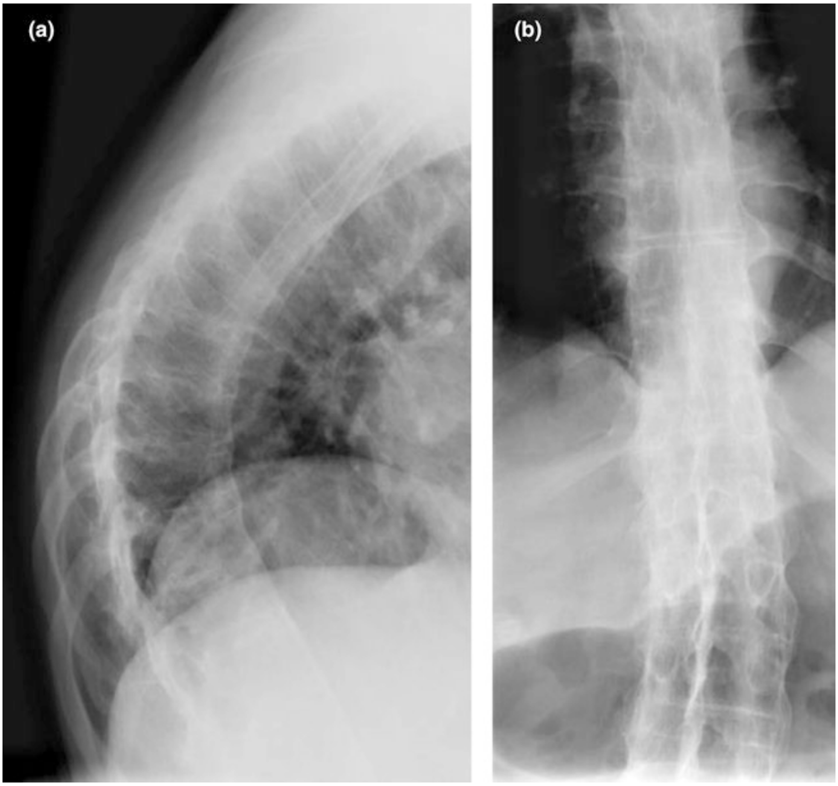


Fig. 6 Lateral (**a**) and AP (**b**) radiographs of the thoracic spine in a patient with ankylosing spondylitis. These demonstrate kyphosis with flowing syndesmophyte formation along the margins of the end plates and vertebral body squaring. This is a classic appearance of ankylosing spondylitis. It is said to resemble the stalk of a bamboo and is termed a "bamboo spine"

- Bone scans are useful for identifying metastases, most demonstrate increased uptake on bone scan, some metastases do not demonstrate uptake on bone scan (Fig. 9).
- Multiple myeloma is the most common primary bone malignancy, typically >50 years. The most common appearance is of multiple "punched out" lytic lesions of the axial skeleton (Fig. 8).

Osteomyelitis/Septic arthritis:

- Refers to infection of bone usually bacterial. Typically results from haematogenous spread, however can result from direct spread in ulcers/trauma.
- Radiograph findings are usually subtle; loss of fat planes, periosteal reaction, cortical loss. MRI is far more sensitive demonstrating bone marrow oedema and cortical destruction.

Fig. 7 Oblique foot radiograph shows an arthropathy of multiple mid-foot joints. There is a disorganized appearance with increased density of the tarsal bones and overlying calcified debris. Also present on the radiograph is linear calcifications in small arteries (e.g. between the first and second metatarsals- arrow), typical of vascular disease of diabetes mellitus with a Charcot arthropathy secondary to the associated neuropathy

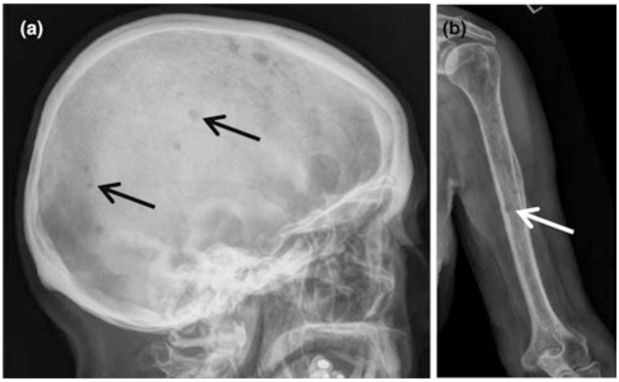


Fig. 8 Lateral skull (**a**) and AP humerus (**b**) radiographs demonstrating multiple well defined lucent lesions throughout the bones (arrows). These are typical of multiple myeloma. When the skull is severely affected by myelomatous deposits, the term "rain drop" skull has been used

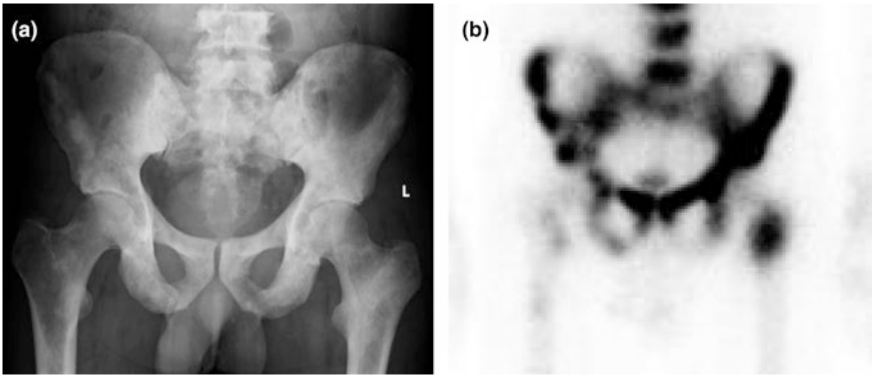


Fig. 9 A gentleman with lower back pain and elevated PSA underwent investigation. An AP pelvic radiograph of the pelvis (**a**) demonstrated increased sclerosis throughout the pelvic bones, left femur and lower lumbar spine. A nuclear medicine bone scan (**b**) confirms increased tracer uptake in the same regions. These appearances are typical of metastatic prostate cancer

- Septic arthritis refers to infection of a joint; the diagnosis is usually made by a combination of clinical findings and joint aspiration. Imaging usually has little role in diagnosis. It constitutes a medical emergency as joint destruction occurs quickly and function may be permanently compromised

Osteoporosis:

- This is reduced bone mineral density defined by the WHO as a T-score of less than −2.5 SD.
- Usually asymptomatic but can present with fragility fractures.
- Radiographic features are not sensitive, decreased cortical thickness and reduced trabecular markings.
- Diagnosis is made by bone mineral density typically with dual energy x-ray absorptiometry (DEXA).

Radiologist's tips: Hand radiographs

- When involvement of the hands is suspected in arthritis then typically posteroanterior and "ball-catchers" views are performed.
- Distribution:
  - RA: MCP, PIP, carpal joints
  - OA 1st MCPJ, DIPJ, particularly DIPJ of index finger
- Erosions:
  - Periarticular: RA
  - Juxtaarticular: Gout
- Deformity: ulnar deviation at MCPJs in RA

Suggested Reading

- Smolen JS, Aletaha D, Barton A, Burmester GR, Emery P, Firestein GS, et al. Rheumatoid arthritis. Nat Rev Dis Prim. 2018; 4:18001. Macmillan Publishers Limited.
- Sommer OJ, Kladosek A, Weiler V, et al. Rheumatoid arthritis: a practical guide to state-of-the-art imaging, image interpretation, and clinical implications. Radiographics. 25 (2): 381–98. https://doi.org/10.1148/rg.25204511.
- Jacobson JA, Girish G, Jiang Y, et al. Radiographic evaluation of arthritis: inflammatory conditions. Radiology. 2008;248 (2):378–89. https://doi.org/10.1148/radiol.2482062110.
- Jacobson JA, Girish G, Jiang Y et al. Radiographic evaluation of arthritis: degenerative joint disease and variations. Radiology. 2008;248 (3):737–47. https://doi.org/10.1148/radiol.2483062112.
- Brant WE, Helms CA. Fundamentals of diagnostic radiology. Lippincott Williams & Wilkins;2007. ISBN:0781765188.
- Greenspan A, Jundt G, Remagen W. Differential diagnosis in orthopaedic oncology. Philadelphia: Lippincott Williams & Wilkins;2007(2006) ISBN:0781779308.
- Dalbeth N, Nicolaou S, Baumgartner S, Hu J, Fung M, Choi HK. Presence of monosodium urate crystal deposition by dual-energy CT in patients with gout treated with allopurinol. Ann Rheum Dis. 2018;77 (3):364–370.
- Solis F, Gonzalez C. Raindrop skull. N Engl J Med. 2018;378 (20):1930.

Tutorial 7: Non-traumatic Neurological Emergencies

Darragh Herlihy and Seamus Looby

Aims and Guidance for Tutors

In the emergency setting, accurate clinical assessment in combination with appropriate imaging is essential for the identification of patients with non-traumatic neurological emergencies. The aim of this chapter is to inform students of the role of imaging for patients presenting with complex neurological emergencies including stroke, seizure, cauda equina syndrome and potentially fatal causes of headache and acute confusion. At the end of the tutorial students should be able to identify the appropriate modality for the investigation of each condition and identify the key radiological features for each emergency. We will start by providing an explanation of cerebral oedema and hydrocephalus, these findings are commonly observed in some of the above neurological conditions.

Cerebral Oedema

- Cerebral oedema is broadly categorized into two main types- vasogenic and cytotoxic oedema.
- Vasogenic oedema (Fig. 1) results from disruption of the blood brain barrier. Intravascular fluid and proteins enter into the extracellular space. Vasogenic oedema affects the white matter.
  - The most common causes are intracranial neoplasms and haemorrhage.

D. Herlihy (✉)
Department of Radiology, Beaumont Hospital, Dublin, Ireland
e-mail: DarraghHerlihy@hotmail.com

S. Looby
Department of Radiology, Beaumont Hospital, Dublin, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_7

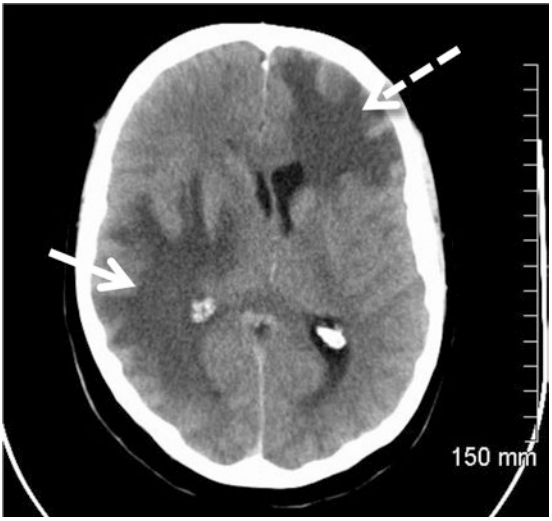


Fig. 1 Low attenuation in the left frontal (dashed arrow) and right parietal (solid arrow) lobes. This is confined to the white matter, this is vasogenic oedema. The oedema is caused by a tumour which is not demonstrated in this image

Fig. 2 Large left middle cerebral artery territory stroke. There is low attenuation in the left frontal and parietal lobes (arrow). This involves both the grey and white matter, this is cyotoxic oedema

- Cytotoxic oedema (Fig. 2) is the result of cells being unable to maintain adenosine triphosphate (ATP)—dependent transmembrane sodium-potassium and calcium pumps. Extracellular fluid then enters these cells and leads to swelling. Grey and white matter become involved leading to loss of differentiation between the two on imaging.

  – The most common cause is acute cerebral infarction.

- Both vasogenic and cytotoxic oedema manifest as areas of low attenuation on non-contrast CT.
- On MRI, Oedema will produce high signal on T2 weighted images and fluid attenuation inversion recovery sequences (FLAIR).

Hydrocephalus

- Hydrocephalus is an abnormal increase in the volume of CSF in the cranial cavity accompanied by expansion of the ventricles. Hydrocephalus may be the result of an issue with the production, flow or absorption of CSF.
- Hydrocephalus is broadly categorized into communicating and non-communicating. It can be acute or chronic.
- Non-communicating hydrocephalus (Fig. 3) may be obstructive as a result of a lesion within the ventricular system or due to a failure of reabsorption of CSF as occurs post intraventricular haemorrhage or SAH.
- Acute obstructive hydrocephalus can progress rapidly and can lead to herniation and death.
- Communicating hydrocephalus (Fig. 4) may occur as a result of CSF overproduction, e.g. as a result of a choroid plexus tumour, or in normal pressure hydrocephalus.

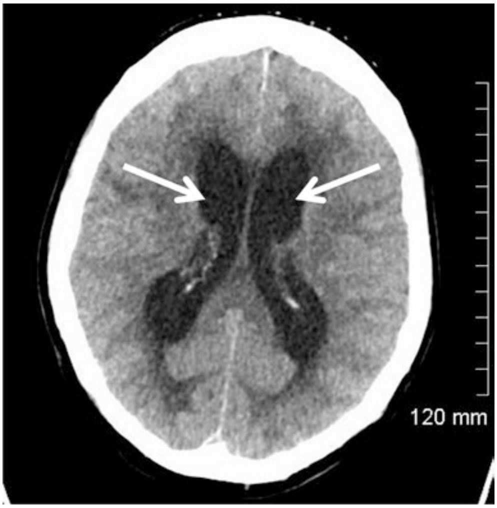


Fig. 3 Non-communicating hydrocephalus due to an obstructing lesion (not visualised). There is dilatation of both lateral ventricles (arrows). Note the presence of low attenuation around the lateral ventricles. This is transependymal oedema and is seen with acute decompensated hydrocephalus

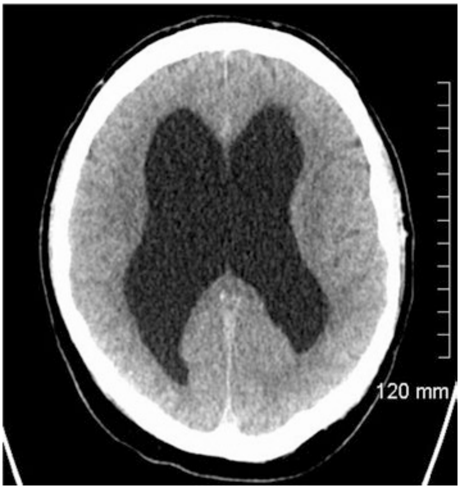


Fig. 4 Communicating hydrocephalus with dilatation of the lateral ventricles in a suspected case of normal pressure hydrocephalus. There is no transependymal oedema suggesting that this is a chronic process

Emergency Presentation with Headache

Subarachnoid Haemorrhage (SAH)

- Haemorrhage in the subarachnoid space can be traumatic or non-traumatic in origin (trauma being more common). *For further reading on traumatic subarachnoid haemorrhage, see head trauma chapter.*
- The main non-traumatic causes are ruptured aneurysms (older patients) and vascular malformations (younger patients). Less frequent causes include drug use such as cocaine, cerebral vasculitis and cerebral amyloid angiopathy.
- Patient presentation varies from headache to severe disability and low levels of consciousness.
  - Sudden onset 'thunderclap headache' is the classically described presentation.
- Non-contrast CT is the initial investigation of choice. It has a high sensitivity for acute SAH, nearly 100% in the first 24 hours.
- Acute SAH is hyperattenuating (white) on CT (Fig. 5).
- A negative CT brain does not exclude SAH. All patients with a negative CT brain but high clinical suspicion for SAH should undergo lumbar puncture to look for xanthochromia.

Angiography:

- Patients with a positive CT brain or xanthochromia positive CSF should undergo angiography of the intracranial vessels to look for aneurysms.
- Angiography is also performed in the elective setting as screening for patients with risk factors for saccular aneurysms.

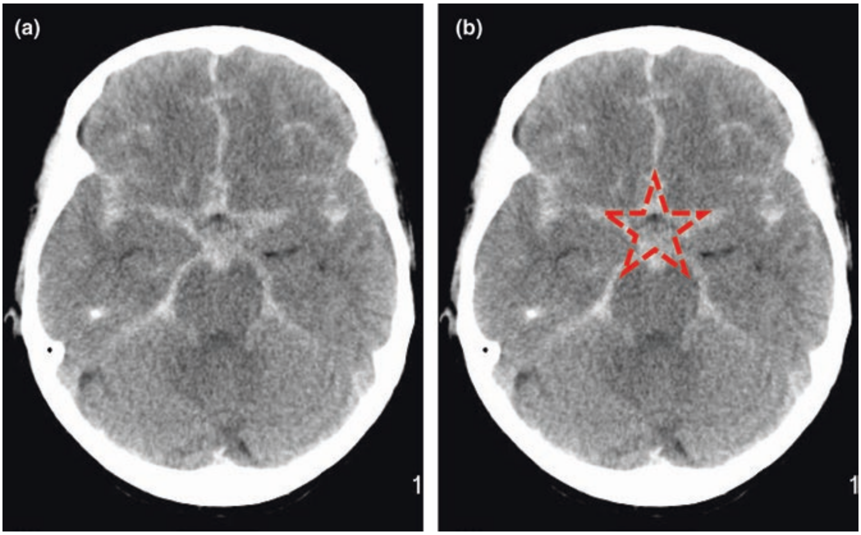


Fig. 5 **a** Non-contrast CT brain performed for a 52 year old female who presented with "the worst headache of her life". This demonstrates extensive subarachnoid haemorrhage corresponding to the five-pointed star shaped high attenuation around the circle of Willis (**b**)

- Angiography is usually performed non-invasively using CT or MRI.
- CT angiogram involves the patient being administered intravenous contrast with imaging acquired while the contrast is ejected from the left ventricle into the intracranial arteries. CT angiogram can be rapidly performed and produces high resolution imaging of the intracranial vasculature. 3D reconstructions can be created to help plan management.
- Magnetic resonance angiography (MRA) is not a first line investigation for the imaging of intracranial vessels as it is limited by motion artifact and is more time consuming. MRA is more useful for patient follow up. MRA has two advantages over CT, it does not result in the patient receiving a radiation dose and does not require administration of intravenous contrast.
- Catheter angiography is utilized in the setting of acute SAH when an aneurysm is not identified on CT angiogram. Catheter angiogram also facilitates endovascular treatment of aneurysms (placement of coils within the aneurysm to induce thrombosis and occlusion of the aneurysm).

Cerebral aneurysms:

- Aneurysms may be saccular (berry), fusiform, mycotic or giant.
- Saccular aneurysms are the most common.
  - Conditions associated with saccular aneurysms include Marfan syndrome, Ehlers-Dahlos and autosomal dominant adult polycystic kidney disease (ADPKD).

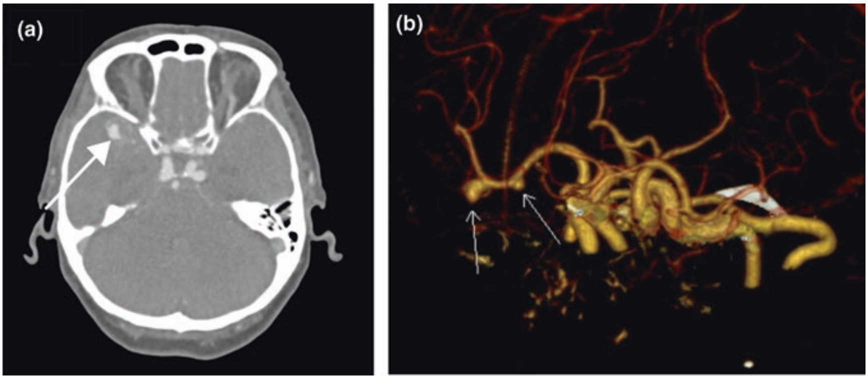


Fig. 6 A symptomatic patient found to have two saccular aneurysms arising from the right middle cerebral artery. **a** Axial CT angiogram image showing one of the aneurysms (arrow). **b** A 3D reconstruction, both aneurysms are labeled with arrows

- Aneurysms occur at branching and end points of vessels as vessel wall stress is higher at these points and blood flow is turbulent.
  - The three most common sites for saccular aneurysms are the anterior communicating artery, posterior communicating artery and the middle cerebral artery (Fig. 6).

Infection

- Central nervous system infection can be classified by the organism involved, i.e. bacteria, virus, fungus and prion, or by location affected, e.g. brain parenchyma, cerebellum, ventricular system, meninges, brain stem or spinal cord.
- Radiological features are dependent on the area involved and the causative organism. For the purpose of simplifying the topic we will focus on meningitis, herpes simplex encephalitis and intracerebral abscess.

Meningitis:

- Inflammation of the meninges is commonly caused by viruses and bacteria. Bacterial meningitis has a high mortality rate (up to 30%).
- Meningitis is a clinical and laboratory diagnosis. Lumber puncture and radiological imaging should not delay the commencement of treatment.
- Bacterial meningitis may present with a classical triad of fever, neck stiffness and altered mental status.
- Non-contrast CT brain is usually normal.
- MRI with intravenous gadolinium contrast is the more sensitive study, The main abnormality is leptomeningeal enhancement (Fig. 7).

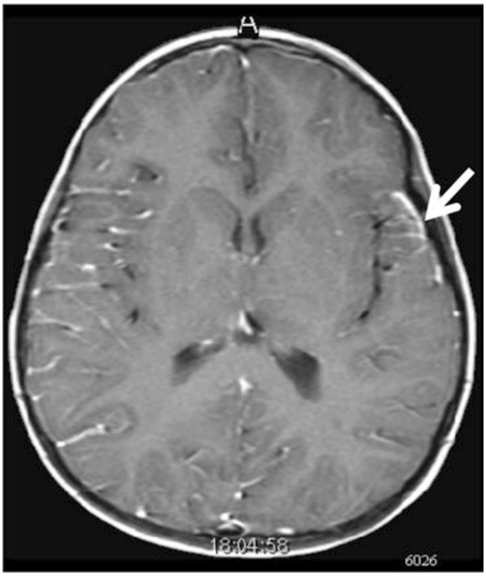


Fig. 7 MRI brain for a young adult with fever, headache and confusion and was diagnosed with bacterial meningitis. An image from the T1 weighted sequence post intravenous contrast demonstrates leptomeningeal enhancement overlying the left frontal lobe

Herpes Simplex Encephalitis (HSV):

- Herpes Simplex virus is the most common cause of fatal viral encephalitis. The majority of HSV encephalitis are caused by HSV 1 (>90%). Autoimmune processes may also cause encephalitis.
- Non-specific clinical features with a classical clinical triad of altered sensorium, fever and headache. Seizures are also common.
- CT is initially insensitive in the first week of symptoms.
- MR is more sensitive earlier in the disease. T2 and FLAIR hyperintensity in the affected regions may be observed (Fig. 8). As the disease progresses haemorrhagic areas may develop which will be hyperintense (bright) on T1. Abnormal enhancement occurs later as the disease progresses.

Intracranial abscess:

- Infections of the brain parenchyma are usually due to haematogenous spread. Infection starts as cerebritis and progresses to abscess formation.
- Capsule formation is the characteristic feature of an abscess.
- The purulent material in the abscess cavity is low in attenuation/signal hypointense and usually demonstrates central diffusion restriction on diffusion weighted imaging (Fig. 9).
- The capsule of the abscess avidly enhances on CT and MRI, this is referred to as “ring enhancement”.

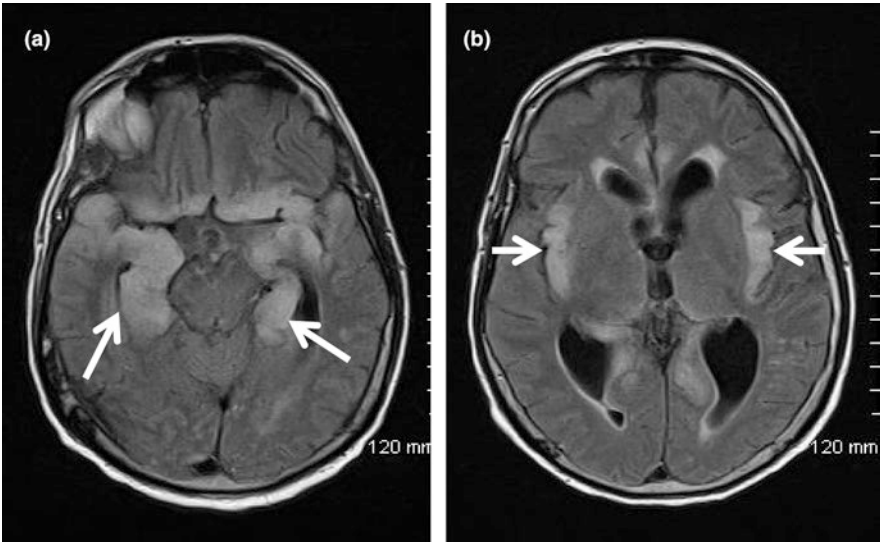


Fig. 8 Two images of the T2 FLAIR sequence from an MRI brain performed for a patient with encephalitis. **a** Hyperintense signal in both temporal lobes and hippocampi (arrows). **b** Hyperintense signal in both insular cortices. The pattern of involvement of signal abnormality in this case is typical for HSV encephalitis

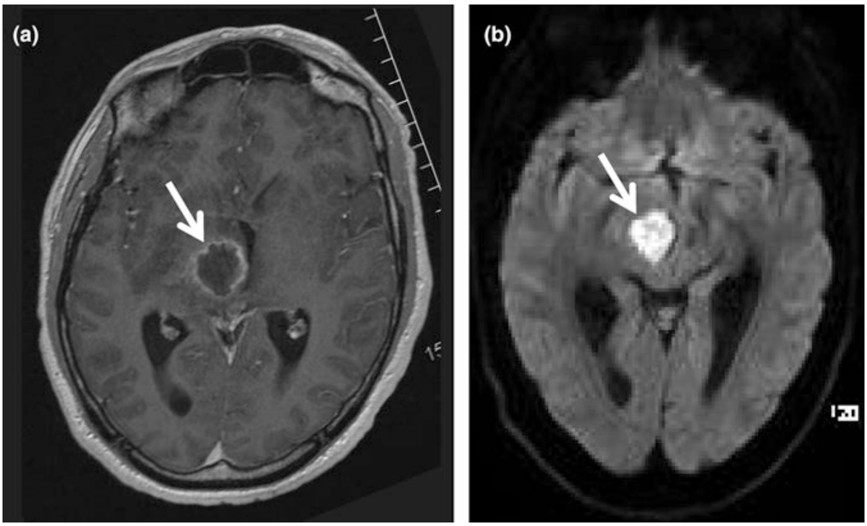


Fig. 9 MRI scan performed for an intravenous drug user who presented with headache and sepsis. **a** This is an image of a T1w post iv contrast (gadolinium) sequence. There is a rim enhancing lesion in the right thalamus (arrow). **b** This is a diffusion weighted sequence from the same study. The lesion demonstrates central high signal indicative of diffusion restriction. These appearances are consistent with a intracranial abscess

Radiologist's tips

- A ring enhancing lesion within the brain has an important differential diagnosis:
  - Malignancy (primary, secondary and lymphoma)
  - Abscess
  - Toxoplasmosis
  - Demyelination
  - Radiation necrosis

Stroke

- Stroke is a clinical term defined as a sudden loss of neurological function due to a loss of blood supply to the brain.
- Stroke is divided into haemorrhagic and ischaemic categories.
  - Approximately 80% of stroke is due to ischaemia while haemorrhage is responsible for 20%.
- Causes of haemorrhagic stroke include hypertension, cerebral amyloid angiopathy, bleeding diathesis, thrombolytic and anticoagulant medication use, illicit drug use (cocaine and amphetamines), vascular malformations and reversible cerebral vasoconstriction syndrome (RCVS).
- Acute ischaemic stroke can be further categorized into thrombotic stroke, embolic stroke and stroke as a result of systemic hypoperfusion.
- In younger patient's arterial dissection should be considered as a cause of acute ischemic stroke.
- The National Institute of Health Stroke Scale (NIHSS) is a scoring category for clinical assessment of acute stroke. This scoring system provides a useful guide for predicting the severity of stroke and helps determine the course of treatment. A higher score on the stroke scale indicates a more severe neurological deficit.
- Neuroimaging plays a key role in the determining the diagnosis and cause of acute stroke.
- Patients require urgent transfer to a stroke centre. The management of acute ischaemic stroke is time dependent and initial management may consist of medications to dissolve clot (thrombolysis) or interventional procedures to reopen intracranial vessels (thrombectomy).

Clinical Features

- A stroke manifests as an acute and focal cerebral loss of function.
- The two vascular territories in the brain are:

  - Anterior circulation: Blood supplied by both internal carotid arteries to the anterior and middle cerebral arteries. This territory involves the frontal, parietal and temporal lobes.
  - Posterior circulation: Blood supplied by the vertebral arteries to the basilar and posterior cerebral arteries. This territory involves the occipital lobe, cerebellum and brainstem.

- Anterior circulation strokes can manifest as:
  - Hemiparesis, sensory loss, dysarthria and aphasia.
  - Note that motor fibres extending from the cerebral cortex in the pyramidal tracts decussate (cross over) at the level of the brainstem. Therefore stroke involving the motor cortex in the right frontal lobe will result in left sided hemiparesis.
  - The speech areas in the brain are located in the dominant cerebral hemisphere, for the majority of patients this is the left cerebral hemisphere.
- Posterior circulation strokes can manifest as:
  - Hemianopia, ataxia, vertigo, nystagmus and 'locked in' syndrome.

Radiological Modalities Utilised for Acute Stroke Imaging

Non-contrast CT:

- This is the initial investigation of choice in all acute stroke patients.
- CT is a rapid test and widely available.
- The test should be performed as quickly as possible as the exclusion of haemorrhage allows for the rapid administration of thrombolytic agents.
- In some cases where there is acute arterial occlusion, a hyperdense vessel sign or a dot sign may be seen (Fig. 10).
- Early ischaemic changes in the brain parenchyma can be subtle on CT (Fig. 11). In the first six hours after stroke onset, patients can have a normal appearing CT brain.
- The Alberta Stroke Program Early CT Score (ASPECTS) is a radiological scoring system used to determine the severity of acute ischemic stroke. 10 separate areas of the brain are assessed and a point is deducted for each area of infarction (a score of 10 thus indicates no ischaemic changes but does not exclude ischaemic stroke).

CT angiogram:

- Once haemorrhage has been excluded the patient should proceed to CT angiography of the head and neck.
- This involves the injection of contrast media via a peripheral cannula for visualisation of the arteries of the head and neck.

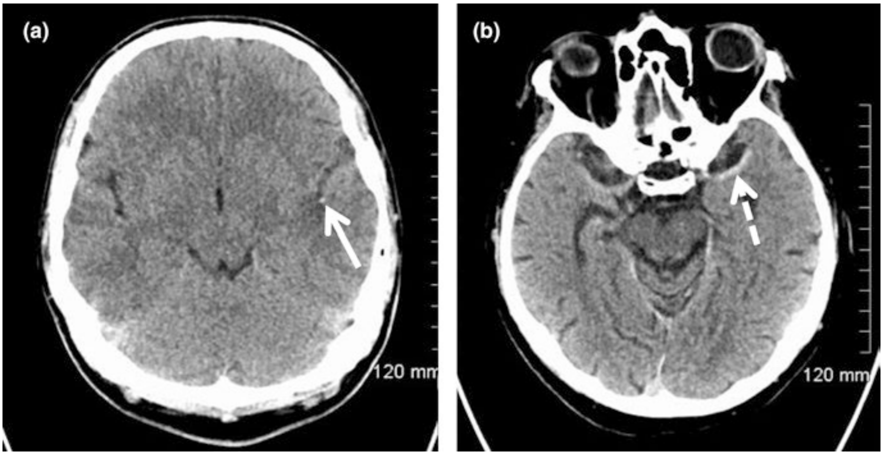


Fig. 10 Non-contrast CT images in two different patients presenting with acute stroke. **a** Dot sign representing thrombus in a branch of the left MCA in the Sylvian fissure (solid arrow). **b** Hyperdense left MCA representing thrombus (dashed arrow). This was confirmed by performing a CT angiogram

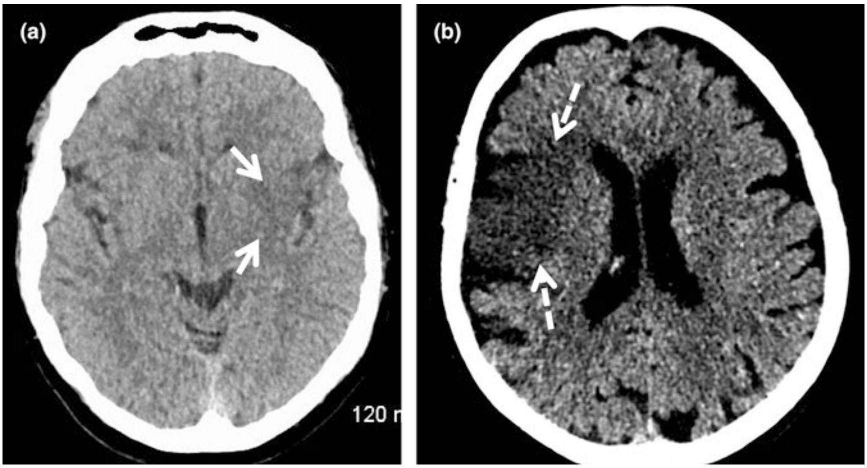


Fig. 11 Non-contrast CT images for two different patients presenting with acute stroke. Image **a** There is a very subtle area of low attenuation in the left middle cerebral artery territory when compared to the contralateral side. This indicates early acute infarction. Image **b** demonstrates a more established area of acute infarction in the right middle cerebral territory. Note the age related atrophy present in the cerebral hemispheres in image (**b**) when compared to image (**a**) this patient was considerably older than the patient in image (**a**)

- The aim of this imaging study is to identify an acute arterial occlusion (Fig. 12) that may be amenable to treatment by thrombectomy.
- In some centres a second and third scan of the head will be performed immediately after the first scan to look for collateral vessels which fill slightly after the primary supplying artery. These collateral vessels may provide oxygen to the brain even when the primary vessel is occluded thus allowing the ischaemic area to survive.
- Knowledge of the volume of collateral vessels is useful in determining whether to proceed to invasive therapy i.e. thrombectomy (Fig. 14).

MRI brain:

- MRI is an excellent test for the investigation of acute ischaemic stroke.
- MRI is not usually the first test performed as it is time consuming and not as widely available as CT.
- Diffusion weighted imaging (DWI) is the key sequence in acute stroke imaging. Acute ischaemia results in abnormal movement (diffusion) of water molecules in the brain parenchyma. This area of abnormal or restricted diffusion looks bright or hyperintense in signal on MRI. The area of diffusion restriction corresponds to the area of acute ischemia (Fig. 13).
- DWI can sensitively identify acute ischaemia within minutes after onset. This enables Radiologists to detect acute infarction, evaluate the size of a region of infarction and help with prognostication.
- MRI can also be helpful to differentiate acute stroke from stroke mimics.
  - Mimics of acute stroke include seizure, malignancy, migraine, infection.

Fig. 12 CT angiogram performed for a patient presenting with acute right-sided hemiparesis which demonstrates an abrupt cut of the left middle cerebral artery consistent with acute occlusion by thrombus. This patient subsequently underwent catheter thrombectomy

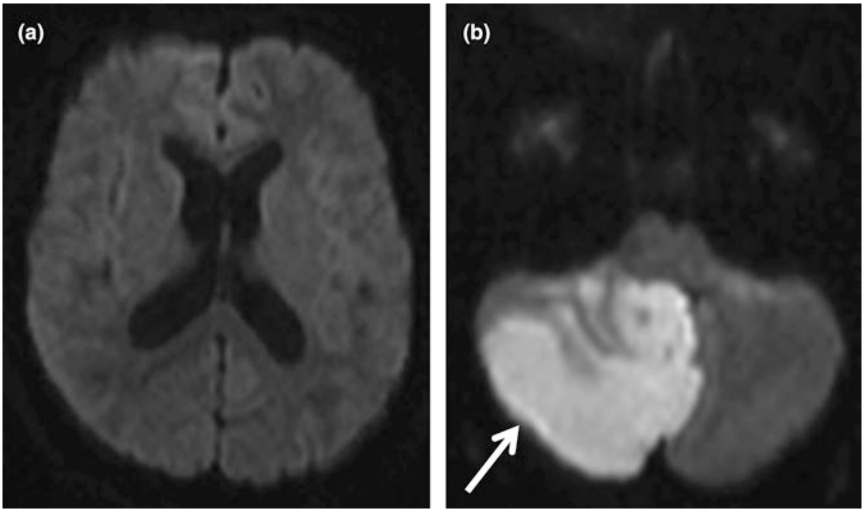


Fig. 13 Two selected images from the DWI sequence of an MRI performed for a patient with acute onset vertigo, vomiting and loss of balance. Image **a** shows no evidence of diffusion restriction in the middle cerebral artery territories. In image **b** there is a large area of diffusion restriction in the right cerebellar lobe (high signal/bright area) consistent with an acute right-sided posterior circulation infarction

Catheter angiography:

- This is predominantly utilised for the treatment of large vessel ischaemic stroke. The interventionalist punctures an artery remote from the occlusion (usually the femoral artery) and using wires and catheters enters the large vessels of the neck and head. Contrast media can be injected directly and live images (fluoroscopy) can be performed. This also allows for the mechanical removal of clot (thrombectomy) (Fig. 14).

Radiologist's tips: Acute stroke imaging

- All suspected stroke patients should undergo urgent non-contrast imaging of the brain. The goal of this imaging is to identify haemorrhage which is a contraindication to thrombolysis.
- Once haemorrhage has been excluded all patients suspected of acute ischemic stroke should proceed immediately to CT angiogram of the head and neck. If the patient has a large vessel thrombus they are suitable for catheter thrombectomy., if not, they may receive systemic thrombolysis

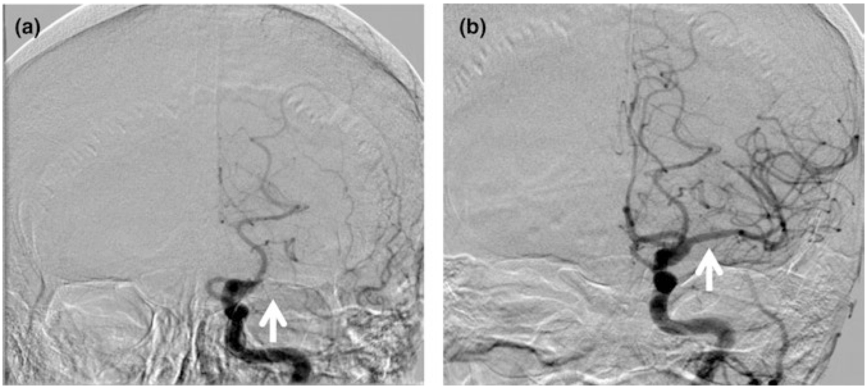


Fig. 14 Pre and post thrombectomy images. Image **a** demonstrates the left middle cerebral artery occlusion (arrow). Image **b** demonstrates recanalisation of the left middle cerebral artery post thrombectomy

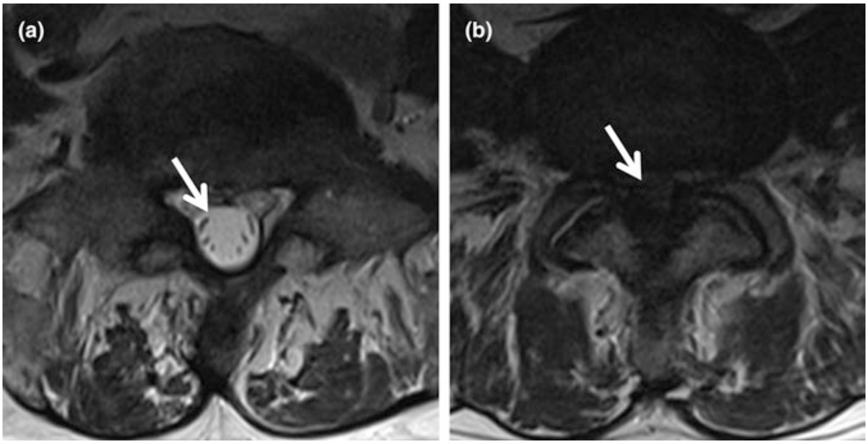


Fig. 15 MRI (T2) axial images at the level of the lower lumbar spine. **a** The normal spinal canal with the thecal sac containing the cauda equina (arrow). **b** In this patient with cauda equina syndrome there is disc herniation narrowing of the spinal canal and compression of the cauda equina nerve roots

Emergency Presentation with Back Pain

Cauda equina syndrome (CES):

- The conus medullaris is the term for the prominent most distal portion of the spinal cord. The conus medullaris gives off a bundle of lumbosacral nerve roots (cauda equina) which innervate the pelvis and lower limbs.

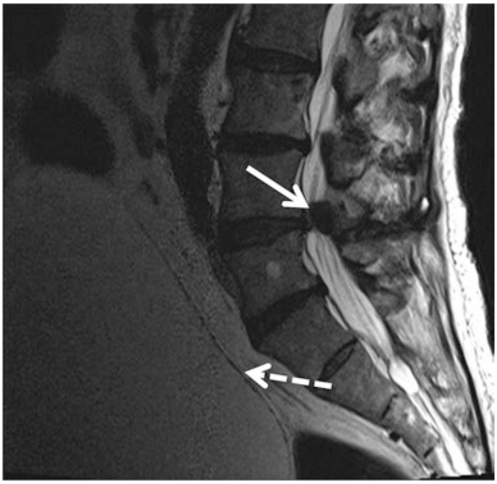


Fig. 16 Sagittal T2 MRI of the lower lumbar spine. This patient presented with severe acute back pain, reduced anal tone and urinary retention. At the level of L5/S1, there is disc herniation compressing the cauda equina (solid arrow). Also note the severe distension of the bladder consistent with retention (dashed arrow). The fluid in the bladder is bright (high signal) as this is a T2 sequence

- CES is a collection of urogenital and neuromuscular symptoms resulting from the compression of the cauda equina (Figs. 15 and 16).
- CES may clinically present as impairment of bladder, bowel, sexual function with saddle and perianal anaesthesia. Low back pain and sensory deficit may also occur.
- CES can be complete (saddle anaesthesia with retention or incontinence of bowel and bladder) or incomplete (saddle anaesthesia without retention/incontinence).
- L4/L5 and L5/S1 disc herniation is the most common cause of compression.
- Herniation is usually the result of degenerative disc disease. Other causes include fractures, epidural haematoma and metastases.
- CES is a neurosurgical emergency.
- Treatment depends on the aetiology. The treatment of CES due to lumbar disc herniation is surgical decompression. This is usually performed within 24 hours.
- Evidence suggests outcomes are better in patients with incomplete CES.

Imaging appearances:

- MRI is the test of choice. Sagittal imaging is performed of the lumbosacral spine with axial T2 imaging through the level of compression. Contrast can be administered if infection is suspected.
- CT myelogram can be used in patients who have a contraindication to MRI. This is performed by injecting contrast into the thecal sac under fluoroscopic guidance and performing a subsequent CT scan of the lumbar spine.
- Plain x ray has no role in the detection of cauda equina syndrome.

Suggested Reading

- Ho M-L, Rojas R, Eisenberg RL. Cerebral edema. Am J Roentgenol. 2012;199(3):W258–W273.
- Gibbs WN, Tanenbaum LN. Imaging of hydrocephalus. Appl Radiol. 2018;47(5):5–13.
- Srinivasan A, Goyal M, Azri FA, Lum C. State-of-the-art imaging of acute stroke. Radiographics. 2006;26(suppl_1):S75–S95.
- Crocker CE, et al. Role of neuroimaging in first seizure diagnosis. Seizure-Eur J Epilepsy. 49:74–8.
- McNamee J, Flynn P, O'Leary S, Love M, Kelly B. Imaging in cauda equina syndrome--a pictorial review. Ulster Med J. 2013;82(2):100–8.
- Cohen-Gadol AA, Bohnstedt BN. Recognition and evaluation of nontraumatic subarachnoid hemorrhage and ruptured cerebral aneurysm. Indiana University School of Medicine, Indianapolis, Indiana. Am Fam Physician. 2013;88(7):451–56.
- Hacein-Bey L, Provenzale JM. Current imaging assessment and treatment of intracranial aneurysms. Am J Roentgenol. 2011;196:32–44. 10.2214/AJR.10.5329.
- Mitchell BC, Dehkharghani S. Imaging of intracranial infectious diseases in adults. Appl Radiol.
- Shih RY, Koeller KK. Bacterial, fungal, and parasitic infections of the central nervous system: radiologic-pathologic correlation and historical perspectives: from the radiologic pathology archives. Radiographics. 2015;35(4):1141–69.
- Koeller KK, Shih RY. Viral and prion infections of the central nervous system: radiologic-pathologic correlation: from the radiologic pathology archives. Radiographics. 2017;37(1):199–233.

Tutorial 8: The Chest Radiograph

Douglas Mulholland and Jane Cunningham

Aims and Guidance for Tutors

The chest radiograph is the most commonly performed radiological investigation. While its ubiquity may lead some to believe that it is easy to interpret, there is a wealth of information that can be garnered from this simple test. This chapter aims to familiarise students with basic chest radiograph anatomy and techniques. It also aims to help students understand the appropriate indications for this test. There are a number of emergent diagnoses which students must be able to recongise on a chest radiograph and then know how to act accordingly, e.g. tension pneumothorax. After completion of this tutorial, students should be able to accurately diagnose common and important clinical conditions on the chest radiograph.

Introduction

- The chest radiograph is the most common imaging test ordered within a hospital.
- Although it is easy to focus on the lungs, there are many other structures visible on the radiograph, including the mediastinum, bones and upper abdomen.
- Each of these has a different radiological density on the image; the lungs are normally dark or 'lucent' as they are composed of air containing alveoli, the mediastinum, vessels within the lung and upper abdomen appear whiter,

D. Mulholland (✉)
Beaumont Hospital, Beaumont Road, Dublin, Ireland
e-mail: doug2057@gmail.com

J. Cunningham
Beacon Hospital, Dublin, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_8

'denser' or 'more opaque' due to their soft-tissue composition, while the bones are the most dense (whitest) structures visible due to their calcification and mineralization.

- A vast range of pathologies can be seen on the chest radiograph as alterations in these normal anatomic densities. Pulmonary infections, malignancies and oedema result in increased densities or opacities in the usually dark lungs. Alternatively abnormal free air in the abdomen (pneumoperitoneum) leads to the usually white upper abdomen appearing darker or more lucent due the accumulation of air density.
- There are also a plethora of instruments and devices that may be visible on the chest radiograph in various patient populations. It is important to be familiar with the more common devices and to be able to discern if their positioning is adequate.
- Posteroanterior (PA), anteroposterior (AP) and lateral chest radiographs all convey different information and it is important to be aware of the strength and limitations of each technique.

Chest Radiograph Anatomy and Technical Principles

PA chest radiograph:

- The term 'PA' or posteroanterior refers to the direction the x-ray beam passes through the patient before it reaches the detector. In this case the patient stands with the front of their chest in contact with the detector and the source of the x-ray beam is positioned at a distance behind the patient.
- This position is the most desirable and is the default position. It may not be possible in certain instances, for example, if a patient is bedbound or immobile. If this is the case, an AP study is performed.

AP chest radiograph:

- This is the technique used for portable chest radiographs, frequently performed in critically ill patients in the intensive care unit. In this case, the patient remains in bed and the detector is placed behind the patient's back, while the x-ray machine is positioned in front of the patient.
- This technique has certain limitations and potential pitfalls for interpretation; for example, a normal sized heart may appear falsely enlarged due to magnification by the image technique (Fig. 1). Also the patient's scapulae are not retracted on an AP film, as they are on a PA film, which can partially obscure the lungs or creasing of the bed-bound patient's skin folds can occasionally be confused for a pneumothorax.

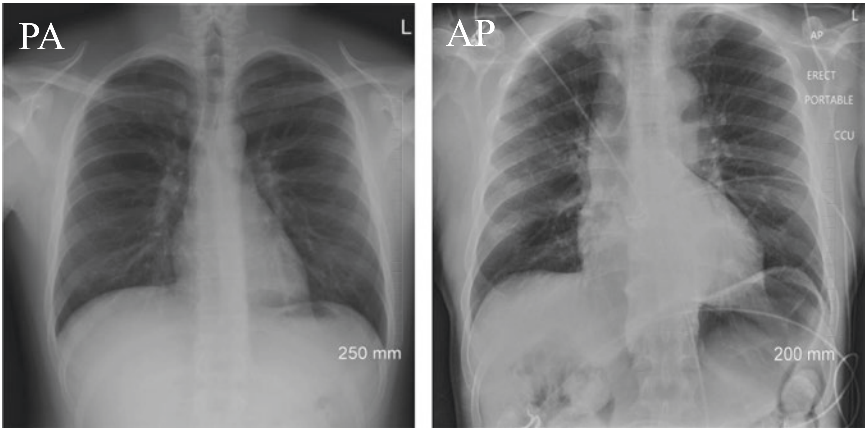


Fig. 1 PA and AP chest radiograph side by side for comparison. Note how the cardiac and mediastinal silhouettes are magnified on the AP view (right), and the scapulae are less retracted

Lateral chest radiograph:

- Although this technique has become less relevant with the advent of CT, it may still be a useful test in certain instances, for example, confirming the position of pacemaker leads or further evaluating abnormalities suspected on PA studies.

Erect chest radiograph:

- Chest radiographs are preferably performed in this position, with the patient upright, when clinically feasible. This is useful for detecting pneumoperitoneum in a patient with a suspected perforated abdominal viscus, which will be seen as free air under the diaphragm. Note the patient should be in the erect position for at least 10 min prior to taking the radiograph.

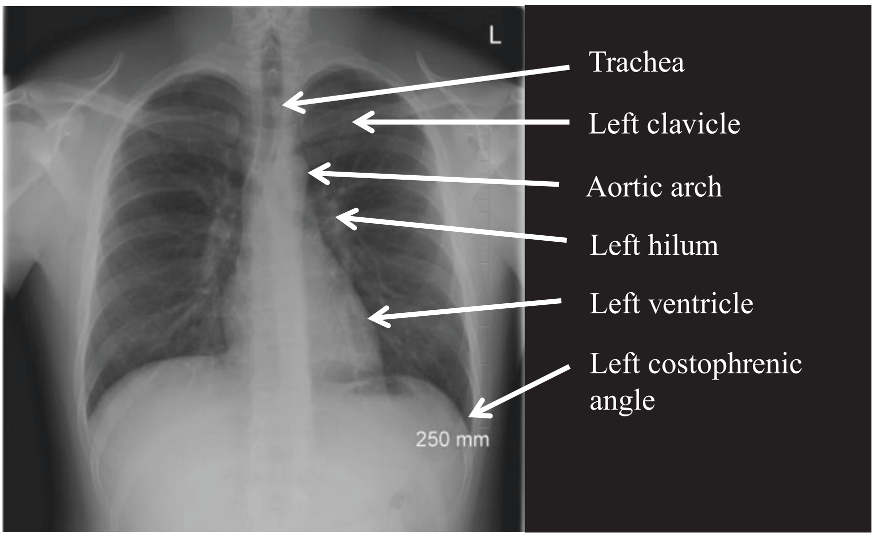
Indications for Imaging

- The need for imaging is determined by clinical assessment.
- In the inpatient or emergency department setting, the chest radiograph can be a useful initial diagnostic screening tool in a generally unwell patient.
- Indications in an outpatient or community setting would include, but are not limited to:
  - Haemoptysis
  - Persistent cough or chest pain
  - Unintended weight loss
  - Night sweats

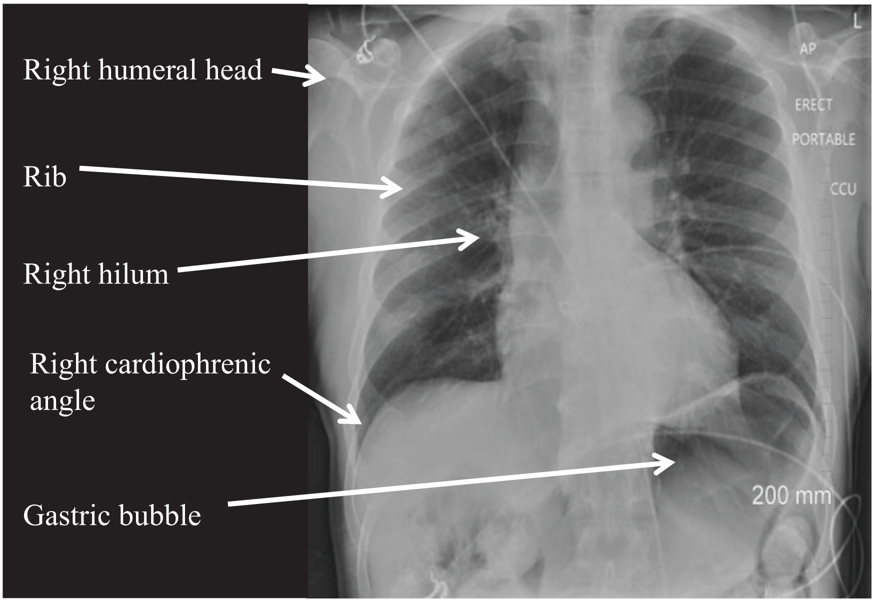
Radiologist's tips

- Develop a system for interpreting chest radiographs. The 'ABCDEFGH' approach is widely used and will capture the vast majority of abnormalities if employed correctly. It is denoted as follows:
  - Airway—central or deviated?
  - Bones—any fractures or lesions?
  - Cardiac silhouette—normal or enlarged?
  - Diaphragm—elevated? Is there pneumoperitoneum? Are the costophrenic angles blunted?
  - Extras—any devices present? Are they in the correct position?
  - Fields—are the lung fields clear?
  - Gastric bubble—is it normally located?
  - Hila—are they enlarged or obscured by a mass?
- Other key review areas include the lung apices, the lower lung fields behind the cardiac silhouette and the hemidiaphragms and breast shadows
- Don't be fooled by nipple shadows, they can mimic lesions in the lower lungs. If in doubt, repeat the radiograph with nipple markers.
- ALWAYS compare the current chest radiograph to any previous chest radiographs available, as an interval change in appearance can help to identify new pathologies.

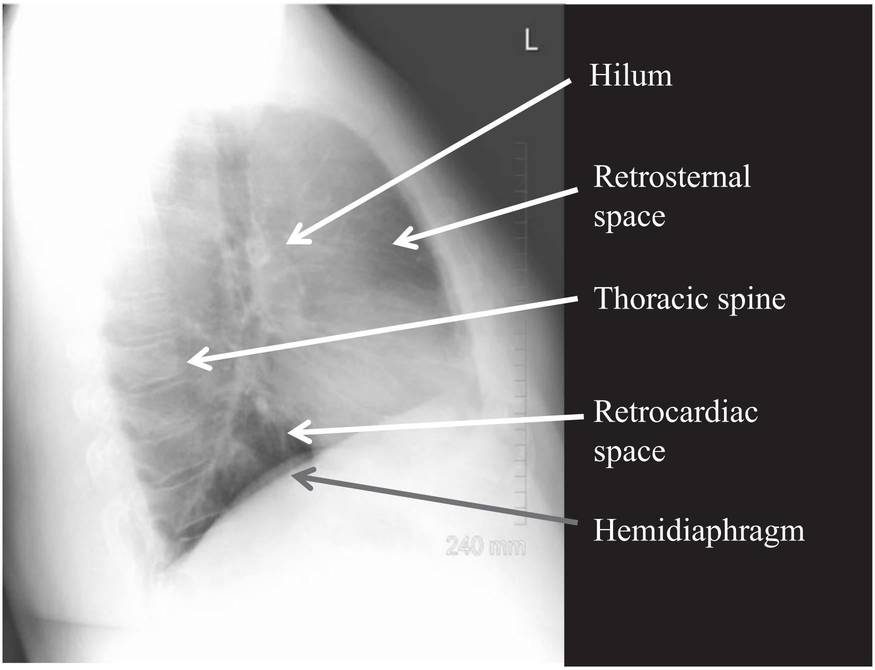
Review of Relevant Radiological Anatomy: PA Chest Radiograph



Review of Relevant Radiological Anatomy: AP Chest Radiograph



Review of Relevant Radiological Anatomy: Lateral Chest Radiograph



Common Pathologies

Pneumonia:

- A variety of pathogens may be responsible, most commonly the bacteria streptococcus pneumoniae in community acquired pneumonia.
- The alveolar sacs fill with pus, limiting oxygen exchange.

Clinical features:

- Productive cough with green sputum.
- Fever.
- Pleuritic chest pain and dyspnoea.
- May progress to sepsis and cardiovascular instability if untreated.

Key imaging appearances:

- Usually presents as pulmonary consolidation (Fig. 2).
- This is seen as an abnormal patchy or confluent area of increased opacification/density in the lung. This can lead to loss of normal interfaces between the usually dark lungs and adjacent denser structures including the heart borders or diaphragms. This is referred to as 'silhouetting'.

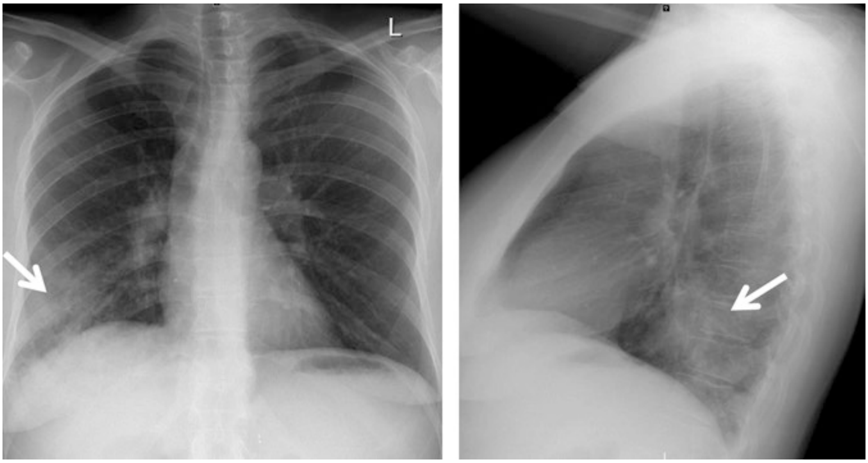


Fig. 2 Right lower lobe pneumonia on PA and lateral chest radiograph. Note the asymmetric patchy increased density in the right lateral lower lung on the PA image. On the lateral view there is abnormal increased opacification overlying the lower thoracic vertebrae, which usually appear darker than upper thoracic vertebral bodies on a normal lateral radiograph, this is known as the Spine Sign

– In severe cases, cavitation may be seen within the infected lung, particularly when the pathogen is Klebsiella pneumoniae or Staphylococcus aureus. This is evidenced by focal air collections within the consolidation.

Radiologist's tip

- It is advisable to obtain a repeat chest radiograph in six weeks following antibiotic therapy in cases of lobar pneumonia to ensure resolution. Failure of the consolidation to resolve could indicate an underlying malignancy requiring respiratory referral and further investigation with CT thorax.

Lobar collapse/atelectasis:

- This refers to loss of air from the lung alveoli leading to volume loss and collapse of the affected lung lobes.
- There are many potential underlying causes including internal airway obstruction from mucus plugging or an endobronchial tumour, or extrinsic compression for example by a pleural effusion.

Clinical features:

– Symptoms include dyspnoea, productive cough or secretions
– There may be ancillary signs of the underlying cause, such as weight loss or hemoptysis in a patient with malignancy

Key imaging appearances:

– Without air in the alveoli the affected part of the lung becomes relatively smaller and more dense/opaque on the chest radiograph
– Typical appearances depend on the lobe involved, however in all cases there will be volume loss +/− associated deviation of the trachea and hilum towards the affected side (Fig. 3). There may also be ipsilateral deviation of the lung fissures or hemidiaphragm.
– In right upper lobe collapse, there is increased opacification in the right upper lung zone and upward deviation of the transverse fissure. In cases due to a central obstructing bronchial tumour, the classic 'Golden S' is observed due to hilar enlargement.
– In left upper lobe collapse, a veil-like opacity is typically seen projected over the left hemithorax. The 'Luftsichel' sign may be appreciated and refers to the compensatory hyperinflation of the superior left lower lobe.
– In right lower lobe collapse the right hemidiaphragm is obscured/silhouetted, and if the right middle lobe is involved, the right heart border is also obscured.

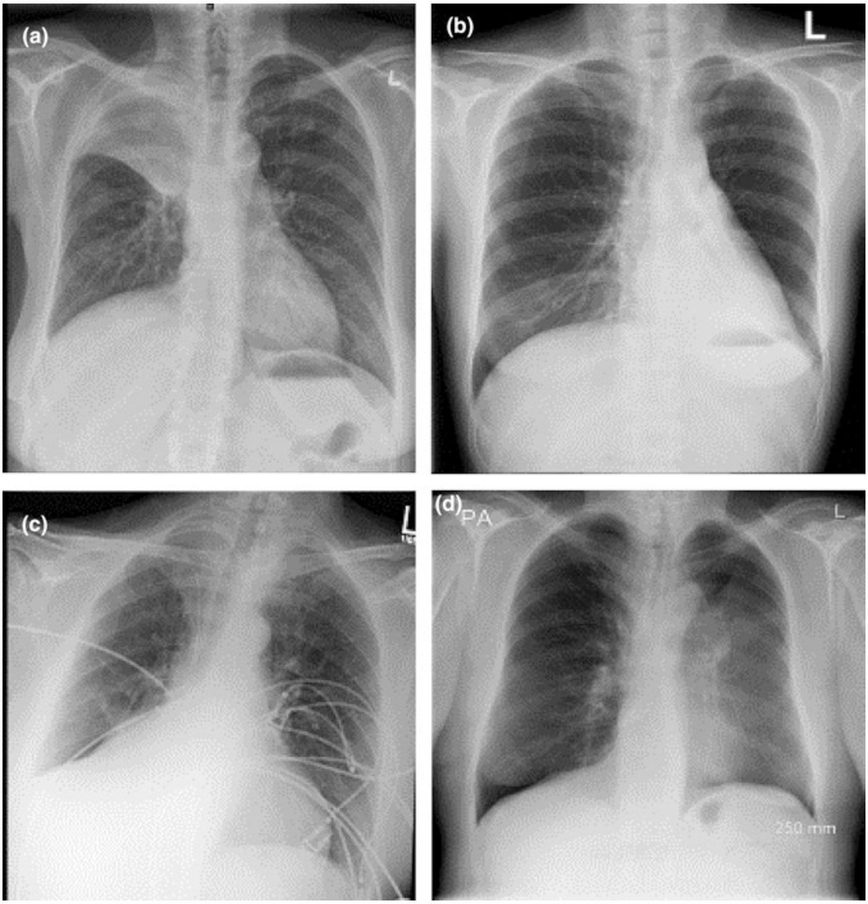


Fig. 3 **a**–**d** Panel of images showing various lobar collapses. **a** Right upper lobe collapse due to right hilar tumour exhibiting S Sign of Golden. **b** Left lower lobe collapse secondary to mucus plugging demonstrating the sail sign. **c** There is relatively increased right-sided retrocardiac density and elevation of the right hemidiaphragm due to right lower lobe collapse. A right subclavian central venous line with tip in the lower SVC is also present. **d** Note the veil-like opacity projected over the left hemithorax. This is the collapsed left upper lobe projected over the remainder of the inflated left lung

– In left lower lobe collapse the left hemidiaphragm is obscured and a retrocardiac 'sail' sign may be seen.
– Lingular collapse is uncommon, but presents with an obscured left heart border.
– Collapse of the entire lung will lead to a 'white-out' appearance with ipsilateral shift of the mediastinum (Fig. 4)

Radiologist's tip

- As lobar collapse may be the initial presentation of a more sinister underlying cause such as an endobronchial mass, it should prompt further investigations with either bronchoscopy or CT thorax or both.

Pleural effusion:

- This refers to the abnormal accumulation of fluid in the pleural space and can be composed of serous fluid, blood (hemothorax), pus (pyothorax/empyema) or chyle (chylothorax).
- Thus, effusions may be due to a variety of etiologies, including cardiac failure, trauma, malignancy, pulmonary infarcts, pneumonia or thoracic duct injury. They can be unilateral or bilateral.

Clinical features:

– Symptoms may be due to the effusion itself causing shortness of breath and pleuritic chest pain, or be related to the underlying cause. On examination, there will be reduced breath sounds and dullness to percussion on the side of the effusion.
– Clinically, pleural effusions tend to be classified into transudative or exudative causes and can be distinguished using Light's criteria.

Key imaging appearances:

– Loss or blunting of the normal costophrenic angle, with a 'meniscus' sign, is indicative of a pleural effusion.

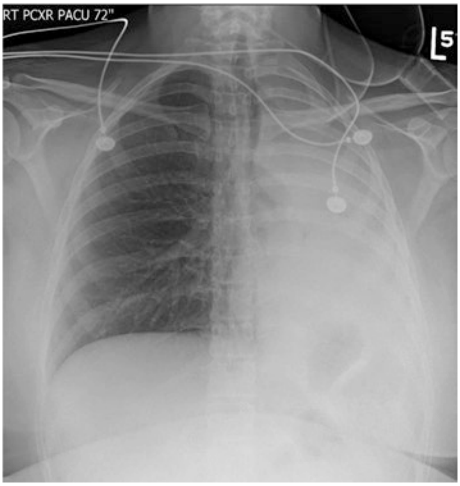


Fig. 4 White-out of the left hemi-thorax due to complete left lung collapse. Note the ipsilateral deviation of the trachea and cardiac silhouette due to the volume loss. There is also resultant elevation of the left hemidiaphragm and underlying bowel gas

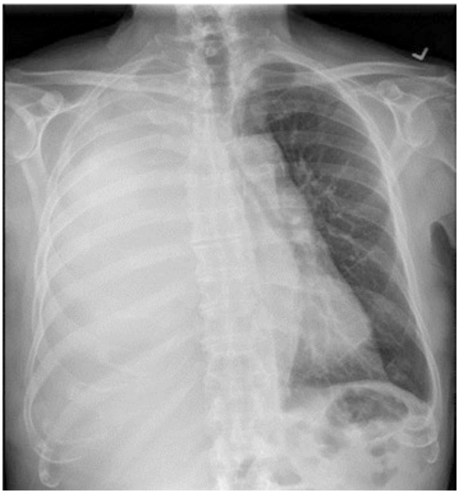


Fig. 5 White-out of the right hemi-thorax due to a very large right pleural effusion. In this case, note the contralateral deviation of the trachea and cardiac silhouette due to the mass effect of the pleural effusion pushing away and displacing these structures

- Very small effusions are first detected on a lateral chest radiograph as blunting of the posterior costophrenic sulcus
- With very large effusions the trachea can be deviated to the contralateral side as the effusion 'pushes' the mediastinum away (Fig. 5).
- Fluid may be seen within the fissures, and if loculated may be mistaken for a mass ('pseudotumour').

Radiologist's tip

- It is not possible to distinguish between a transudate or exudate or to determine the pleural fluid composition on chest radiographs

Heart failure:

- Consideration of the underlying pathophysiology of heart failure helps explain the chest radiographic appearances (Fig. 6).
- Loss of left ventricular function leads to increased pressure within the left atrium and pulmonary veins, causing them to enlarge and fluid to 'seep out', first into the pulmonary interstitium and then into the alveoli of the lung parenchyma and possibly the pleural spaces.

Clinical features:

- Symptoms include dyspnoea on exertion, orthopnoea, peripheral oedema.

Key imaging appearances:

- Air-space opacities represent fluid-filled '**A**lveoli'.
- Interstitial oedema is represented by peripheral Kerley '**B**' lines.

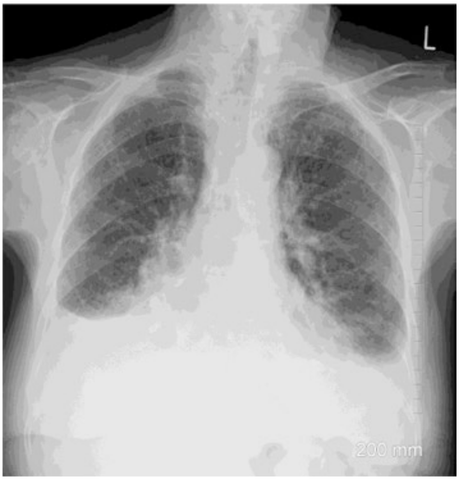


Fig. 6 This patient presented acutely short of breath with a history of prior myocardial infarction. There is cardiomegaly, bilateral pleural effusions, increased perihilar vasculature and increased bilateral interstitial markings compatible with pulmonary oedema

– **C**ardiomegaly—the width of the cardiac silhouette will be greater than 50% of the width of the thorax.
– **D**ilated hilar vessels represent enlarged pulmonary veins.
– Pleural **E**ffusion, usually bilateral but may be unilateral.

> **Radiologist's tip**
>
> • The imaging appearance of heart failure may be remembered by the 'ABCDE' mnemonic.

Pneumothorax:

• This refers to the abnormal accumulation of gas within the pleural space.
• Most commonly due to trauma, rupture of a bulla or iatrogenic (e.g. post pacemaker insertion or lung biopsy).

Clinical features:

– Typical symptoms include pleuritic chest pain and shortness of breath.
– If it continues to enlarge, a tension pneumothorax may develop which is a life-threatening condition and needs to be recognized and treated emergently by placing a large bore (14-G or 16-G) cannula into the ipsilateral 2nd intercostal space in the mid-clavicular line, followed by chest drain insertion.

Key imaging appearances:

– The typical feature is the presence of a thin white line (representing the pleural surface), peripheral to which there is only gas with no lung markings evident (Fig. 7).

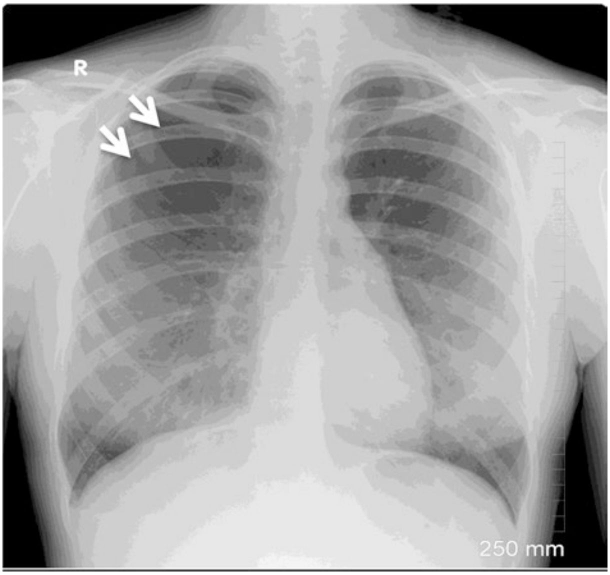


Fig. 7 Erect PA chest radiograph showing a spontaneous right-sided apical pneumothorax in a 32-year old patient. Arrows demonstrate the visceral pleural line. Note the absence of lung vascular markings peripheral to this line

– Usually this pleural line is seen in the apicolateral lung field on a chest radiograph performed with the patient upright.
– If there is uncertainty, an expiratory phase chest radiograph may be helpful to accentuate the pneumothorax
– When patients are semi-recumbent or in the supine position the air tends to accumulate in the non-dependent anteroinferior pleural space and can be seen as costophrenic angle lucency or 'deep sulcus sign'.
– Ancillary signs include subcutaneous emphysema and pneumomediastinum.

Radiologist's tip

- Signs of a tension pneumothorax include a large volume of air in the pleural space with collapse of the adjacent lung, flattening of the ipsilateral hemidiaphragm and contralateral deviation of the trachea and cardiomediastinal structures (Fig. 8). This requires urgent needle decompression as described.

Support Devices (Fig. 9):

- Nasogastric tubes—the tip of these should be visible below the diaphragm on chest radiograph before enteral feeding is commenced.
- The tip of an endotracheal tube should be within 3–7 cm of the carina in an adult patient.
- A PICC line should have its tip at the superior cavoatrial junction. Dialysis catheters, Hickmann lines and Port-A-Caths should have their tips in the right atrium.

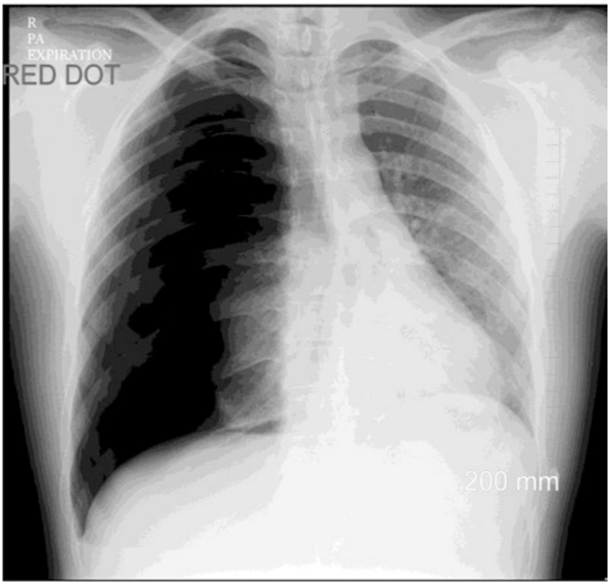


Fig. 8 Right-sided tension pneumothorax. Note the large volume of gas in the right pleural space with associated cardiomediastinal shift to the contralateral side, flattening and depression of the right hemidiaphragm and almost complete collapse of the right lung. This is an emergency and the patient needs to be decompressed immediately!

- Lead positions of cardiac devices are best assessed with PA and lateral views and typical placement can include right atrial, right ventricular and coronary sinus leads.
- A Swan-Ganz catheter should be positioned within the proximal right or left main pulmonary artery.
- The tip of an intra-aortic balloon pump should be positioned 2–3 cm distal to the origin of the left subclavian artery. A position of approximately 2 cm above the level of the carina or left main bronchus can be a helpful landmark on chest radiograph.

Important Differential Diagnoses

Nodules:

Solitary pulmonary nodule:

- Has an extremely broad differential which is often overlooked!
- Tumour is the main concern, this may be malignant such as a bronchogenic carcinoma or a solitary pulmonary metastasis. However, it could represent a low grade carcinoid, benign hamartoma or bronchocele.

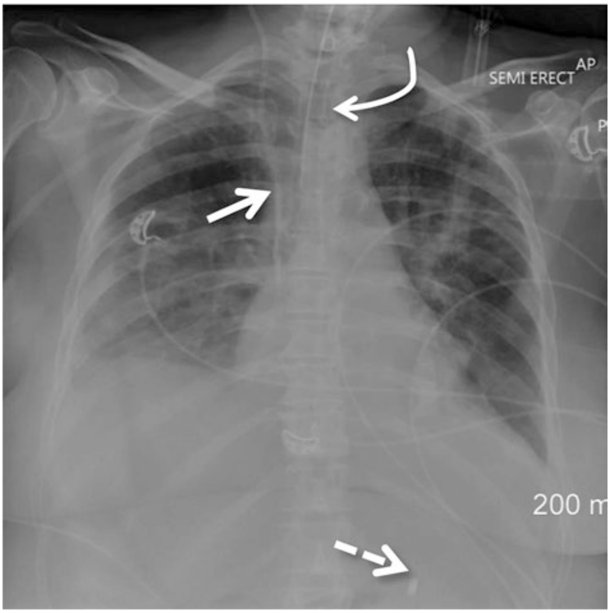


Fig. 9 This is an AP chest radiograph taken in an ICU patient. Support lines and tubes are in satisfactory positions. Note the central venous catheter in the right internal jugular vein with its tip at the superior cavo-atrial junction (solid arrow). An endotracheal tube is also visible with its tip approximately 4 cm from the carina (curved arrow). The tip of a naso-gastric tube is suitably placed within the stomach (dashed arrow). Numerous external cardiac monitoring leads are also visible. Other findings include left lower lobe consolidation and atelectasis, perihilar vascular congestion and oedema, and a small right pleural effusion that is layering dependently given the semi-erect position

- Inflammatory processes are the most common, ranging from a granuloma to a focus of pneumonia to abscess.
- Vascular causes such as pulmonary arteriovenous malformation, pulmonary infarction or septic embolus may present as a nodule.
- In cases of trauma, a pulmonary contusion can have this appearance.
- Congenital abnormalities such as cysts or CPAMs should also be considered.
- Always compare with a prior if available and bear in mind the clinical context.

Multiple pulmonary nodules:

- The worrying differential here is metastatic disease (Fig. 10). The most common malignancies to metastasise to the lung are breast, colorectal, renal, head and neck tumours and primary lung neoplasms.
- Infection is definitely a consideration, particularly in immunocompromised patients, including TB and fungal infection.

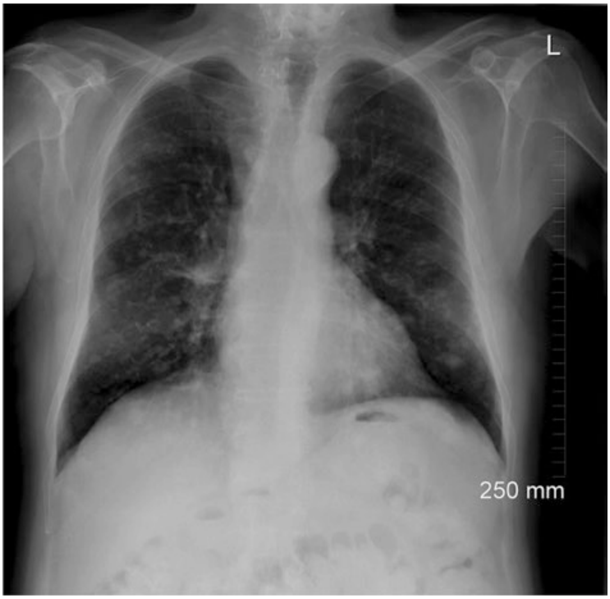


Fig. 10 This radiograph shows numerous small solid pulmonary nodules. There are very subtle surgical clips in the superior mediastinum/lower midline neck. This patient had a history of thyroidectomy for thyroid malignancy and represented with progressive shortness of breath. The diagnosis here was recurrent metastatic thyroid cancer

- Less common are granulomatosis with polyangiitis (formerly Wegener's granulomatosis, and usually cavitating but may appear solid on radiograph), hypersensitivity pneumonitis and sarcoidosis.
- Nodules may be long-standing or calcified in patients with a history of granulomatous disease (e.g. histoplasma) or varicella.

Cavitating nodules:

- Cavitating lesions may be due to diverse and severe pathologies; recognition of these is extremely important (Fig. 11). The mnemonic 'CAVITY' may be used:

  – Cancer—particularly primary squamous cell lung cancer, metastatic head and neck or cervical squamous cell carcinoma.
  – Autoimmune—granulomatosis with polyangiitis (formerly Wegener's).
  – Vascular—septic emboli.
  – Infection—seen in Staph aureus, Klebsiella pneumoniae and TB. This includes pulmonary abscess, which may have an air-fluid level.
  – Trauma—also known as a pneumatocele, these usually spontaneously regress.

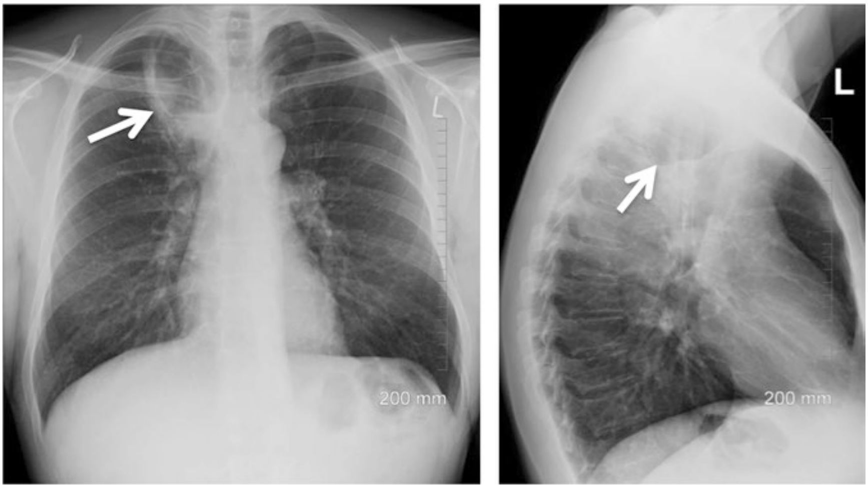


Fig. 11 Here we have a right upper lobe cavitating lesion in a 36-year old intravenous drug user. This patient presented with purulent sputum, weight loss and fevers. The diagnosis was a pulmonary abscess. Note the internal air-fluid level (arrows). Given the location and appearance, TB is a consideration, and the patient may need to be initially isolated

– Young—congenital pulmonary airway malformations (CPAMs) may present as a cavitating lesion on chest radiograph. Seen in newborns and infants.

Radiologist's tip: Managing the solitary pulmonary nodule

- It is important to keep the broad differential in mind, however, this may be the first presentation of a malignancy. As such, it is essential that appropriate follow-up is made to ensure the nodule resolves. A follow-up chest radiograph 4–6 weeks after treatment should be performed in all cases. If the nodule persists, referral to a Respiratory Rapid Access Clinic with a view to performing CT Thorax for further evaluation is advised.

Bihilar lymphadenopathy:

- This may be the presenting feature of sarcoidosis (Fig. 12). As this condition may progress to pulmonary fibrosis, which is irreversible, it is important to recognize it at this stage.
- The other main differential is malignancy, particularly lymphoma. Although any malignancy may metastasise to mediastinal nodes, if the abnormality is symmetrical, lymphoma is considered more likely.

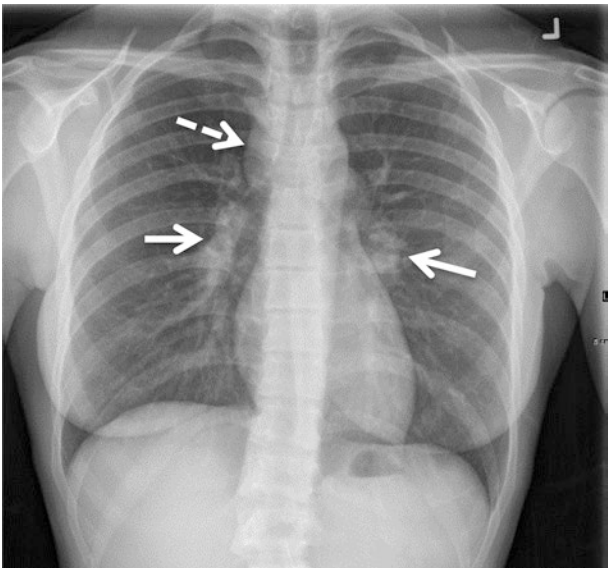


Fig. 12 In this patient with sarcoidosis, the characteristic mediastinal and bilateral hilar lymphadenopathy is present. This is evidenced by widening of the right paratracheal region (dashed arrow) and increased density and lobular contour of the hila bilaterally (solid arrows). No pulmonary parenchymal features of sarcoidosis are demonstrated

Tuberculosis (TB):

- No chapter on the chest radiograph would be complete without mentioning TB. It may present in a variety of ways, and the appearances on chest radiograph are dependent on whether it is primary or post primary infection.
- In **primary TB** (i.e. the time of initial infection), the most common appearances are a patchy area of consolidation (usually apical) with ipsilateral hilar or mediastinal lymphadenopathy. Pleural effusions, particularly large volume effusions, may also occur.
- In **post-primary TB** (i.e. reactivation occurring years later), there may also be patchy consolidation, however cavitation is more likely to occur. Again, the upper lobes are most commonly affected.
- **Miliary TB** is an important consideration and represents hematogenous dissemination of mycobacterium tuberculosis infection. This appears as innumerable nodules measuring 1–3 mm throughout the lung parenchyma.

Suggested Reading

- Callister ME, Baldwin DR, Akram AR et al. British Thoracic Society Guidelines for the investigation and management of pulmonary nodules. Thorax. 2015; 70:ii1–ii54.
- Cardinale L, Volpicelli G, Lamorte A, Martino J. Revisiting signs, strengths and weaknesses of standard chest radiography in patients of acute dyspnea in the emergency department. J Thorac Dis. 2012;4:398–407.
- Parkar AP, Kandiah P. Differential diagnosis of cavitary lung lesions. J Belg Soc Radiol. 2016;100(1):100.
- Nin CS, de Souza VV, do Amaral RH, et al. Thoracic lymphadenopathy in benign diseases: a state of the art review. Respir Med. 2016;112:10–17.
- Cardinale L, Priola AM, Moretti F, Volpicelli G. Effectiveness of chest radiography, lung ultrasound and thoracic computed tomography in the diagnosis of congestive heart failure. World J Radiol. 2014;6:230–37.
- Hunter TB, Taljanovic MS, Tsau PH, Berger WG, Standen JR. Medical devices of the chest. Radiographics. 2004;24(6):1725–46.

Tutorial 9: Cardiovascular Imaging

Douglas Mulholland and Matthew Barrett

Aims and Guidance for Tutors

Cardiovascular imaging has been at the forefront of innovation in recent years. With the advent of CT coronary angiography (CTCA) and cardiac MRI, the management of both acute and chronic cardiac disease has changed substantially. In addition, technological advances have allowed CT angiography and MR angiography to become an important adjunct in the management of peripheral vascular disease. It is important the student understands these modalities as they have a significant bearing on common clinical presentations. After completion of this tutorial students should be able to describe the key imaging findings in common cardiovascular diseases.

Introduction

- Cardiovascular imaging includes, but is not limited to, CT Angiography, MR angiography, CTCA and Cardiac MRI.
- A number of common and potentially life-threatening presentations are dependent on these tests for diagnosis, including pulmonary embolus, aortic dissection and acute limb ischemia.
- The indications for these tests are varied and it is important to factor in concepts such as radiation dose and target anatomy. It is crucial to elicit a detailed clinical history in order to ensure the correct test is performed.

D. Mulholland (✉)
Douglas Mulholland, Beaumont Hospital Beaumont Road, Dublin, Ireland
e-mail: doug2057@gmail.com

M. Barrett
Matthew Barrett, Beacon Hospital, Dublin, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_9

- CT of the coronary arteries has become a mainstay in recent years in the evaluation of low-risk patients with acute coronary syndrome.
- Cardiac MRI has an array of applications, including the evaluation of myocardial function, suspected myocarditis and congenital abnormalities.

Radiological Modalities Utilised

CT coronary angiogram:

- This is a complex technique, whereby contrast is rapidly injected intravenously and multiple CT images are acquired at specific points in the cardiac cycle. It allows for detailed analysis of the coronary arteries and other cardiac structures.
- It is the investigation of choice in the evaluation of patients with low or intermediate pretest probability of coronary artery disease.
- By visualizing the coronary arteries in this way, we can identify coronary artery plaques which are likely to be obstructive and may require treatment with percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG).
- CTCA has an excellent negative predictive value and as such is often seen as a gatekeeper to catheter angiography.

CT pulmonary angiography:

- An extremely common investigation in hospital medicine which allows for visualization of the pulmonary arteries.
- Intravenous contrast is rapidly injected and a CT is performed precisely at the point where the volume of contrast is greatest in the pulmonary arteries.
- It is the test of choice in patients with suspected pulmonary embolism. In order to avoid scanning patients inappropriately, Well's criteria should be applied in cases of suspected pulmonary embolism, in addition to judicious use of serum D-dimer levels.

CT thoracic and abdominal angiography:

- These investigations may be performed separately or together. They are used to evaluate the thoracic and abdominal aorta.
- Again, intravenous contrast is injected and the scan is timed for when the bolus of contrast is within the aorta.
- This is performed to evaluate patients with suspected dissection, aneurysm or active bleeding in the chest, abdomen or pelvis.
- It may be combined with non-contrast and delayed phase imaging to allow for more in-depth analysis, particularly in cases of suspected internal bleeding.

CT peripheral angiography:

- CT may be used to evaluate the peripheral vasculature, both upper and lower limbs.
- It is test of choice in acutely ischemic limbs but also is useful in characterizing the pathology of patients with chronic symptoms of peripheral vascular disease.
- In conjunction with ankle:brachial indices or toe:brachial indices, and the clinical picture, CTA can be used to identify stenotic or occlusive lesions in peripheral vessels for treatment.
- In traumatic cases, CTA plays a major role in evaluating arterial injury, identifying transected or damaged vessels adequately. This allows for expedient surgical or Interventional Radiology management.
- CTA is limited in its ability to evaluate heavily calcified vessels, particularly the below knee vessels due to streak artefact from calcium deposited in vessel walls. This is particularly difficult in diabetic patients.

MR angiography

- This allows for excellent visualization of the peripheral vasculature and avoids the problems associated with calcified vessels seen in CT imaging.
- This modality also avoids the use of potentially damaging ionizing radiation.
- These scans are more time-consuming than their CT counterpart and often are not available due to inadequate access to an MRI scanner.

Digital subtracted angiography

- This involves puncturing the artery directly and injection of contrast under fluoroscopy. This has the greatest diagnostic accuracy of all methods of angiography and also allows for interventions, such as angioplasty at the same time.
- It is particularly useful in evaluating below knee vessels. However, there are increased complications by virtue of the fact that an artery is punctured. These include pseudoaneurysm and embolization.

Cardiac MRI

- May be used to evaluate a host of cardiac pathologies, including coronary artery disease, cardiomyopathies, valvular disease, congenital cardiac disease and pericardial disease.
- It allows for the production of high resolution images of cardiac structures and is not limited by the presence of bone or air in the way that echocardiography is.
- However, these scans are time-consuming and are not be suitable in evaluating unstable patients. They are also unsuitable in patients with MRI-incompatible devices, such as aneurysms clips or older pacemakers.

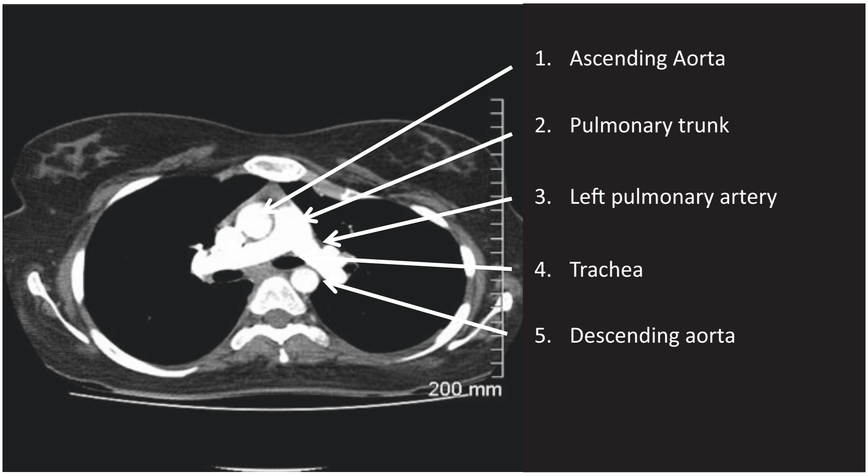
The 'Triple Rule-out' study

- This is a combination of CTCA, CTPA and a CT Thoracic Aorta
- It is useful in patients with severe acute symptoms, which are difficult to distinguish using other mechanisms
- This study can evaluate patients for the presence of aortic dissection, pulmonary embolism and coronary artery disease.
- It is not a first-line investigation for all patients due to the higher radiation dose involved, but rather should be reserved for the acutely unwell, difficult to diagnose patient

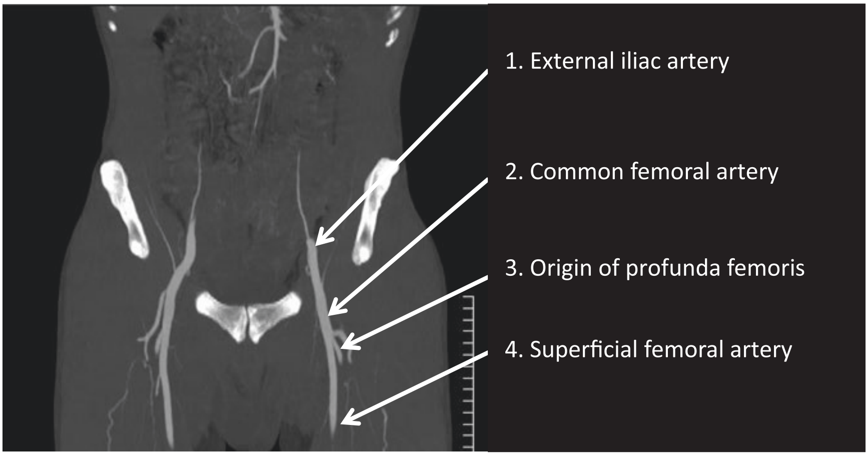
Radiologist's tips: Interpreting CTPA

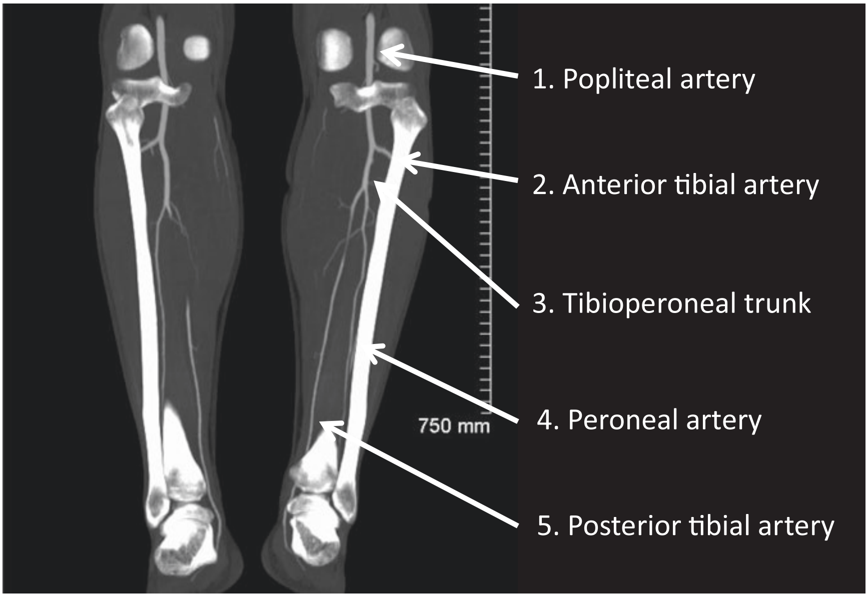
- In the presence of pulmonary embolus, the student should always check for the presence of right heart strain and areas of pulmonary infarction.
- Right heart strain is a marker of cardiovascular instability. The signs on CTPA include right ventricular enlargement, flattening of the interventricular septum and reflux of contrast into the hepatic veins.
- If these signs are present, patients require urgent review and treatment.

Review of Relevant Radiological Anatomy: CT PA

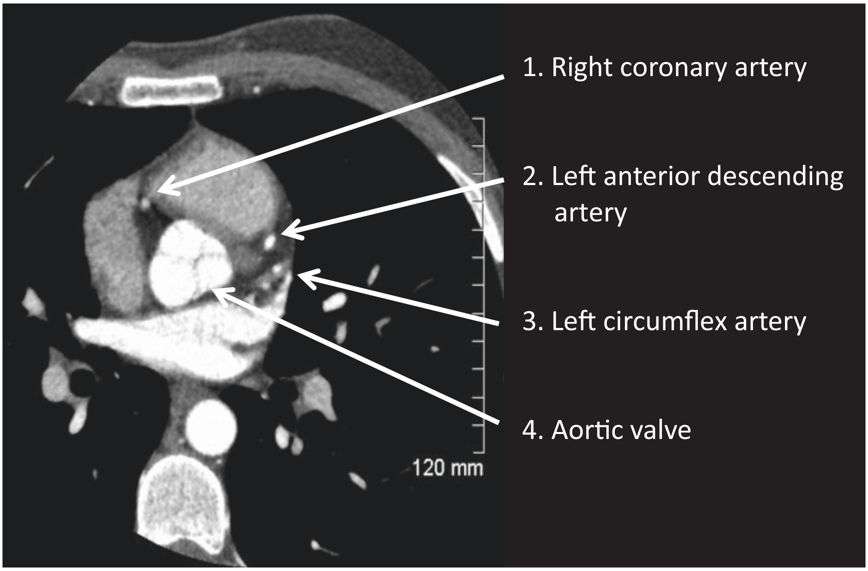


Review of Relevant Radiological Anatomy: CT Lower Limb





Review of Relevant Radiological Anatomy: CT Coronary Angiogram



Acute Cardiovascular Imaging

Acute aortic dissection:

- This may occur anywhere in the aorta and its branches. It involves blood entering the media of the vessel through a tear in the intima and forming a second blood-filled channel, the false lumen, which parallels the true lumen.
- In the thorax, it is characterized by either the Stanford or DeBakey system. These describe the location of the dissection with respect to the arch vessels (brachiocephalic artery, left common carotid and left subclavian arteries). Stanford A (or DeBakey I) is a dissection proximal to the arch vessels while Stanford B (or DeBakey III) is distal to the left subclavian artery.
  – The distinction is crucial as Stanford A dissections require surgery, while Stanford B may be treated conservatively.

Clinical features:

- In the thoracic aorta, patients develop chest pain, classically described as 'tearing' in character which goes through to the back.
- If the dissection extends into the arch vessels, patients are at risk of stroke.

- If it extends distally, the patient may develop limb ischemia or abdominal organ ischemia.

Key imaging appearances:

- The dissection flap may be seen within the vessel (Fig. 1). It is important to precisely locate the beginning and end point of the flap and determine which major arteries are involved.
- Determining the true lumen from the false lumen may be difficult, but is extremely important, particularly if the patient is undergoing surgical management, such as endovascular stenting.
- The aorta may be dilated in caliber.
- An intramural hematoma may be present, this will be visible as high density within the wall of the aorta.

Radiologist's tips: Distinguishing the true lumen from the false lumen

- The true lumen will enhance with contrast more brightly. It is often, counterintuitively, the smaller of the two, due to compression by the false lumen. The celiac trunk, SMA and right renal artery usually arise from the true lumen.

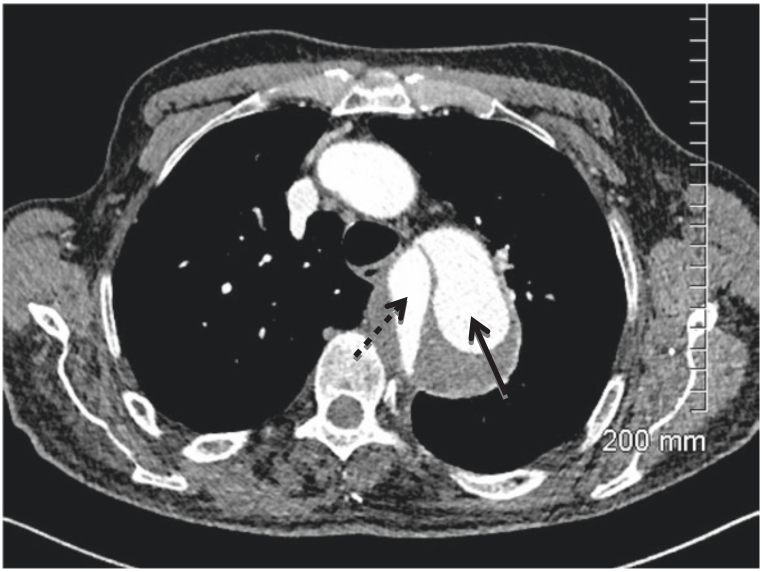


Fig. 1 This is an axial view of a CT Thoracic Angiogram in a patient presenting with severe chest pain radiating through to the back, with a blood pressure differential in both arms. This image shows a thoracic aortic dissection. The true lumen, denoted by the broken arrow is being compressed by the larger false lumen, denoted by the unbroken arrow. The dissection flap can be seen as the line between the two lumens. The ascending aorta is unremarkable. This was a Stanford Type B dissection

Fig. 2 This is a coronal reformat of a CT Pulmonary angiogram performed in a 26-year old patient presenting with pleuritic chest pain. The patient reported a history of taking the oral contraceptive pill. This study showed an embolus in a segmental branch of the right lower lobar pulmonary artery, denoted by the white arrow

Pulmonary embolus:

- This occurs when a pulmonary artery is occluded by an embolus (Fig. 2). The embolus is usually due to a blood clot which has originated in the lower limbs. However, there are a variety of other causes, including fat, tumour, amniotic fluid or air.
- A saddle embolus is an important diagnosis to make (Fig. 3). This refers to a central embolus obstructing the outflow of the main pulmonary arteries or pulmonary trunk.

Clinical features:

- Pleuritic chest pain, dyspnea and hemoptysis.
- Symptoms of a DVT may or may not be present, including asymmetric lower limb swelling, erythema and calf pain.
- Hypotension and shock may occur in the presence of a saddle embolus so called massive pulmonary embolus.

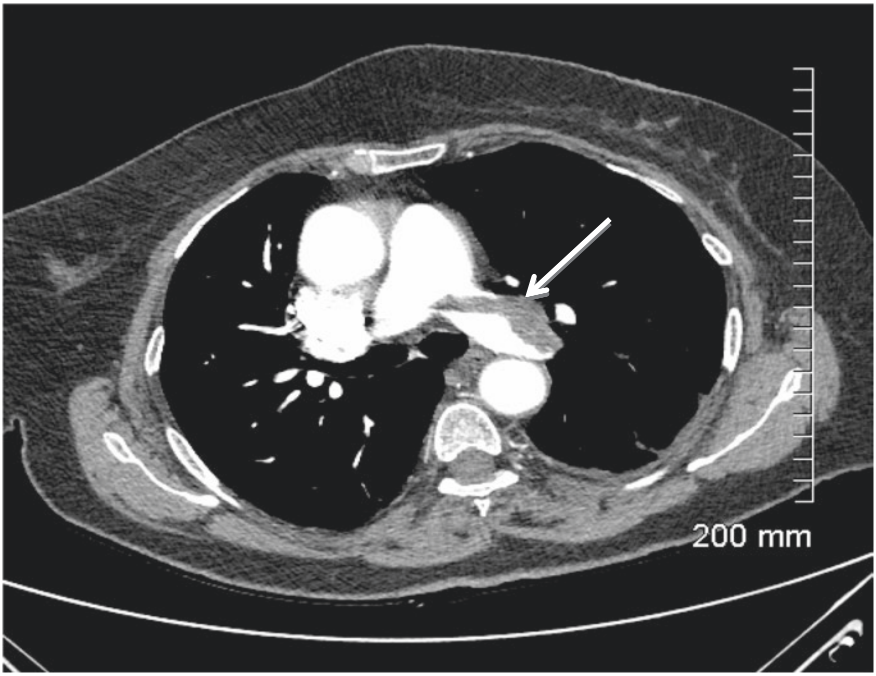


Fig. 3 3 CTPA of a 56-year old who presented with acute chest pain and hypotension. This shows a saddle-type embolus predominantly in the left main pulmonary artery, denoted by the arrow. This patient was thrombolysed

Key imaging appearances:

- The embolus will appear as a filling defect in the pulmonary artery affected. Acute emboli may be occlusive or non-occlusive and typically make an acute angle with the vessels, as opposed to chronic emboli which are typically occlusive and make an obtuse angle with the vessel.
- Emboli may be characterized by order e.g. 1st order in the main pulmonary artery, 2nd order within lobar arteries, 3rd order within segmental branches and 4th order within subsegmental vessels.
- The lungs should also carefully be inspected for signs of pulmonary infarction, which will appear as opacification in the distribution peripheral to the pulmonary embolus.
- Features of right heart strain, as previously described.

<u>Deep venous thrombosis</u>:

- This is defined as the presence of thrombus within a deep vein either within the upper or lower limb.
- The most common location is the iliofemoral veins of the lower limbs.

Clinical features:

- Pain, swelling and erythema of the affected limb are common.
- Clinical features are non-specific and Well's criteria should be applied when considering requesting imaging.
- If it becomes chronic or is left untreated, valvular damage may occur leading to venous hypertension, discoloration and ulceration.

Key imaging appearances:

- On doppler ultrasound, the key feature will be non-compressibility of a vein (Fig. 4).
- Lack of flow within the vessel may also be seen.
- The vein may be expanded in size in acute thrombus, but normal are decreased in size in chronic thrombus.

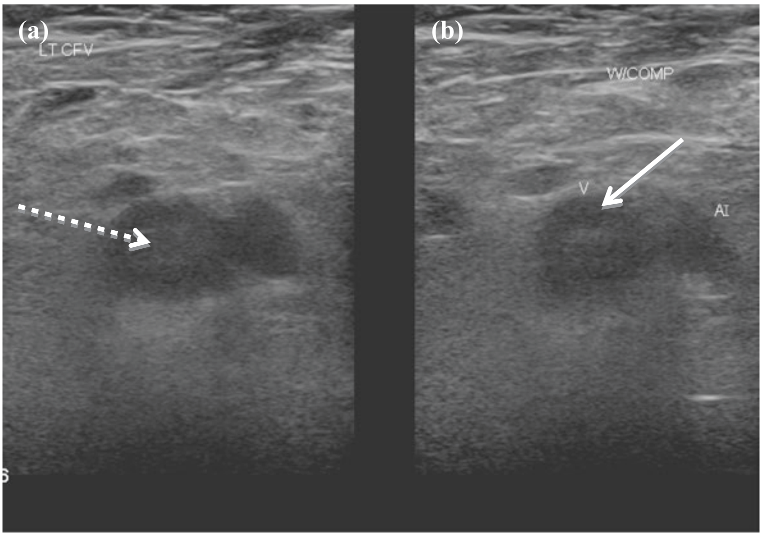


Fig. 4 Ultrasound of the left common femoral vein in a patient presenting with a swollen, painful left leg. Image **a** shows echogenic material within the vessel, consistent with acute thrombosis, denoted by the broken arrow. Image **b** demonstrates non-compressibility of the vessel, denoted by the white arrow. Both findings are consistent with acute DVT

- Acute thrombus is usually anechoic, while chronic thrombus is usually hyperechoic.
- A CT Venogram can be performed to delineate the full extent of a clot.

Radiologist's tips: Well's criteria

- For each point, a +1 is applied if present. If the person scores 2 or more a DVT is considered likely and further investigation with D-dimer or Doppler ultrasound is advised. If the patient scores −2 if an alternative diagnosis is more likely.
- The positive criteria are active cancer, recently bedridden for ≥ 3 days, major surgery within the last 12 weeks, tenderness along the distribution of the deep venous system, entire leg swelling, calf swelling > 3 cm compared with the asymptomatic leg (measured at 10 cm below the tibial tuberosity), pitting edema (greater than on the asymptomatic leg), collateral superficial veins (non-varicose), previously documented DVT.

Abdominal aortic aneurysm:

- This is defined as abnormal dilatation of the abdominal aorta to greater than 3 cm in diameter. An 'ectatic' aorta is one which is greater than 2.5 cm in diameter.
- If incidentally detected, a patient should be referred to a vascular surgical service for surveillance imaging or operative repair.
- The major risk is rupture, which is a life-threatening event. The risk of rupture directly relates to the size of the aneurysm.
- In cases of suspected rupture, patients should be immediately transferred to CT for evaluation and vascular surgeons contacted.

Clinical features:

- Abdominal pain, back pain, hypotension and symptoms of shock.
- There may be signs of lower limb ischemia as patients are at risk of embolus.

Key imaging appearances:

- The abdominal aorta will be dilated.
- Careful evaluation of the retroperitoneum for hemorrhage or contrast extravasation is required. Due to the nature of ruptured aneurysms this is usually obvious due to the volume of hemorrhage involved (Fig. 5).
- However, in certain cases, impending rupture can be very subtle and can only be seen as subtle irregularity or stranding surrounding the aneurysm sac.
- The relationship of the aneurysm to the renal arteries is critical, as this will affect the type of treatment provided.

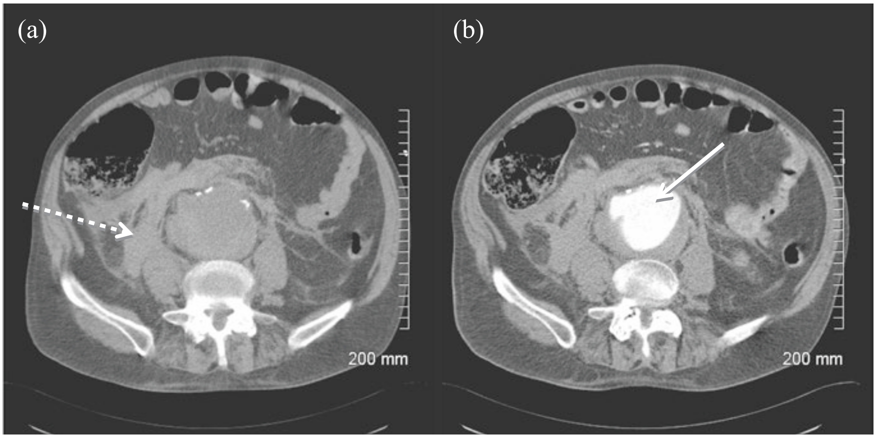


Fig. 5 Image **a** is a noncontrast CT of the abdomen showing large volume fluid in the retroperitoneum, suspicious for hemorrhage, labelled by the broken arrow. Image **b** is an arterial phase image showing an abdominal aortic aneurysm, as labelled by the white arrow, with free fluid in the retroperitoneum and irregularity of the sac in the 11 o'clock position. Findings were consistent with a ruptured AAA

Limb ischemia:

- This is usually due to thrombus or embolus within an upper or lower limb artery. In the lower limb, this is usually in an artery above the knee.
- An antecedent cause is usually present, i.e. atrial fibrillation, valvular disease or iatrogenic arterial puncture.

Clinical features:

- The classic symptoms of a pulseless leg include the 6 'P's; pain, paralysis, paresthesia, pulselessness, pallor and perishing cold
- If left untreated, this can progress to severe tissue loss or even loss of limb.

Key imaging appearances:

- When inspecting the vasculature, there will be an abrupt cut-off of contrast at the level of embolus (Fig. 6).
- This can be difficult to distinguish from a chronic occlusion. In chronic cases, there may be collaterals which have had time to develop around the lesion. Patients may also have a history of claudication, rest pain or night pain.
- A source of embolus should also be searched for, such as thrombus within the left atrial appendage.

Fig. 6 This is a coronal view of a CT lower limb angiogram in a 56-year old patient presenting with a pulseless left lower leg. There is an abrupt cut-off of contrast at the origin of the left superficial femoral artery, demonstrated by the white arrow. This is consistent with an acute thrombus at this level. The patient was referred for endovascular thrombolysis

Acute abdominal hemorrhage:

- CT can be used to evaluate for hemorrhage within the abdomen. There are a variety of causative factors including trauma, iatrogenic or spontaneous (particularly in those on anticoagulant therapy).

Clinical features:

- Patients may present with pain, pallor or signs of cardiovascular instability depending on the severity of hemorrhage.
- GI hemorrhage may present with bright red blood par rectum, hematemesis or melena.

Key imaging appearances:

- A triple phase study is usually performed, including noncontrast, arterial phase and delayed phase imaging.
- Noncontrast may show a collection of heterogenous, but increased density, indicating hemorrhage.

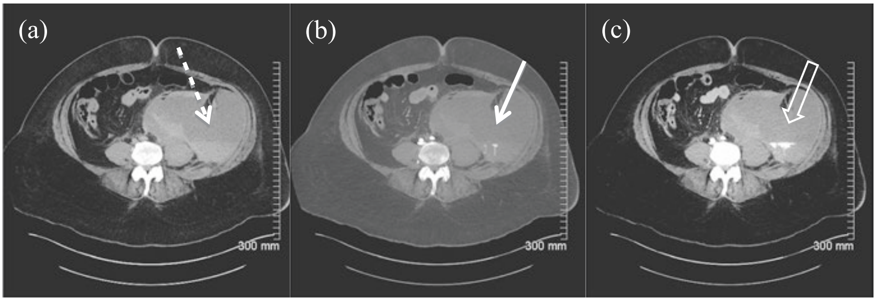


Fig. 7 Triple phase CT Abdominal Angiogram showing large left sided retroperitoneal hemorrhage. Noncontrast imaging in image **a** shows large volume left-sided retroperitoneal fluid, with layering, demonstrated by the broken arrow. This is consistent with hemorrhage. There is an active blush on the arterial phase (denoted by the white arrow in image (**b**)) with progressive contrast extravasation on the delayed phase (denoted by the empty arrow in image (**c**)). This patient presented in hypovolemic shock having recently been commenced on warfarin therapy for atrial fibrillation. The patient was subsequently referred for emergency embolization

- The arterial phase study may show a 'blush' of contrast at the exact site of hemorrhage. This indicates contrast material leaking through the bleed point.
- Delayed phase imaging will show an increase in the volume of contrast at the site of hemorrhage (Fig. 7).

Advanced Cardiac Imaging

The specifics of the various pathologies present on CT Coronary Angiography and Cardiac MRI are beyond the scope of this chapter. Instead we will focus on the indications for these investigations, described as follows.

CT Coronary Angiogram indications:

- Investigation of intermediate risk chest pain in the follow patients:
  - Atypical pain with high risk factor profile (Fig. 8).
  - Typical pain with low risk factor profile.
- Assessment for anomalous coronary arteries. These are particularly clinically relevant as they may be responsible for sudden cardiac death in young people (Fig. 9).
- When coronary arteries or bypass grafts are incompletely assessed at invasive angiography.
  - Aberrant coronary arteries.
  - Known vein grafts unable to be engaged with coronary catheters.
  - Difficult to engage right coronary artery—e.g. high anterior origin.
- To identify origin and course of coronary artery fistulas.

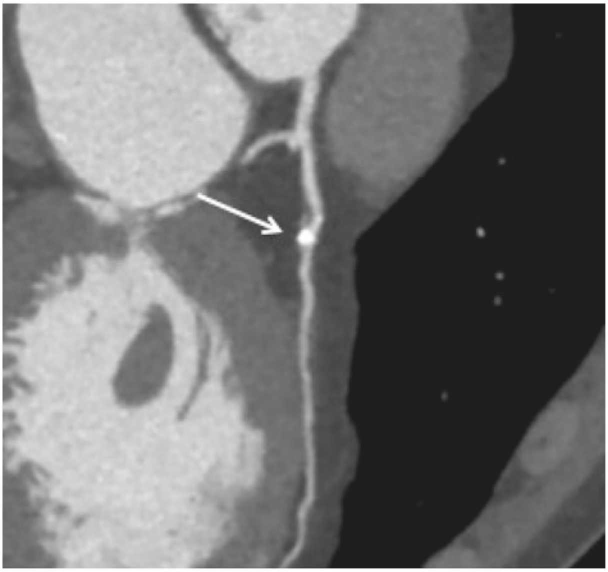


Fig. 8 CT Coronary Angiogram in a 63-year patient with atypical symptoms. This shows a mixed calcified/non-calcified plaque, with significant positive remodeling and fissuring of the soft plaque with associated contrast penetration, labelled by the white arrow. This is a high risk plaque and the patient was referred for percutaneous coronary intervention

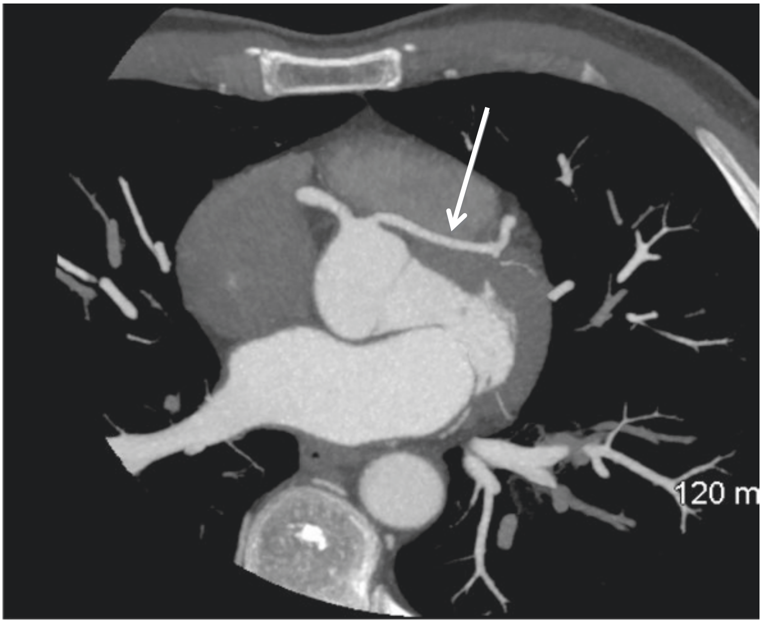


Fig. 9 This is an oblique MPR of a CTCA showing an aberrant left main stem. It arises from the right coronary cusp and then takes an interatrial course. This means it is potentially compressible in systole, which may result in ischemia and cardiac arrest

- To exclude coronary disease in asymptomatic patients.
  - To exclude ischaemia as a cause of cardiomyopathy
  - To exclude significant coronary disease prior to major surgery (such as liver transplant)

Cardiac MRI indications:

- Cardiomyopathy assessment:
  - Investigating aetiology
  - Precise evaluation of left ventricular function to guide appropriate ICD therapy
  - Identification and quantification of fibrosis
- Inflammatory cardiac condition assessment:
  - Suspected cases of myocarditis—e.g. in the setting of elevated troponin without significant coronary disease
- Ischaemia assessment:
  - Perfusion imaging sequences in cases of suspected cardiac chest pain (Fig. 10)
  - Evaluation of myocardial perfusion in the setting of known coronary disease or prior revascularization

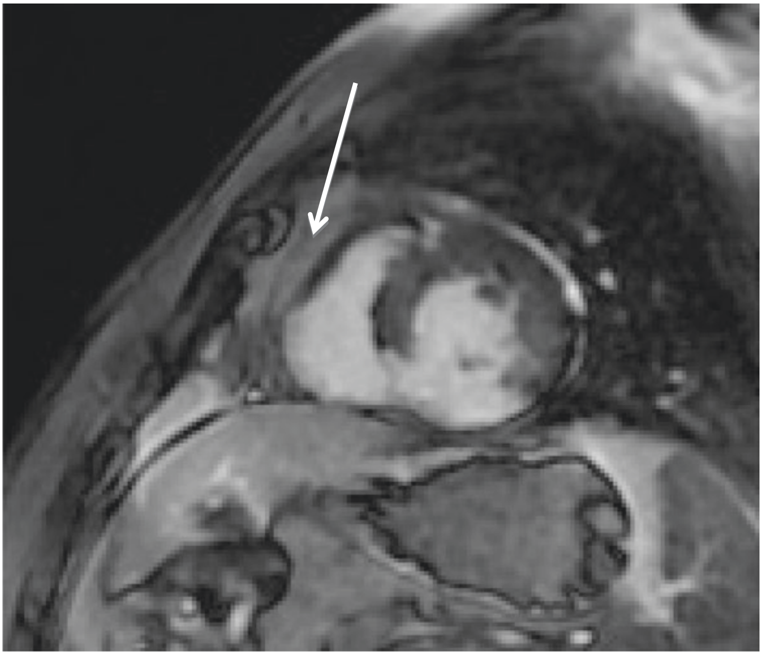


Fig. 10 A basal short axis slice from a Cardiac MRI. There is myocardial thinning in the inferoseptal and inferior walls with transmural delayed enhancement (denoted by the white arrow) as well as thinning of the inferior portion of the RV wall

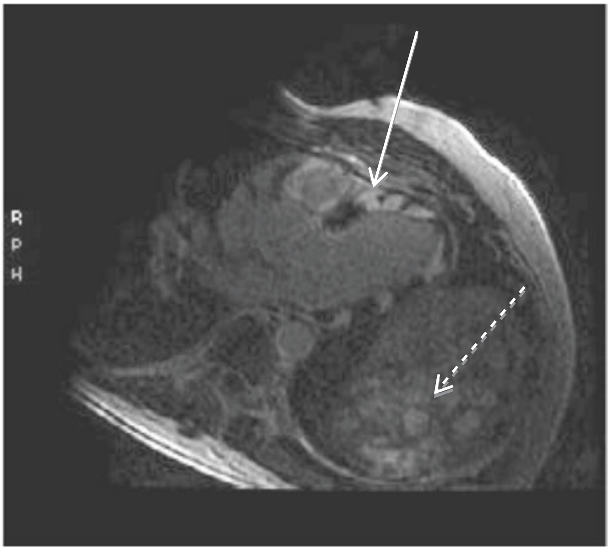


Fig. 11 Cardiac MRI showing a three-chamber view of cardiac sarcoidosis. Relevant findings are multiple foci of scar which involve the subendocardium, mesocardium and subepicardium and transmural in spots (white arrow). Also notable is right ventricular delayed enhancement as well as multiple enhancing foci in the adjacent spleen (broken arrow)

- Viability assessment:
  - In the setting of known coronary disease, to assess myocardial viability to guide appropriate revascularization i.e. prior to attempting complex percutaneous coronary intervention or coronary artery bypass grafting.
- Evaluation of congenital heart disease:
  - Right and left ventricular systolic function
  - Valvular disorders
  - Quantification of shunt fraction
  - Assessment of baffles and conduits
  - Quantification of relative right and left pulmonary artery flow
- Assessment of infiltrative disorders:
  - E.g. cardiac amyloid, sarcoid (Fig. 11).

Suggested Reading

- Alfakih K, Byrne J, Monaghan M. CT coronary angiography: a paradigm shift for functional imaging tests. Open Heart. 2018;5(1):e000754
- Fleischmann D, Chin AS, Molvin L, Wang J, Hallett R. Computed tomography angiography: a review and technical update. Radiol Clin North Am. 2016;54(1):1–12.
- Yu T, Zhu X, Tang L, Wang D, Saad N. Review of CT angiography of aorta. Radiol Clin North Am. 2007;45(3):461–83, viii.
- Wittram, C. How i do it: CT pulmonary angiography. 2007;188(5).
- Saeed M, Van TA, Krug R, Hetts SW, Wilson MW. Cardiac MR imaging: current status and future direction. Cardiovasc Diagn Ther. 2015;5:290–310.

Tutorial 10: The Abdominal Radiograph

Timothy E. Murray and Emily H. T. Pang

Aims and Guidance for Tutors

The abdominal radiograph is an examination performed for a variety of indications. It encompasses many organs and spaces and a structured approach to interpreting the abdominal radiograph is essential to detect pathology. It is important that students comprehend the contemporary role of the abdominal radiograph. Its use has largely been replaced by CT for the radiological assessment of the acute abdomen. However in several settings the abdominal radiograph can provide important diagnostic information. Even where specific radiographic findings are present such as free intra-abdominal air or bowel obstruction which previously represented absolute indications for laparotomy in current practice a subsequent CT is often performed to assess the exact location and severity of pathology guiding treatment decisions. This chapter aims to present the student with a structured approach to interpreting an abdominal radiograph

Introduction

- The abdominal radiograph provides information on five radiographic densities; from least dense (darkest) to most dense (brightest) these are gas, fat, fluid/soft tissue, bone/calcium and metal. Further differentiation between tissue subtypes

T. E. Murray (✉)
Department of Radiology, University of British Colombia, Vancouver, BC, Canada
e-mail: murraytim0@gmail.com; timothy.murray@vch.ca

E. H. T. Pang
Vancouver General Hospital, Vancouver, BC, Canada

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_10

is typically not possible due to inherent limitations in radiograph contrast resolution (Fig. 1).

- Gas is typically confined to the gastrointestinal tract. With instrumentation, gas can be seen in other organs. Air outside of the GI tract or instrumented organ is typically pathological.
- Fat is a normal constituent of the abdominal wall (forming the properitoneal fat plane), encases the retroperitoneal organs, and also occurs within the peritoneal cavity in the form of mesentery and omentum.
- Fluid and soft tissue (such as organ tissue and muscle) are typically of similar density (reflecting the high percentage of water in the cellular contents of organs). The difference between fluid and various solid abdominal organs is typically too small to be reliably perceived on radiography.
- Bone, vascular calcification and mineral calculi are formed from the deposition of minerals such as calcium, phosphate and magnesium. The much higher density of these minerals, as compared with the other tissue types on abdominal radiographs, makes them readily assessable on radiography.
- Metallic foreign bodies may be visualised in the form of surgical clips, staples, or devices, and can provide clues as to the surgical history.

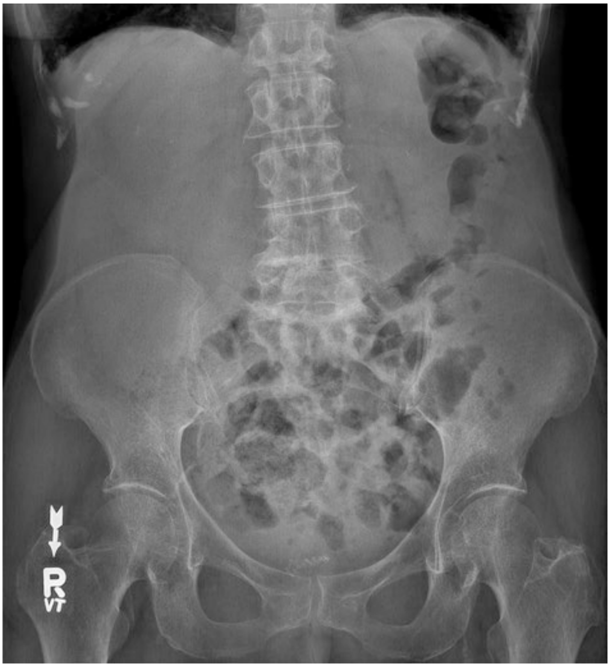


Fig. 1 A satisfactory abdominal radiograph. The radiograph includes the diaphragm superiorly, lateral abdominal walls laterally, and the inferior pubic rami inferiorly. In addition, patient orientation (supine) is demarcated by the downward arrow, and the side of the radiograph is marked (R indicating right)

Abdominal Radiography Technical Principles and Anatomy

- Abdominal radiographs can be performed in a variety of ways. Patient positioning can alter the appearance on a radiograph, particularly the way gas and fluid behave. Position should thus be specified on the radiograph for the reporting radiologist. For example, a supine radiograph is less sensitive than an erect radiograph in assessing for free air, but both can look identical unless the image is labelled appropriately.
- The x-ray tube generates an x-ray beam with exposure factors optimised to maximise differentiation between soft tissues (generally the structures of interest), whilst ensuring adequate beam penetration.
- The dose from an abdominal radiograph is approximately 1.3 mSV, which is much greater than that of a chest radiograph, and approximately one quarter of the dose of a full abdominopelvic CT (Fig. 2).
- The following structures should be included on an abdominal radiograph:
  - The diaphragm superiorly
  - The lateral abdominal walls laterally
  - The inferior pubic rami inferiorly

Anatomy

Although not exhaustive, an outline of the following structures may be visible on abdominal radiography. Larger organs may be visible under normal conditions (indicated below with *), whereas smaller organs may only be apparent under pathological

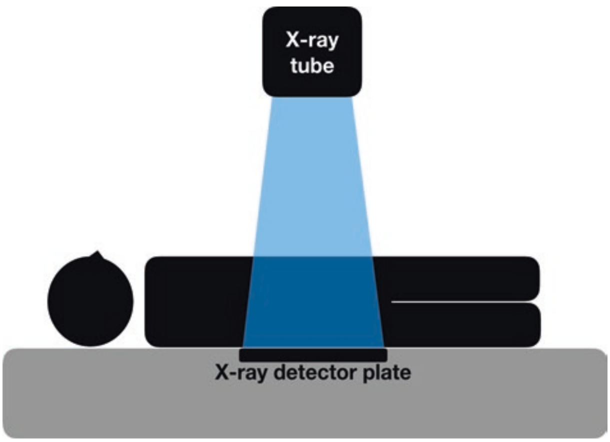


Fig. 2 Graphic representation of standard acquisition of abdominal radiograph. The x-ray tube (positioned over the patient) directs x rays toward the detector plate (positioned under the patient)

conditions such as enlargement or calcification. A knowledge of expected location and normal appearance will aid in detecting pathology (Figs. 3 and 4).

- Solid organs:
  - Liver*
  - Spleen*
  - Kidneys*
  - Pancreas
  - Adrenal glands
  - Uterus and ovaries
  - Prostate
- Hollow organs:
  - Gastrointestinal tract*
  - Renal collecting system, ureters and urinary bladder
  - Gall bladder, biliary tree
- Other:
  - Cavities (peritoneal, retroperitoneal)
  - Subcutaneous tissues (such as the properitoneal fat plane)

Fig. 3 Relative radiographic position of the liver (L), gallbladder (GB) and urinary bladder (UB) are outlined, with coronal contrast-enhanced CT for reference

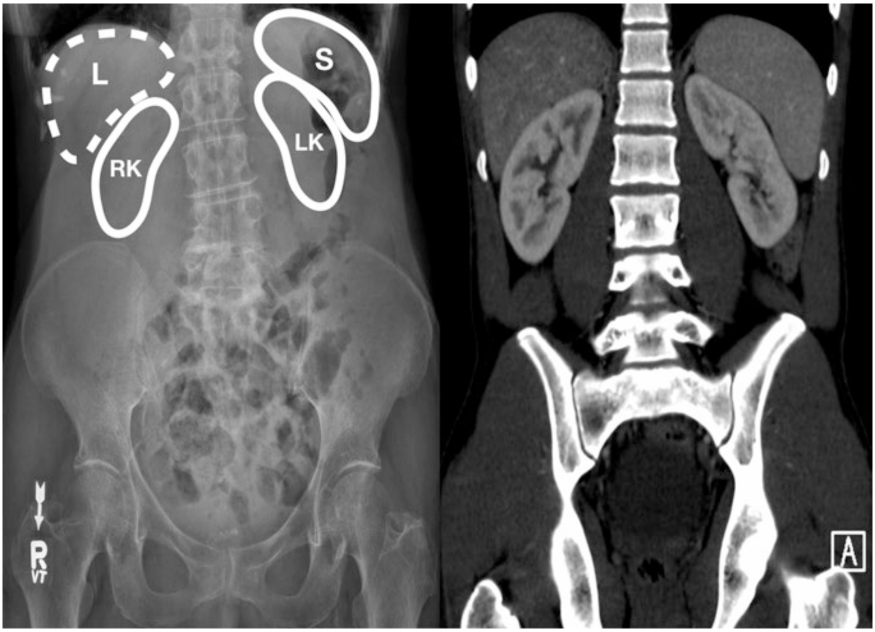


Fig. 4 More posteriorly within the abdomen, the relative radiographic position of the liver (L), spleen (S), left kidney (LK) and right kidney (RK) are outlined, with coronal contrast-enhanced CT for reference

- Lung bases
- Bones
- Hardware

Indications

- While CT has replaced abdominal radiography for most indications, there are some persisting indications for abdominal radiography.
  - Abdominal radiographs are a rapid and easily performed test for suspected acute pathologies such as perforation, obstruction, or urinary stone disease.
  - Abdominal radiographs can be used to follow established diagnoses such as obstruction or toxic megacolon. The radiograph assesses for improvement or worsening over serial studies, without requiring a full repeat CT each time.
  - Abdominal radiographs allow for the assessment of medical hardware (such as tubes, stents, electrical stimulation devices), to ensure no dislodgement or breakage.

Contraindications

- There are no absolute contraindications to abdominal radiography. Due to reasonably high radiation dose, judicious use in young patients is advised. In possible or confirmed pregnancy, alternative modalities which do not involve radiation such as ultrasound or MRI should be considered.

Obstruction

Small Bowel Obstruction

- Small bowel obstruction occurs when there is an impedance to transit along the length of the small bowel (Fig. 5). This is the most common level of gastrointestinal obstruction. Common causes are adhesions, herniae, malignancy and strictures from inflammatory bowel disease or radiation. Objects causing obstruction (such as gallstones or ingested foreign bodies) frequently become impacted within the terminal ilium, the narrowest point of the enteric tract.

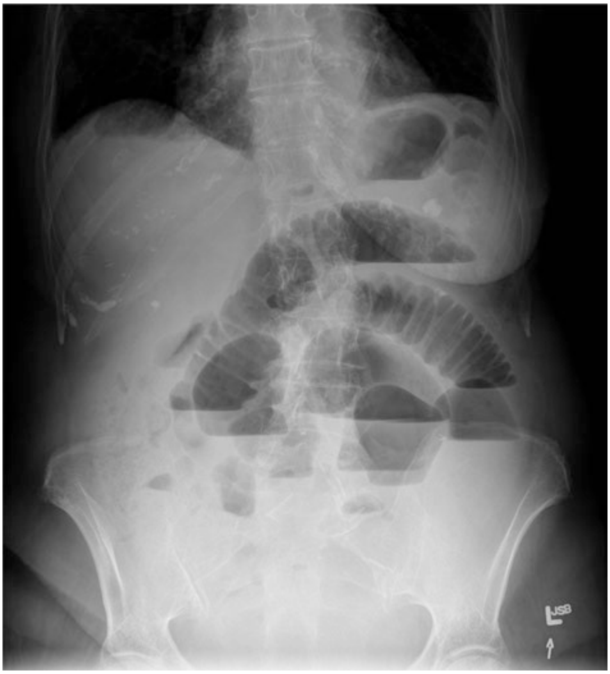


Fig. 5 Dilated loops of small bowel are identified within the central abdomen. On this erect radiograph, air-fluid levels are present within the dilated small bowel loops

Clinical features:

- Vomiting (as the gastrointestinal tract continuously secretes many litres of digestive fluids each day, which can only decompress proximally when obstructed distally).
- Abdominal distention.
- Abdominal pain.
- Increased bowel sounds.
- Reduction in passage of stool or flatus per rectum.

Key imaging appearances:

- Dilated loops of small bowel (measuring > 3 cm in diameter) throughout the abdomen. Small bowel loops are characterised by regular, fine folds (called valvulae coniventes) which fully encircle the bowel and differentiate them from large bowel. Small bowel loops are also smaller and tend to be located centrally within the abdomen, forming a ladder-like configuration when obstructed.
- Dilated small bowel loops are generally only seen when (at least some of) the bowel loops contain air, which provide contrast with the background fluid/soft-tissue density of the abdomen. Fluid-filled loops of small bowel are generally occult on radiographs, although well seen on CT.
- Dilated stomach can be present, however both vomiting or the placement of a gastric decompression tube can result in an empty stomach.
- Differential air-fluid levels, in which there are different heights of air-fluid interfaces in the same loop of bowel, may also aid in determining the presence of a mechanical obstruction.
- The cause of the obstruction may be visible on the radiograph, such as an inguinal hernia, a radiopaque gallstone or foreign body.
- Complications of obstruction (such as perforation, pneumatosis, etc.) may also be visible and should be closely searched for once small bowel obstruction has been diagnosed.

Large Bowel Obstruction

- Large bowel obstruction occurs when there is a blockage located anywhere between the caecum and the anus (Fig. 6). This is less common than small bowel obstruction. Causes include malignancy (classically from a stricturing colorectal cancer), volvulus and inflammatory strictures (such as from inflammatory bowel disease or chronic sigmoid diverticular disease).

Clinical features:

- Constipation or obstipation.
- Abdominal distention.

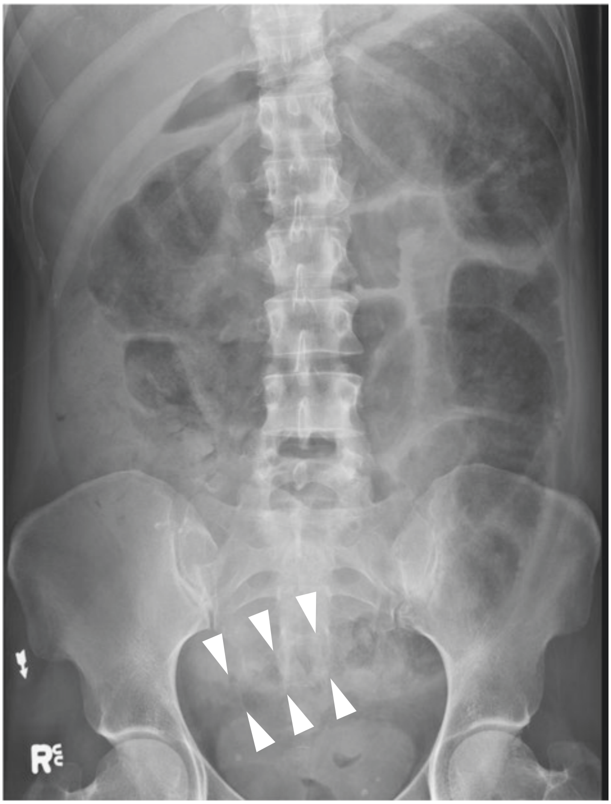


Fig. 6 The large bowel is dilated down to the level of the sigmoid colon, where there is a non-dilated segment is seen (*arrowheads*), distal to which the remaining sigmoid colon and rectum are decompressed. Mildly dilated loops of small bowel within the central abdomen are also noted. Subsequent CT confirmed an obstructing sigmoid tumour

- Abdominal pain.
- Large bowel obstruction can cause upstream dilatation of the small bowel (particularly in patients with an incompetent ileocaecal valve which permits the obstructed large bowel to decompress proximally). Thus, symptoms of large and small bowel obstruction often overlap.

Key imaging appearances:

- Large bowel is characterised by a wider diameter than small bowel, with folds (called haustra) which do not fully encircle the bowel. In addition, large bowel tends to be located at the peripheral margins of the abdominal cavity.
- Dilatation of the cecum beyond 9 cm, or the remaining large bowel beyond 6 cm is worrisome for obstruction.

- As dilatation occurs upstream from the level of the obstruction, the location of the dilated large bowel may hint at the level of obstruction.
- As with small bowel obstruction, the cause of large bowel obstruction and its complications may be visible on the abdominal radiograph, and should be carefully searched for.
- When large bowel dilatation occurs in the absence of a clear cause, it is known as pseudo-obstruction (Ogilvie syndrome) (Fig. 7).

Common Radiographically Characterisable Causes of Bowel Obstruction

Herniation:

- The presence of a bowel loop (either small or large) outside of the expected location of the abdominal cavity with co-existing bowel obstruction suggests

Fig. 7 Abdominal radiograph performed for abdominal distention in a nursing home resident. Dilated loops of large bowel are present. CT failed to identify a specific cause for obstruction, favouring a diagnosis of pseudo-obstruction

an obstructing hernia. Gas within a loop of bowel inferior to the inguinal ligament may suggests an inguinal or femoral hernia, collectively the commonest obstructing hernias.

Volvulus:

- The large bowel may twist on its mesentery, which can pinch off a loop of large bowel. This commonly occurs at the sigmoid (which can elongate and become mobile in the elderly, predisposing it to volvulus). This is also seen within the caecum, which can be hypermobile in predisposed individuals.
- The loop may untwist itself, or intervention may be required in the form of intubation (such as with a rectal tube) or surgery.
- The abdominal radiograph will typically demonstrate a dilated loop of large bowel, said to resemble a coffee bean, although this is often questionable. A dilated loop arising from the right lower quadrant favours a caecal volvulus, while a dilated loop arising from the left lower quadrant favours a sigmoid volvulus.

Perforation:

- Perforation of the gastrointestinal tract can lead to spillage of contents into the peritoneal cavity (if intraperitoneal) or retroperitoneum (if retroperitoneal), depending on the part of the bowel that perforates.
- In addition to air, spilled contents typically include fluid when arising from the stomach or small bowel, or feculent material from the colon.
- The presence of intra-abdominal air that does not conform to the shape of the gastrointestinal lumen suggests perforation (Fig. 8).
- As air is the least dense constituent of all abdominal components, it will rise. Erect radiographs can be used to detect even small amounts of air rising up under the diaphragm. A curvilinear lucent line beneath the undersurface of the diaphragm on erect abdominal or chest radiograph may be seen.

Colitis/Toxic Megacolon:

- Colitis is broad term describing diseases in which the colon is inflamed, and can be secondary to a variety of causes such as infection, inflammatory bowel disease, ischaemia and medications.
- On radiographs, this may be seen as thickening of the colon wall. The normally thin colon wall becomes thicker, and the normally thin haustral folds progress from fine lines to thicker indentations (likened to the width of the thumb, and thus referred to as "thumbprinting") (Fig. 9).

Gallstone Ileus:

- Air within the gallbladder suggests either gas forming bacteria within the gallbladder, or a communication between the gallbladder and bowel (in the absence of intervention).

Fig. 8 An abdominal radiograph demonstrates air under the right hemi-diaphragm, consistent with pneumoperitoneum. A positive Rigler sign is also noted, with both sides of the bowel wall exquisitely outlined by air (both intraluminal and extramural). Dilation of both the small and large bowel is also noted

- In chronic cholecystitis, fistulation between the gallbladder and the bowel can occur. Large gallstones, which would normally be prevented from passing into the GI tract by the narrow width of the cystic duct, can therefore pass through fistulae into bowel, causing obstruction (or gallstone ileus) (Fig. 10).
- The characteristic combination of small bowel obstruction, an ectopic gallstone, and air in the biliary tree (due to fistulation between the gallbladder and bowel) is known as Rigler's triad, and is detectable on abdominal radiography (Fig. 11).

Genitourinary Tract

- Non-contrast is considerably more sensitive for the detection of urinary tract calculi.
- Urinary calculi can be composed of a variety of material. Stones containing calcium (oxalate stones, struvite stones) are typically well seen on abdominal radiographs. Calculi composed of uric acid, cystine, indinavir or matrix stones can be invisible on abdominal radiograph.
- Calculi can occur at any level within the urinary tract, including the kidneys, ureters, bladder and urethra (Fig. 11).
- As with other hollow organs, air can be introduced into the urinary tract by instrumentation, by gas forming bacteria, or by infarction of the wall. Clinical correlation is instructive in such cases.

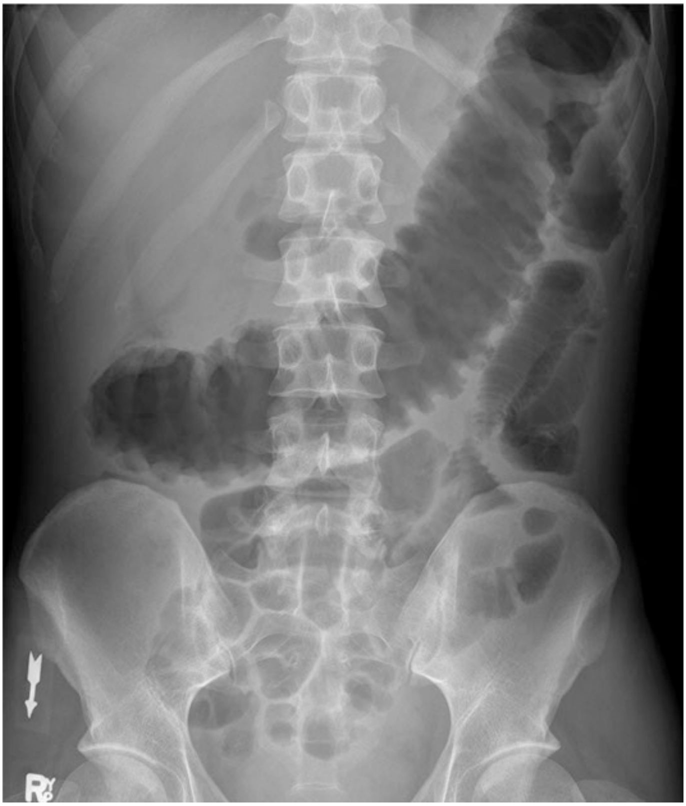


Fig. 9 The transverse colon is dilated in a patient with ulcerative colitis and toxic megacolon. The normally-thin haustral folds are now thickened, giving the appearance of thumbprints projecting from the bowel wall

Mimics of urinary tract calculi:

- Phleboliths:
  - Calcification within veins is a common occurrence, particularly within the pelvis.
  - These calcifications (referred to as phleboliths) are typically well-circumscribed and round, with a lucent centre. They are often symmetrical and bilateral.
- Stool in air-filled bowel:
  - Stool within bowel overlying the genitourinary tract can obscure urinary calculi disease. Additional views in various phases of respiration can be used in an effort to shift overlying bowel.

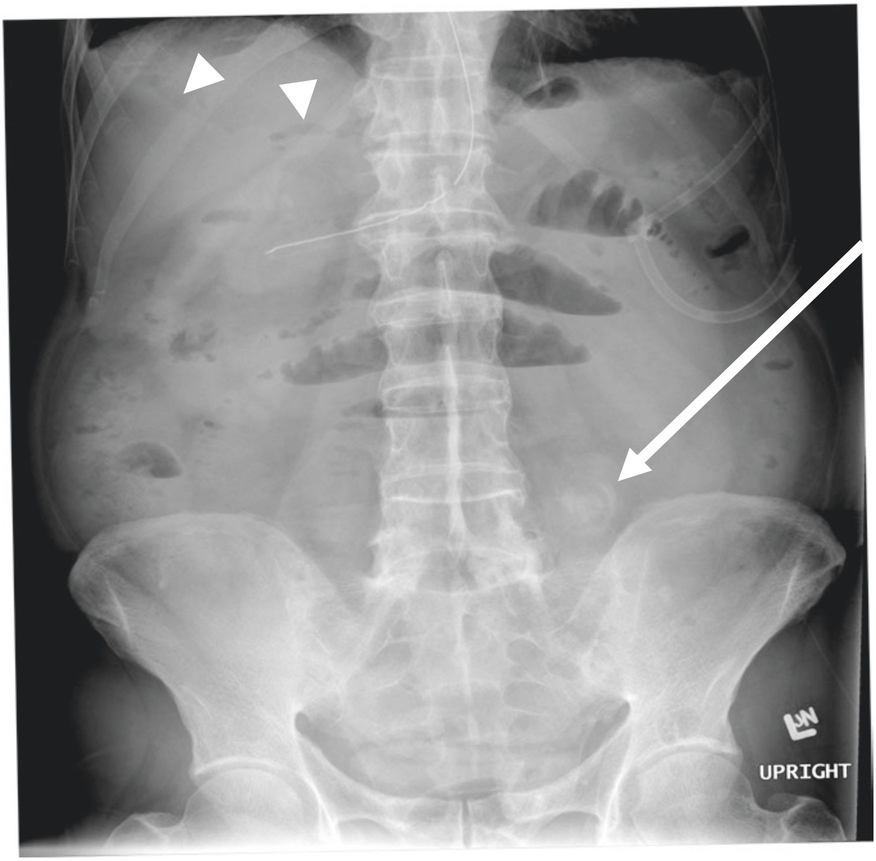


Fig. 10 A calcified gallstone is identified within the left central abdomen (*arrow*). Dilated loops of small bowel are present. Linear air-filled tubular structures within the right upper quadrant consistent with pneumobilia (*arrowheads*). This is consistent with Rigler's triad (gallstone ileus). A nasogastric tube has been inserted for gastric decompression

- Excreted contrast from recent IV contrast administration:
  - Renal excretion of iodinated contrast can appear dense within the urinary tract, and can mimic calculi. Typically this is bilateral and symmetrical, and there is a history of recent intravascular contrast administration.

Retroperitoneum

- Under normal circumstances, the retroperitoneum contains organs and structures separated by fat.

Fig. 11 Abdominal radiograph demonstrates a staghorn calculus within the left renal collecting system. No calculi are seen within the right kidney

- Where a retroperitoneal structure perforates, it may leak contents into the retroperitoneum. This may be seen with perforation of duodenum, ascending or descending colon, pancreas, biliary tree or urinary tract. Leaked content (such as air in the case of bowel perforation) tracks along tissue planes and may outline retroperitoneal structures such as the psoas muscles (Fig. 12).

Displacement of Structures

- The abdominal organs can enlarge secondary to a number of causes.
- Enlargement may be detectable by displacement of surrounding structures away from their expected location.
- Splenic enlargement (splenomegaly) enlarges from the left upper quadrant inferiorly and medially, and may displace bowel inferomedially (Fig. 13). This may be seen secondary to portal hypertension or any haemoglobinopathy.

Fig. 12 Abdominal radiograph performed in a patient with a remote history of cholecystectomy, presenting with acute upper abdominal pain. The right kidney and right psoas demonstrate a lucent outline, when compared with the left side. This is consistent with a right-sided pneumoretroperitoneum (secondary to a perforated duodenal ulcer)

- Liver enlargement (hepatomegaly) enlarges from the right upper quadrant inferiorly, and may displace bowel inferiorly and medially. This is commonly seen due to primary liver disease or metastases.
- A pelvic mass or distended bladder displaces bowel superiorly and peripherally.
- Large volume ascites will tend to centralise bowel loops as well as obscure liver and splenic margins.

Medical Hardware and Foreign Bodies

- A variety of medical devices are commonly encountered within the abdomen:
  - Peritoneal Dialysis Catheter
  - Endovascular Stents
  - Biliary Stents
  - Ureteric Stents, urethral catheters
  - Bowel Stents
  - Feeding Tubes (NG, gastrostomy, etc.)
  - Nerve Root Stimulators

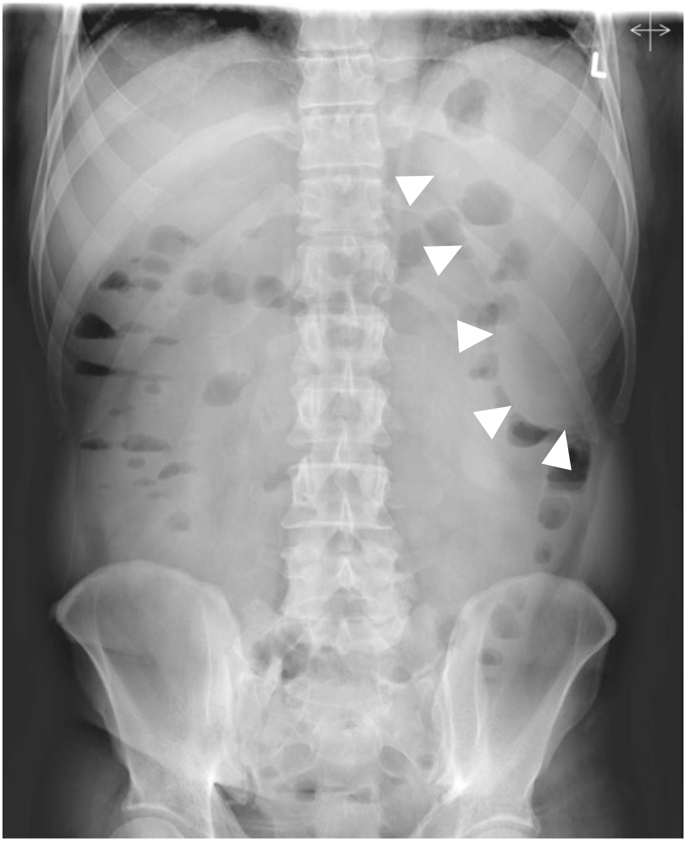


Fig. 13 Abdominal radiograph demonstrates a soft-tissue density structure extending from the left upper quadrant and displacing the colon inferomedially, consistent with splenomegaly

– Surgical Implements or Gauze
– Femoral lines
– IUD

Radiologist's tips

- When describing a medical device, first determine what is the nature of the device.
- Ensure that the device is intact, by assessing for any breakage or discontinuity along the line of a device.
- Ensure the device is within the expected position. Devices may migrate with time, particularly devices with the peristalsing gastrointestinal or urinary tract.
- Finally, assess if the device could be retained or lost to follow-up. Retained gauze, forgotten ureteric stents or IVC filters represent a significant cause of morbidity.

Vascular Calcification

- Blood vessels are of a similar density to fluid and soft-tissue, and are thus not directly visualised on abdominal radiographs.
- Calcific atherosclerotic disease may sufficiently calcify a vessel to allow radiographic assessment however.
- In addition to signifying increased systemic risk of cardiovascular disease, calcified vessel diameters can be assessed to permit the diagnosis of aneurysms.

Radiologist's tips:

A checklist to ensure all structures have been assessed is helpful in ensuring a thorough interpretation.

- Begin by clarifying patient gender, age, radiograph orientation and position.
- Air—Assess bowel gas pattern. Air should only be present within bowel loops, and any air outside of bowel merits close scrutiny. Unexpectedly-well demarcated tissue planes outlining structures such as the psoas muscles can be a sign of surrounding air.
- Fat—Assessment of fat planes may be helpful to localise pathology.
- Fluid/Soft Tissue Density—Loss of normally-seen tissue planes can indicate interposed fluid/soft-tissue, as can be seen with ascites. Displacement of structures away from their expected location can indicate mass effect, such as with organomegaly.
- Calcifications—All calcifications should all be explainable. Calcification of the costal cartilages, phleboliths, prostate and vascular calcification are all commonly encountered and of little acute clinical significance. Calcification over the genitourinary tract or gallbladder however may indicate stone disease.
- Surgical hardware/medical devices—Where surgical hardware or medical devices are present, their position and integrity should be assessed.

Suggested Reading

- James B, Kelly B. The abdominal radiograph. Ulster Med J. 2013;82 (3): 179.
- Jaffe T, Thompson WM. Large-bowel obstruction in the adult: classic radiographic and CT findings, aetiology, and mimics. Radiology. 2015;275(3):651–63.
- Wasnik AP, Maturen KE, Kaza RK, Al-Hawary MM, Francis IR. Primary and secondary disease of the peritoneum and mesentery: review of anatomy and imaging features. Abdom Imaging. 2015;40(3):626–42.

Tutorial 11: Radiological Approach to the Acute Abdomen

Caoilfhionn Ní Leidhin and Ian Brennan

Aims and Guidance for Tutors

The aim of this chapter is to familiarize students with the role of imaging in patients presenting with an "acute abdomen". It is important that students understand the various imaging modalities used in the assessment of patients with acute abdominal pain—the indications, advantages and disadvantages of each. They should also, on completion of this tutorial, be able to recognise the most commonly-encountered and most important acute abdominal pathologies on CT, US and plain radiography.

Introduction

- The "acute abdomen" is a term used to describe sudden-onset, severe abdominal pain, often with associated abdominal tenderness and rigidity.
- There are many causes of acute abdominal pain—from benign, self-limiting conditions that can be managed conservatively to life-threatening conditions, that require urgent intervention.
- History taking, physical examination and laboratory tests are important in establishing a differential diagnosis, however, imaging is often required for definitive diagnosis and to guide management.
- CT is the most important imaging modality in the work-up of patients with acute abdominal pain.

C. Ní Leidhin (✉)
Specialist Registrar in Radiology, Radiology Department,
ST. James's Hospital, Dublin, Ireland
e-mail: caoilfhionn.nileidhin@gmail.com

I. Brennan
Consultant Radiologist, Radiology Department, ST. James's Hospital, Dublin, Ireland
e-mail: ibRennan@stjames.ie

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_11

Radiological Modalities Utilised

Computed Tomography

- The most important imaging modality in the work-up of patients with acute abdominal pain.
- CT abdomen/pelvis takes seconds to perform, is accurate, and widely-available.
- CT involves exposure to ionizing radiation, thus alternative imaging should be considered in pregnant women, children.
- The CT protocol should be tailored to the suspected pathology.
- The standard CT abdomen/pelvis is acquired 70 seconds after intravenous (IV) injection of iodinated contrast material—so-called portal venous phase imaging.
- Caution should be taken with IV contrast in patients at risk of contrast-induced nephropathy.
- Iodinated contrast ingested orally is sometimes given in conjunction with IV contrast; by opacifying small bowel, oral contrast can help to differentiate fluid-filled bowel loops from fluid collections but it takes about 2 hours for oral contrast to reach the caecum, so this can delay treatment.
- Additional phases of imaging should be considered in selected patients.
- Non-contrast CT can detect renal/ureteric calculi and intramural haematoma in patients with ruptured abdominal aortic aneurysm/mesenteric ischaemia.
- Arterial phase imaging (triggered when IV contrast reaches the aorta at the level of the renal arteries) is useful in detecting active arterial bleeding and may identify arterial thromboembolism in mesenteric ischaemia.
- Delayed imaging (3 or 5 minute delay) is useful in identifying contrast pooling in patients with active bleeding.

Ultrasound

- First line in patients with suspected acute cholecystitis.
- As US does not involve exposure to ionizing radiation, it should be considered the initial imaging modality in women of childbearing age presenting with acute lower abdominal pain.
- It is safe for use in pregnant women and children.
- Reasonably fast, inexpensive, widely-available, dynamic, can be performed at the bedside in critically-ill patients.

Magnetic Resonance Imaging

- Excellent at detecting common bile duct stones, can also diagnose acute appendicitis, acute diverticulitis, acute cholecystitis, and acute pancreatitis.
- Does not involve exposure to ionizing radiation, thus useful in pregnant patients, especially when US inconclusive.

- However, MRI involves long scan times, is expensive, not readily available outside of standard working hours, some patients are unsuitable for MRI due to claustrophobia/contraindications to MRI, children often require sedation.

Conventional radiography

- Erect chest radiography may identify subdiaphragmatic free air in patients with hollow viscus perforation.
- Abdominal radiography should be limited to patients with suspected bowel obstruction and renal/ureteric calculi.
- Fast, cheap, widely-available, low radiation dose.
- Further imaging is often required.

Indications for Imaging

- History, physical examination and laboratory results determine which patients with acute abdominal pain require imaging and which do not.
- For example, young men with a classic presentation for acute appendicitis may go straight to theatre for appendicectomy, without the need for imaging.
- Similarly, haemodynamically-unstable patients with suspected abdominal aortic aneurysm rupture often go straight to theatre without any imaging, so that treatment is not delayed.
- However, in most patients with acute abdominal pain, some form of imaging is required in order to establish a definitive diagnosis and determine management.

Review of Relevant Anatomy: CT Abdomen/Pelvis

Figures 1, 2, 3, and 4.

Normal bowel diameter:

- Normal small bowel diameter is 2.5–3 cm.
- The colon measures up to 6 cm and the caecum up to 9 cm.

Arterial supply to the bowel:

- The coeliac artery supplies the foregut from the distal oesophagus to the second part of the duodenum.
- The superior mesenteric artery supplies the midgut from the second part of the duodenum to the junction between the middle and distal thirds of the transverse colon.

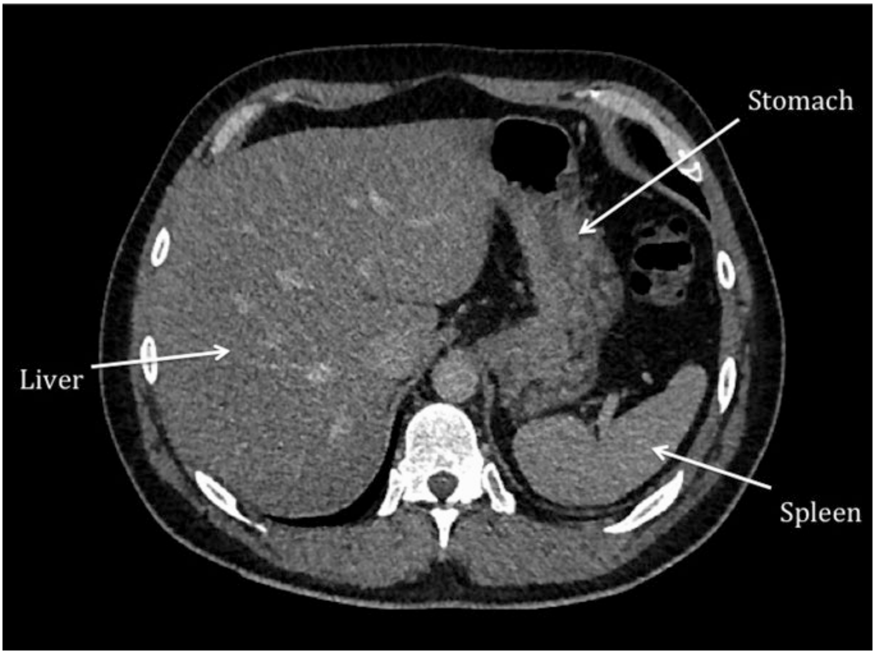


Fig. 1 Axial slice from contrast-enhanced CT abdomen/pelvis demonstrating normal anatomy

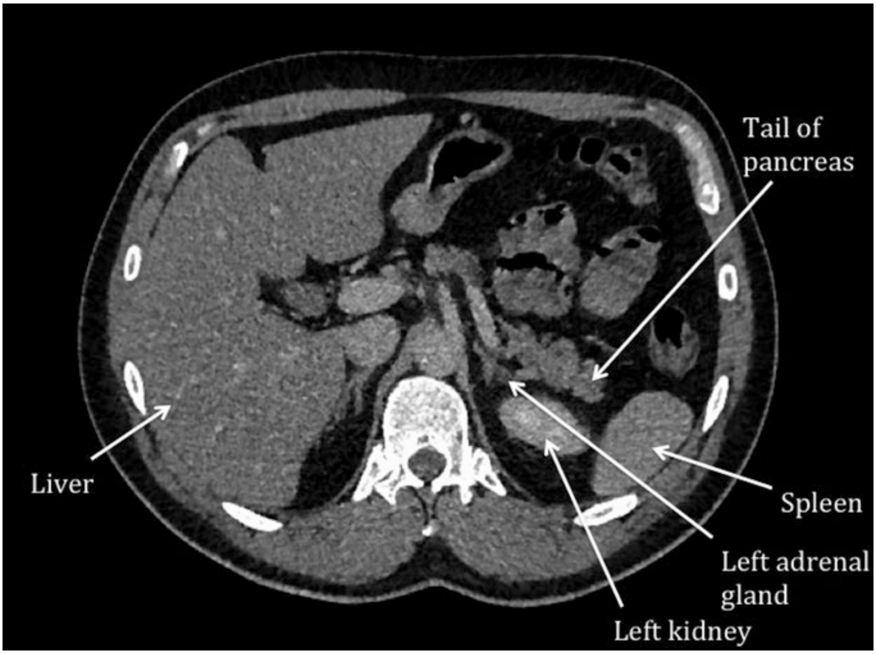


Fig. 2 Axial slice from contrast-enhanced CT abdomen/pelvis demonstrating normal anatomy

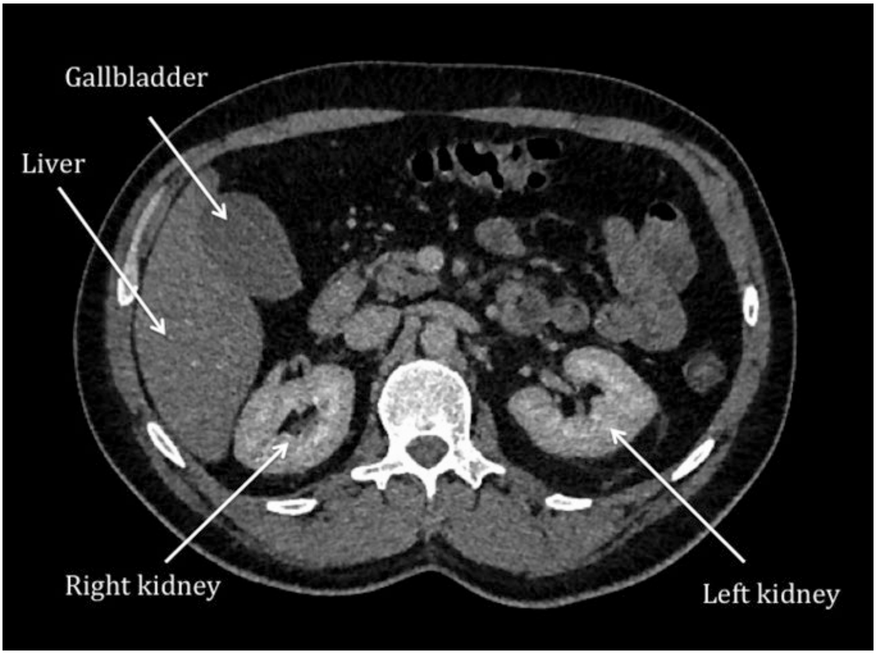


Fig. 3 Axial slice from contrast-enhanced CT abdomen/pelvis demonstrating normal anatomy

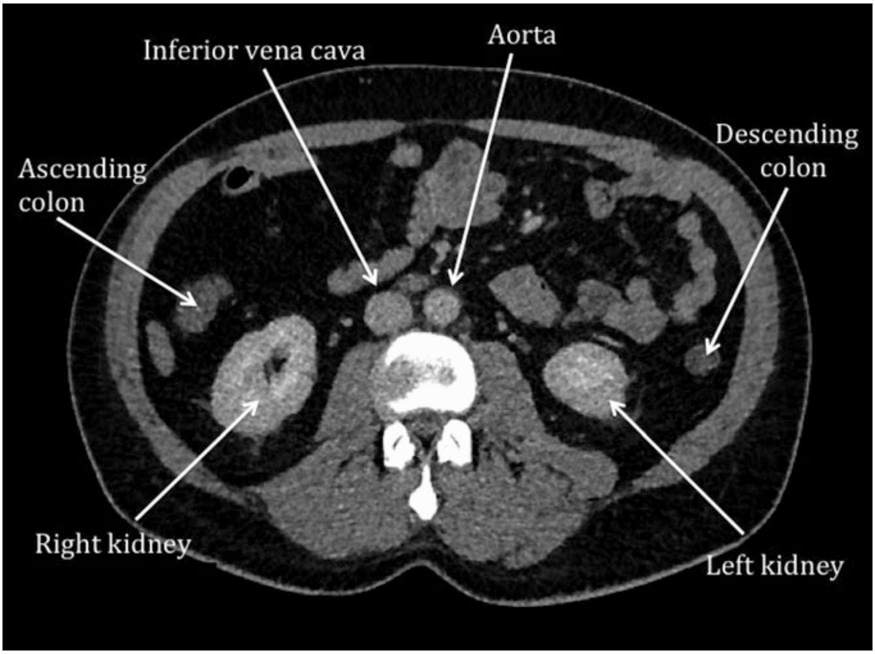


Fig. 4 Axial slice from contrast-enhanced CT abdomen/pelvis demonstrating normal anatomy

- The inferior mesenteric artery supplies the hindgut from the splenic flexure to the upper two-thirds of the rectum.

Differential Diagnosis for Acute Abdominal Pain

- There is a very broad differential diagnosis for acute abdominal pain.
- Some of the differential diagnoses, by quadrant, are listed below.
- Small and large bowel obstruction, bowel ischaemia and abdominal aortic aneurysm rupture typically present with *generalized* abdominal pain (Fig. 5).

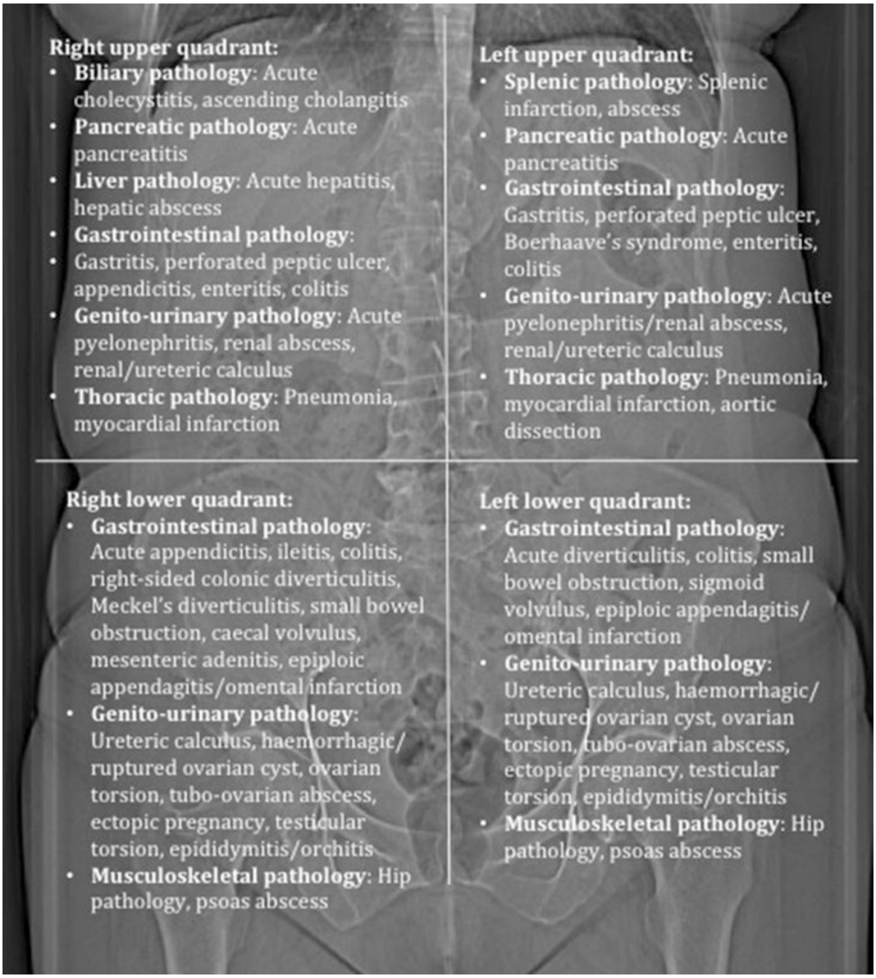


Fig. 5 Quadrant-based approach to differential diagnosis

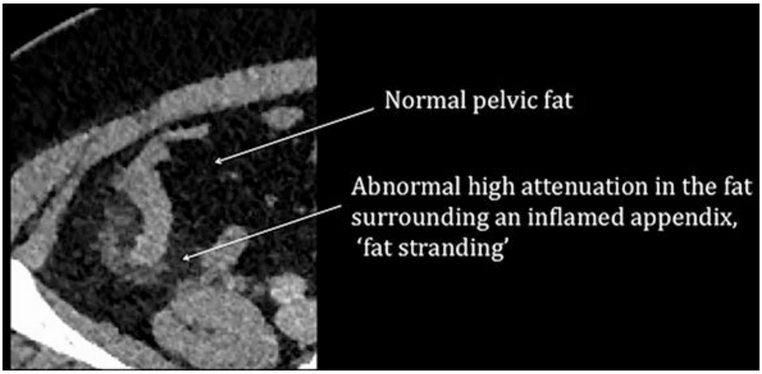


Fig. 6 Example of inflammatory fat stranding

Radiologist's tips: Fat stranding on CT

- Fat standing on CT refers to abnormal high attenuation within abdominal/pelvic fat due to oedema and engorged lymphatics
- It is a non-specific sign
- Commonly infectious and inflammatory conditions cause fat standing, however it can also be seen in the setting of malignancy and trauma

Acute Cholecystitis

- Obstruction of the cystic duct, typically by gallstones, leads to acute inflammation of the gallbladder.
- US is the imaging investigation of choice in patients with suspected acute cholecystitis.
- CT can also identify acute cholecystitis and its complications.
- Magnetic resonance cholangiopancreatography (MRCP) excels in detecting calculi in the cystic and common bile ducts.
- Cholecystectomy is the definitive treatment for patients with acute cholecystitis, however, US/CT-guided percutaneous drainage may be considered in patients with severe acute cholecystitis and sepsis/organ failure.

Clinical features:

- Classic presentation is of right upper quadrant pain, fever and raised white cell count (WCC).
- A distended gallbladder may be palpable.

- Positive Murphy's sign: Pain and inspiratory arrest on palpation of the right upper quadrant.

Key imaging appearances:

- US:
  - Gallstones—typically hyperechoic with posterior acoustic shadowing.
  - Thickened gallbladder wall >3 mm.
  - Pericholecystic fluid.
  - Distended, non-compressible gallbladder.
  - Positive sonographic Murphy's sign—pain on inspiration when US probe placed over gallbladder (Fig. 7).
- CT:
  - Findings as on US.
  - In addition, mucosal hyperenhancement and pericholecystic inflammatory fat stranding can be seen.
  - Superior to US in detecting complications of acute cholecystitis, i.e. perforation, abscess formation (Fig. 8).

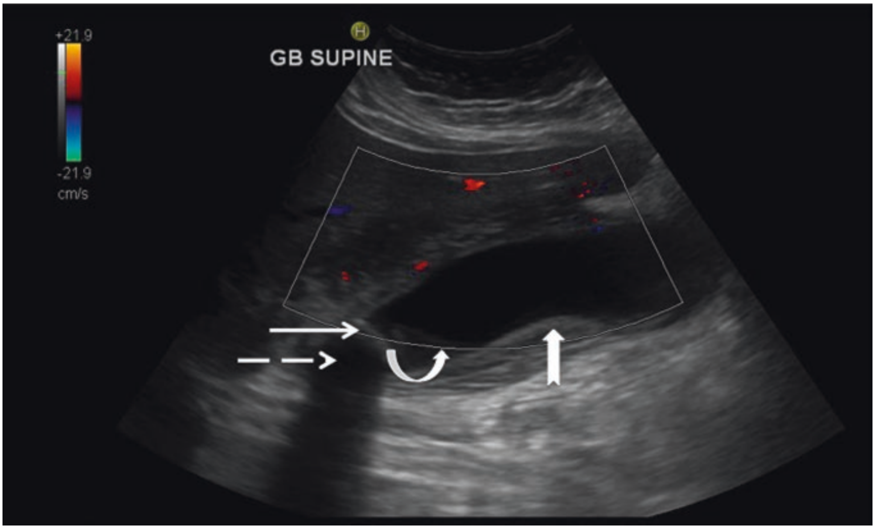


Fig. 7 A 54-year-old woman with known gallstones presents with right upper quadrant pain, tenderness and raised inflammatory markers. Ultrasound demonstrates a distended gallbladder full of hypoechoic bile, a hyperechoic calculus (solid arrow) with posterior acoustic shadowing (dashed arrow), sludge (curved arrow) and a thickened gallbladder wall (notched arrow). Findings are in keeping with acute cholecystitis. The patient was sonographically Murphy's positive

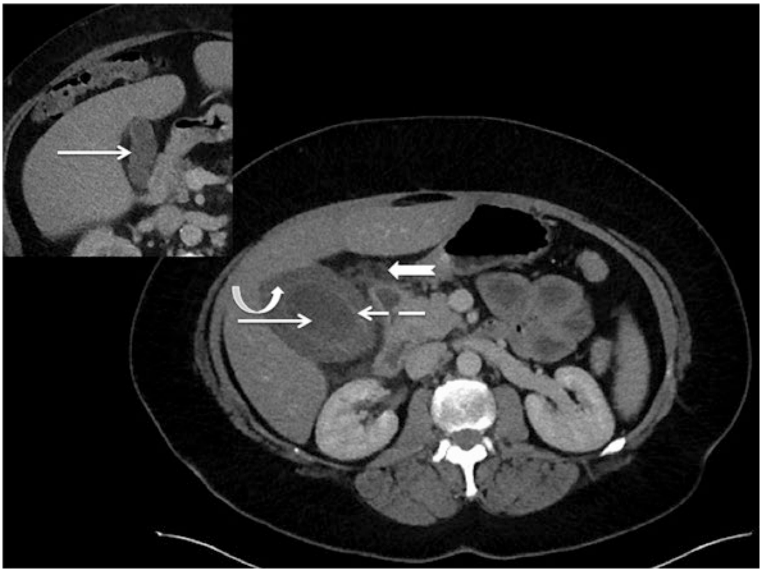


Fig. 8 A 76-year-old woman with a history of dementia presents with generalized abdominal pain, pyrexia and raised inflammatory markers. Axial contrast-enhanced CT abdomen demonstrates a distended gallbladder (solid arrow), which is of low attenuation due to fluid but which demonstrates a high attenuation/enhancing wall (dashed arrow). There is large volume low attenuation pericholecystic fluid (curved arrow) and high attenuation inflammatory fat stranding (notched arrow). Findings are in keeping with acute cholecystitis. (Inset: See normal gallbladder (solid arrow) for comparison). The patient underwent emergency percutaneous (US-guided) cholecystostomy due to severe sepsis

- MRCP:
  - Cystic/common bile duct calculi are seen as low signal filling defects within the biliary tree on heavily T2-weighted sequences (Fig. 9).

Acute Pancreatitis

- Acute inflammation of the pancreas, most commonly due to alcohol and gallstones.
- Acute pancreatitis ranges from a mild, self-limiting condition (80–90%) to a severe condition with multiorgan failure and a mortality of up to 25%.
- A diagnosis of acute pancreatitis is usually made on the basis of clinical and laboratory findings alone, without the need for imaging.
- However, CT is important in assessing disease severity in patients with severe acute pancreatitis and in identifying complications.

Fig. 9 A 63-year-old man with gallstone pancreatitis and deranged liver function tests undergoes MRCP to evaluate for common bile duct stones. Coronal MRCP demonstrates a dilated common bile duct (solid arrow), which contains a low signal filling defect distally (dashed arrow), in keeping with an obstructive calculus

Clinical features:

- Severe epigastric pain, radiating through to the back, relieved by sitting up and leaning forward.
- Nausea, vomiting.
- Epigastric/generalized abdominal tenderness, guarding, rigidity.
- Raised WCC, lipase, amylase.

Key imaging appearances:

- CT:
  - Focal or diffuse pancreatic enlargement.
  - Indistinct pancreatic margins.
  - Free fluid and inflammatory fat stranding in the peripancreatic/retroperitoneal tissues.
  - Heterogenous enhancement of the pancreatic parenchyma due to oedema, which can progress to lack of enhancement with pancreatic necrosis.
  - Pancreatic or peripancreatic fluid/necrotic collections, which may be sterile or infected.

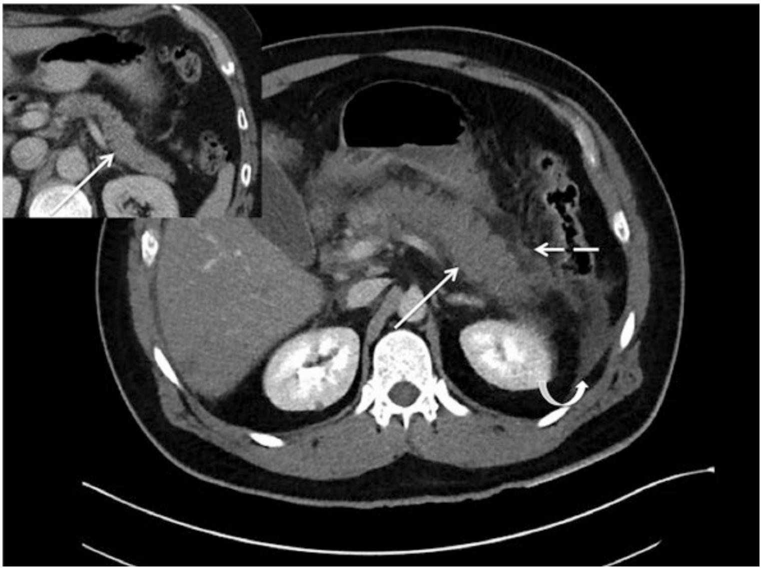


Fig. 10 A 55-year-old man presents with upper abdominal pain. Axial contrast-enhanced CT abdomen demonstrates an enlarged, oedematous pancreas (solid arrow) with surrounding inflammatory fat stranding (dashed arrow) and small volume upper abdominal free fluid (curved arrow). Findings are in keeping with acute uncomplicated pancreatitis. (Inset: See normal pancreas (solid arrow) for comparison)

  - Pancreatic calcification indicates chronic inflammation (Figs. 10 and 11).
- US:
  - Identifies gallstones as a cause of pancreatitis.

Acute Appendicitis

- Acute inflammation of the appendix typically occurs due to obstruction of the appendiceal lumen by a faecolith/lymphoid hyperplasia.
- If appendicitis goes unrecognised, there is a risk of perforation and increased mortality, so timely diagnosis is crucial.
- Treatment is with appendicectomy, however select patients with uncomplicated appendicitis may be managed conservatively with IV antibiotics.

Clinical features:

- Periumbilical abdominal pain due to inflammation of visceral peritoneum, localizing to the right lower quadrant (RLQ) due to inflammation of parietal peritoneum.
- Nausea, vomiting.

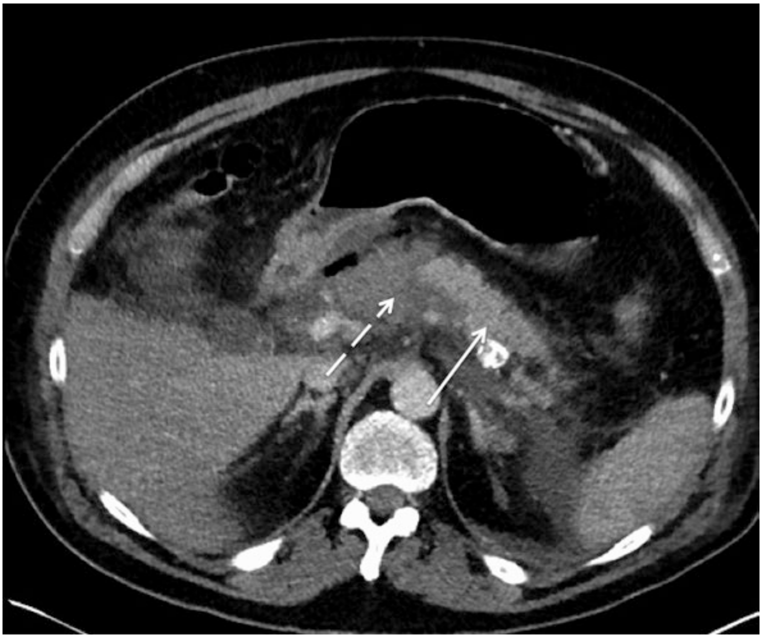


Fig. 11 A 57-year-old man with known pancreatitis undergoes CT abdomen due to persistently raised inflammatory markers. Axial contrast-enhanced CT demonstrates normal enhancement (high attenuation) of the distal pancreatic body and tail (solid arrow) but lack of enhancement (low attenuation) in the pancreatic head and proximal body (dashed arrow), in keeping with pancreatic necrosis

- Fever.
- Abdominal tenderness—maximal over McBurney's point, guarding, rigidity.
- Raised inflammatory markers.

Key imaging appearances:

- CT:
  - Dilated, fluid-filled appendix, >6 mm.
  - Thickened, enhancing appendiceal wall.
  - Appendicolith.
  - Periappendiceal free fluid and inflammatory fat stranding.
  - Inflammatory phlegmon, abscess (Figs. 12 and 13).
- US:
  - Non-compressible, blind-ending tubular structure in the RLQ with surrounding fluid.
- MRI:
  - Thickened appendix.
  - Increased signal intensity.
  - Infiltration of surrounding fat.

Fig. 12 A 44-year-old man presents with right iliac fossa pain and raised inflammatory markers. Axial contrast-enhanced CT abdomen/pelvis demonstrates a dilated, fluid-filled appendix (solid arrow) with surrounding inflammatory fat stranding (dashed arrow), in keeping with acute uncomplicated appendicitis. (Inset: See normal appendix (solid arrow) for comparison)

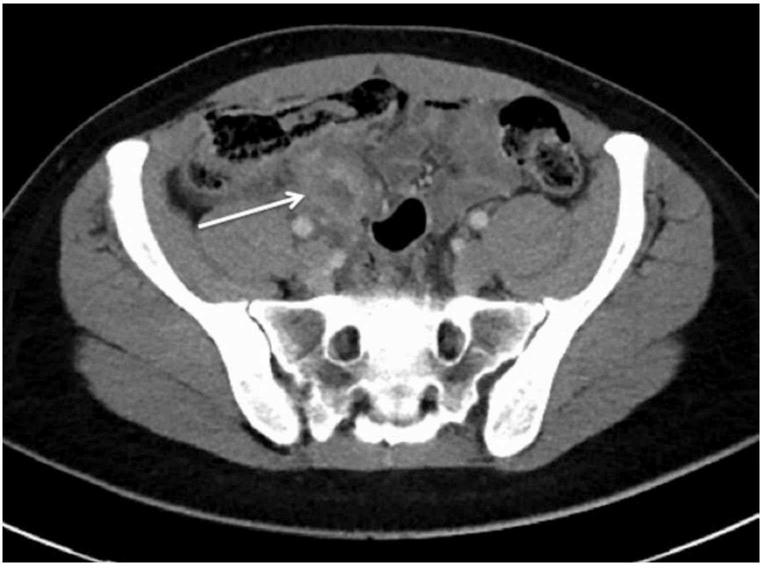


Fig. 13 A 23-year-old man presents with a four-day history of right iliac fossa pain and is tender and guarding on examination. Axial contrast-enhanced CT abdomen/pelvis demonstrates an inflammatory soft tissue mass in the right iliac fossa, in keeping with acute appendicitis with phlegmon formation

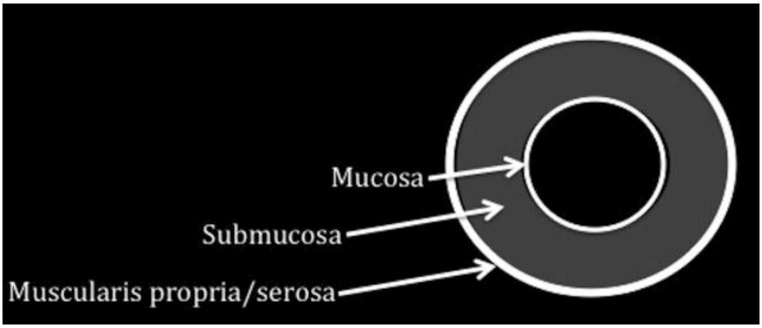


Fig. 14 Schematic illustration of bowel wall 'target sign'

Radiologist's tips: The bowel wall 'target sign' on CT

- The 'target sign' may be seen on contrast-enhanced CT
- It describes a thickened bowel wall with 3 distinct layers—an inner high attenuation layer of enhancing mucosa, a middle low attenuation layer due to oedema in the submucosa and an outer high attenuation layer due to enhancing muscularis propria/serosa
- It is a non-specific sign
- It can be seen in ischaemic bowel, acute inflammatory bowel disease and infectious colitis (including pseudomembranous colitis)

Acute Enteritis/Ileitis

- Acute inflammation of the small bowel can occur due to a variety of causes: infection (bacterial, protozoal or viral), inflammation (Crohn's disease, chemotherapy or radiotherapy), ischaemia.
- Differentiating between these conditions is important as they are managed differently.
- While stool cultures and endoscopic biopsies are often required, CT can help in identifying the most likely diagnosis due to the distribution of bowel involvement.

Clinical features:

- Abdominal pain.
- Diarrhoea.
- Nausea, vomiting.

- Abdominal tenderness.
- Elevated inflammatory markers.

Key imaging appearances:

- CT:
  - Thickening of the small bowel wall.
  - Bowel wall thickening is segmental in Crohn's disease but typically involves the terminal ileum.
  - 'Mesenteric comb sign' in Crohn's disease is due to increased blood flow in the mesenteric vessels.
  - Lymphadenopathy (Fig. 15).

Acute Colitis

- As with enteritis, acute inflammation of the large bowel can occur due to infection, inflammation or ischaemia.
- Patients with acute colitis do not always require imaging, however it is useful in confirming the diagnosis and in detecting complications.
- Clostridium difficile is an important cause of infectious pancolitis (inflammation involving all of the large bowel), as it can result in toxic megacolon and colonic perforation.

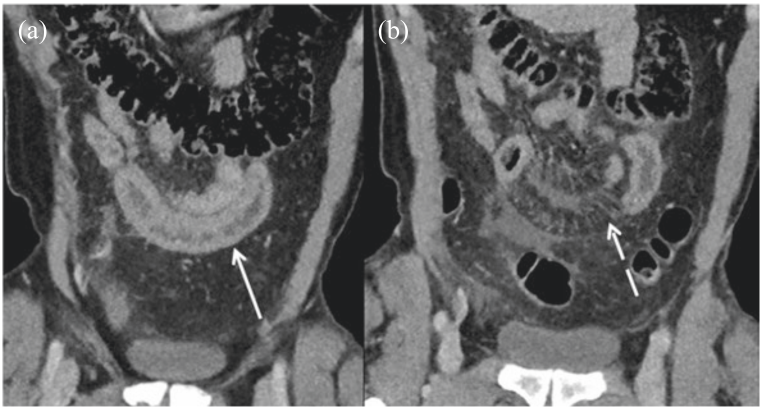


Fig. 15 A 20 year old man with known Crohn's disease presents with increased frequency of bowel motions, blood and mucous per rectum, pyrexia, tachycardia and raised CRP. Coronal contrast-enhanced CT abdomen/pelvis demonstrates wall thickening in the terminal ileum (image A-solid arrow) and the 'mesenteric comb sign' (image B-dashed arrow). Findings are consistent with active inflammation

Clinical features:

- Abdominal pain.
- Diarrhoea, often bloody.
- Nausea, vomiting.
- Fever.
- Abdominal tenderness.
- Elevated inflammatory markers.

Key imaging appearances:

- CT:
  - Thickening of the large bowel wall.
  - Enhancement of bowel wall mucosa with submucosal oedema—see 'target sign' above.
  - Bowel wall thickening is continuous in ulcerative colitis, it always involves the rectum and a variable amount of colon.
  - Ischaemic colitis follows a vascular distribution and occurs at "watershed" areas.
  - The 'accordion sign' is quite specific for clostridium difficile infection; it refers to oral contrast interposed between thickened haustral folds.

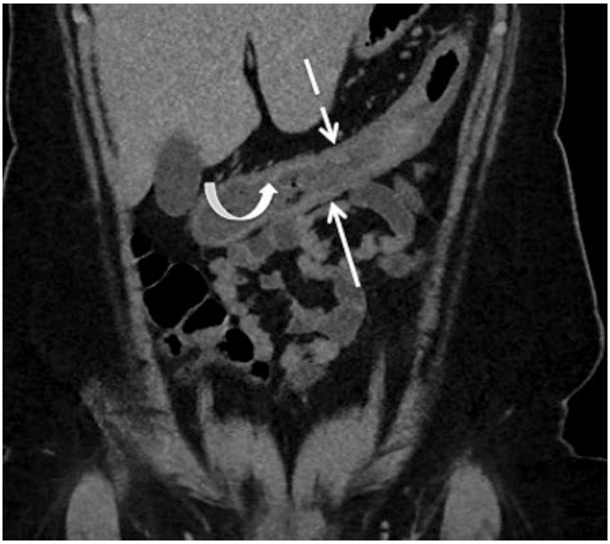


Fig. 16 A 43-year-old man presents with abdominal pain, diarrhoea and raised inflammatory markers. Coronal contrast-enhanced CT abdomen/pelvis demonstrates thickening of the wall (solid arrow) and haustra (dashed arrow) of the transverse colon with mucosal high attenuation/hyperenhancement (curved arrow). Findings are in keeping with acute colitis

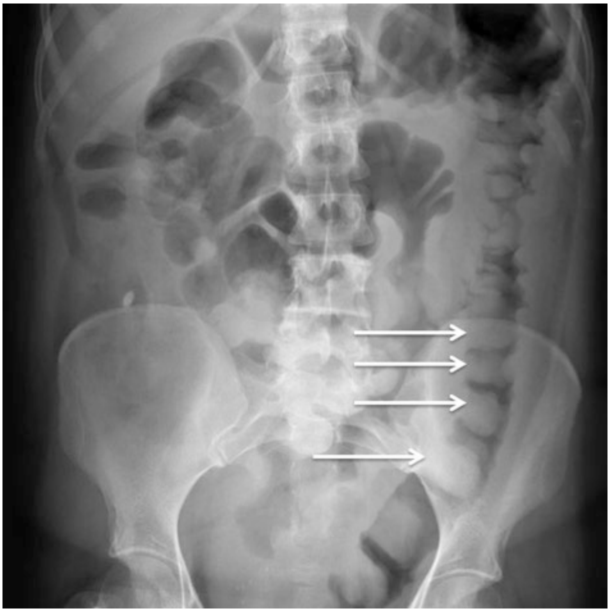


Fig. 17 Abdominal radiograph demonstrating 'thumbprinting'/thumb-like indentations in the large bowel (solid arrows) due to haustral oedema in a patient with acute colitis

  - Toxic megacolon (usually secondary to pseudomembranous colitis/ulcerative colitis) manifests as dilated large bowel with wall thinning and loss of haustral markings (Fig. 16).

- Abdominal radiography:
  - Thumb-like indentations in the large bowel wall due to haustral oedema, 'thumbprinting' (Fig. 17).

Acute Diverticulitis

- Diverticula are outpouchings of mucosa and submucosa at weak spots in the bowel wall, where blood vessels and nerves pierce the muscularis.
- Diverticulosis most commonly occurs in the descending/sigmoid colon.
- If one or more diverticula become obstructed, inflammation, infection and perforation can result.
- CT is useful in confirming the diagnosis and in staging the disease.
- Uncomplicated diverticulitis can often be managed conservatively with antibiotics and diet modification.
- Diverticulitis with perforation and abscess formation often requires percutaneous drainage (US/CT-guided).
- Surgery is reserved for those who fail conservative management.

Clinical features:

- Abdominal pain, typically in the left lower quadrant (LLQ).
- Altered bowel habit.
- Nausea, vomiting.
- Low-grade fever.
- Tenderness, guarding, rigidity and/or a palpable mass in the LLQ.
- Raised inflammatory markers.

Key imaging appearances:

- CT:
  - Diverticulosis.
  - Wall thickening in the affected colon.
  - Significant surrounding inflammatory fat stranding—more than would be expected for the degree of colonic wall thickening.
  - Fascial thickening.
  - Accumulation of fluid in the root of the sigmoid mesentery gives rise to the 'comma sign'.
  - Engorged mesenteric vessels result in the 'centipede sign'.
  - Important in detecting complications, i.e. perforation, abscess formation, fistulae etc. (Fig. 18).

Radiologist's tips: Small versus large bowel obstruction on xray

- **Small bowel obstruction**:
  - Dilated, central small bowel loops (>3 cm)
  - Valvulae conniventes traverse the bowel lumen
- **Large bowel obstruction:**
  - Dilated, peripheral large bowel loops (>6 cm/>9 cm for caecum)
  - Haustra partially cross the bowel lumen

Small Bowel Obstruction

- Small bowel obstruction (SBO) refers to mechanical blockage of the small bowel lumen.
- It is far more common that large bowel obstruction.
- Post-operative adhesions are the most common cause of SBO, followed by hernia(e).

Fig. 18 A 64-year-old woman presents with left iliac fossa pain and raised inflammatory markers. Axial contrast-enhanced CT abdomen/pelvis demonstrates diverticula (solid arrow), with wall thickening in the sigmoid colon (dashed arrow), marked pericolonic inflammatory fat stranding (curved arrow) and fascial thickening (notched arrow), in keeping with acute uncomplicated diverticulitis

- Low-grade/partial/incomplete small bowel obstruction can usually be managed conservatively with a “drip and suck” technique (patient kept nil by mouth, nasogastric tube inserted, IV fluids commenced).
- In patients with high-grade/complete small bowel obstruction, surgery is often required due to the risk of bowel ischaemia.
- CT is useful in establishing the site, cause and severity of the obstruction and in detecting complications like ischaemia.

Clinical features:

- History of prior abdominal surgery.
- Crampy abdominal pain.
- Abdominal distension.
- Nausea, vomiting.
- Absolute constipation.
- High-pitched bowel sounds.
- Hernia on clinical exam.

Key imaging appearances:

- CT:
  - Dilated, fluid-filled small bowel loops proximal and collapsed small bowel loops distal to the point of obstruction—the so-called ‘transition point’.
  - Faeces-like material in distended small bowel loops proximal to the transition point—the ‘small bowel faeces sign’.
  - Small air locules can become trapped between valvulae conniventes, giving rise to the ‘string-of-pearls sign’ (may also be seen on abdominal x-ray).
  - Adhesions are invisible on CT.
  - In closed-loop SBO, the small bowel is obstructed at two points, usually due to an internal hernia; closed-loop obstruction is associated with a higher risk of ischaemia and requires urgent surgery (Fig. 19).
- Abdominal radiography:
  - Please refer to Tutorial 10: The Abdominal Radiograph.

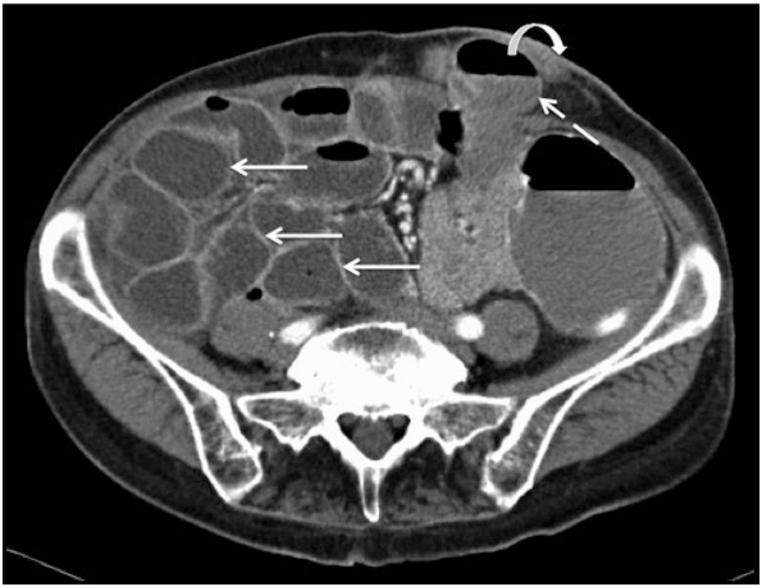


Fig. 19 A 66-year-old woman with a prior colectomy for colorectal cancer presents with severe abdominal pain, vomiting, no output from her stoma and an irreducible parastomal hernia on exam. Axial contrast-enhanced CT abdomen/pelvis demonstrates dilated, fluid-filled small bowel loops (solid arrows). There is a point of transition from dilated proximal small bowel loops to collapsed distal small bowel loops at the level of a parastomal hernia in the left iliac fossa. Note the dilated small bowel loop in the left anterior abdominal wall (dashed arrow) adjacent to the stoma, which communicates with the skin (curved arrow)

Large Bowel Obstruction

- Large bowel obstruction (LBO) refers to mechanical blockage of the large bowel lumen.
- It is far less common than small bowel obstruction.
- It is most commonly caused by colorectal cancer, followed by sigmoid volvulus and diverticular disease.
- Sigmoid/caecal volvulus cause closed-loop obstruction.
- As with SBO, CT is useful in identifying the level and cause of obstruction and the presence of complications.

Clinical features:

- Crampy abdominal pain.
- Abdominal distension.
- Nausea, vomiting.
- Absolute constipation.
- High-pitched bowel sounds.

Key imaging appearances:

- CT:
  - Dilated large bowel loops proximal and collapsed large bowel loops distal to the point of obstruction—the so-called ‘transition point’.
  - The proximal colon is filled with faeces, air and fluid.
  - If the ileocaecal valve is competent, the small bowel will not be dilated, however if the ileocaecal valve is incompetent, both the small and large bowel will be dilated (Fig. 20).
- Abdominal radiography:
  - Please refer to Tutorial 10: The Abdominal Radiograph.

Gastrointestinal Perforation

- There are innumerable (non-traumatic) causes of gastrointestinal perforation, the most common of which are perforated peptic ulcer disease and diverticulitis.
- Often patients with gastrointestinal perforation require urgent surgery.
- CT (+/− erect chest/abdominal x-ray) will demonstrate free intra-abdominal air (pneumoperitoneum).
- CT often demonstrates the site and cause of the perforation.
- However, CT may not be performed if it will delay emergency surgery.

Fig. 20 A 79-year-old woman presents with abdominal pain and constipation. Coronal contrast-enhanced CT abdomen/pelvis demonstrates dilated proximal sigmoid colon (solid arrow), with an abrupt transition to collapsed distal sigmoid colon (dashed arrow) at the point of volvulus

Clinical features:

- Sudden-onset, severe, constant upper abdominal pain.
- Anorexia, nausea, vomiting.
- Patient may lie completely still.
- Abdominal tenderness, involuntary guarding, rigidity.
- Haemodynamic instability—tachycardia/hypotension.

Key imaging appearances:

- CT:
  - Can detect small amounts of free intraperitoneal air.
  - Free air, free fluid and inflammatory fat stranding is usually maximal adjacent to the site of hollow viscus perforation.
  - May demonstrate the site of perforation as a focal defect in the stomach/bowel wall.
  - There may be bowel wall thickening at the site of perforation (Fig. 21).

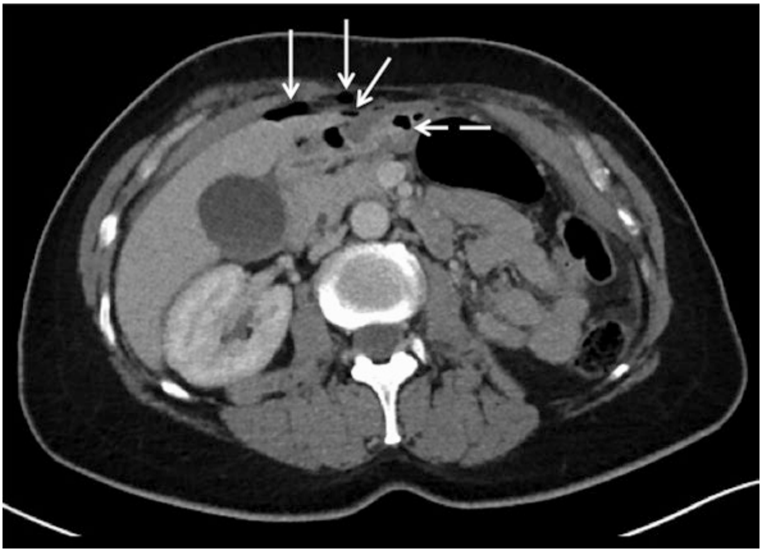


Fig. 21 A 55-year-old woman presents with sudden-onset upper abdominal pain, peritonism and subdiaphragmatic free air on chest radiograph. Axial contrast-enhanced CT abdomen/pelvis demonstrates locules of free air (solid arrows) in the upper abdomen, adjacent to the liver and the distal stomach (dashed arrow), suggestive of gastroduodenal perforation

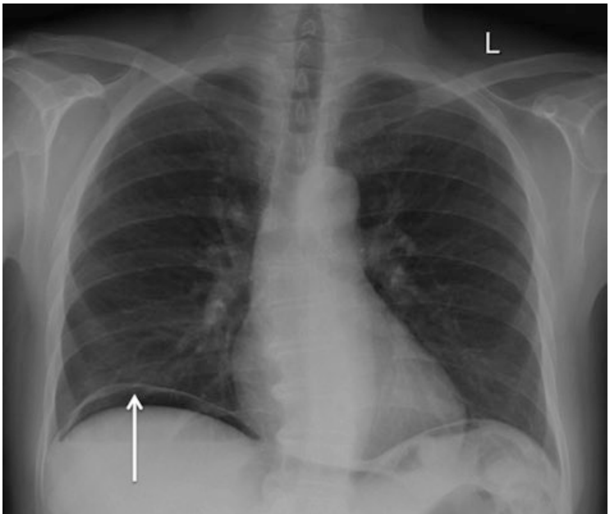


Fig. 22 Erect chest radiograph demonstrates free intra-abdominal air as a lucent crescent beneath the right hemidiaphragm (solid arrow)

- Erect chest radiography:
  - Free intra-abdominal air is seen as a lucent crescent below the diaphragm (Fig. 22).

Bowel Ischaemia

- Bowel ischaemia is a life-threatening cause of acute abdominal pain with a mortality of approximately 70%.
- Acute mesenteric ischaemia occurs because of decreased blood flow to the bowel either due to acute arterial or venous occlusion or systemic hypoperfusion.
- CT can identify the cause, location, extent and severity of bowel ischaemia.
- Often, non-contrast, arterial and portal venous phase imaging is performed when bowel ischaemia is suspected.
- Differentiating between arterial and venous bowel ischaemia is important as arterial bowel ischaemia typically requires urgent surgery/radiological intervention, whereas venous bowel ischaemia can often be managed conservatively with anticoagulation.

Clinical features:

- History of cardiovascular disease (i.e. atrial fibrillation, atherosclerosis), prior embolic event or risk factors for same, intra-abdominal infection/inflammation/neoplasm.
- Sudden-onset, severe, generalized abdominal pain, classically disproportionate to clinical findings.
- Vomiting, diarrhoea (sometimes bloody).
- As bowel ischaemia progresses to infarction, abdominal distension occurs, peritoneal signs develop and bowel sounds disappear.
- Elevated lactate.

Key imaging appearances:

- CT:
  - Filling defect in the lumen of a mesenteric artery on the angiographic phase study indicates thromboembolism.
  - Filling defect in the lumen of a mesenteric vein on portal venous phase imaging indicates thrombosis.
  - Abnormal bowel wall thickness—the bowel wall is often thickened due to oedema, haemorrhage or superimposed infection, however, in occlusive

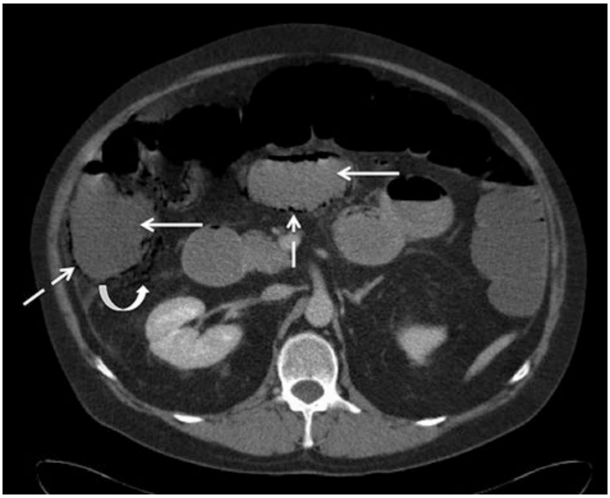


Fig. 23 A 63-year-old man presents with severe generalized abdominal pain. Contrast-enhanced (portal venous phase) CT abdomen/pelvis demonstrates fluid-filled small and large bowel (solid arrows) with air lying dependently in the small and large bowel wall—pneumatosis intestinalis/coli (dashed arrows) and in pericolonic veins (curved arrow). CT also showed an occlusion of the superior mesenteric artery (not shown)

arterial mesenteric ischaemia/infarction, the bowel wall may become 'paper-thin'.
- Abnormal bowel wall enhancement—there may be bowel wall hyperenhancement due to hyperperfusion (see 'target sign' above) or decreased/absent bowel wall enhancement in the setting of arterial occlusion without reperfusion/infarction.
- Dilated, fluid-filled bowel.
- Pneumatosis intestinalis/coli—air within the small or large bowel wall indicates transmural infarction.
- Pneumatosis portalis—air in mesenteric/portal veins, may extend to the periphery of the liver (Fig. 23).

Urinary Tract Calculi

- Calculi, most often composed of calcium, can collect in the renal collecting system/ureter(s).
- If obstructing, calculi result in hydronephrosis and hydroureter with distension of the renal collecting system/uretar proximal to the calculus.

Fig. 24 An 86-year-old man presents with right flank pain and sepsis. Non-contrast CT (KUB) demonstrates an obstructing high attenuation calculus in the proximal right ureter (solid arrow). A further non-obstructing calculus is noted in the lower pole of the right kidney (notched arrow). The patient underwent emergency percutaneous (US-guided) nephrostomy due to urosepsis

- Non-contrast CT (KUB) is the imaging modality of choice for suspected renal/ureteric calculi.
- Small calculi typically pass spontaneously.
- Percutaneous nephrostomy may be required in patients with urosepsis secondary to an obstructing renal/ureteric calculus.

Clinical features:

- Severe, colicky flank/loin-to-groin pain.
- Patient can't lie still.
- Haematuria.

Key imaging appearances:

- CT:
  - Detects and can accurately measure the size of renal and urinary tract calculi.
  - Hydronephrosis/Hydroureter.
  - Perinephric/Periureteric inflammatory fat stranding.

- US:
  - Variable accuracy in detecting and measuring calculi.
  - Detects hydronephrosis but ureter poorly visualised (Fig. 24).

Suggested Reading

- Paolantonio P, Rengo M, Ferrari R, et al. Multidetector CT in emergency radiology: acute and generalized non-traumatic abdominal pain. Br J Radiol. 2016;89(1061):20150859.
- Stoker J, van Randen A, Laméris W, et al. Imaging patients with acute abdominal pain. Radiology. 2009;253(1):31–46.
- Murphy KP, Twomey M, McLaughlin PD, et al. Imaging of ischemia, obstruction and infection in the abdomen. Radiol Clin North Am. 2015;53(4):847–69, ix–x.
- Mattson B, Dulaimy K. The 4 quadrants: acute pathology in the abdomen and current imaging guidelines. Semin Ultrasound CT MR. 2017;38(4):414–23.
- Childers BC, Cater SW, Horton KM, et al. CT evaluation of acute enteritis and colitis: is it infectious, inflammatory, or ischemic? Resident and fellow education feature. Radiographics. 2015;35(7):1940–1.
- Uyeda JW, Gans BS, Sodickson A. Imaging of acute and emergent genitourinary conditions: what the radiologist needs to know. AJR Am J Roentgenol. 2015;204(6):W631–9.
- Pereira JM, Sirlin CB, Pinto PS, et al. Disproportionate fat stranding: a helpful CT sign in patients with acute abdominal pain. Radiographics. 2004;24(3):703–15.

Tutorial 12: Radiological Investigation of Common Malignancies

Brian Gibney, Michael Conroy and Helen Fenlon

Aims and Guidance for Tutors

Radiological investigations are central to cancer screening, diagnosis and follow-up. This chapter aims to familiarise students with the role of imaging in oncology. It is important for students to understand when imaging is appropriate and what studies are most helpful for different cancer types and at different stages in the patient's journey.

We will highlight the most relevant radiological investigations for the most common cancers, specifically colorectal, lung, breast, prostate and pancreatic cancer. After completion of this tutorial, students should be able to choose the preferred imaging investigations for these malignancies, identify basic imaging features and understand the principles of cancer screening staging and surveillance.

Introduction

The radiological investigation of common malignancies can be divided into 4 categories: screening; diagnosis and staging; restaging; and surveillance.

B. Gibney (✉) · H. Fenlon
Radiology Department, Mater Misericordiae University Hospital, Eccles St., Dublin 7, Ireland
e-mail: bgibney1@gmail.com

M. Conroy
Oncology Department, St. James's Hospital, Dublin 8, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_12

Principles of screening:

- Screening involves performing a diagnostic test in asymptomatic populations with the aim of identifying pre-cancerous change or cancer at an early stage prior to the onset of symptoms.
- It must conform to several criteria and quality assessments to ensure that the benefits of early detection outweigh the risks of overdiagnosis and overtreatment (Fig. 1).
- Screening programmes that utilise radiological imaging have been established for breast, lung and colorectal cancer.
- Sensitivity: The probability that the screening test will be positive among those who are diseased.
- Specificity: The probability that the screening test will be negative among those who do not have the disease.
- Challenges for any screening test include both false positive (healthy people incorrectly identified as sick) and false negative (sick people incorrectly identified as healthy).
  - 'False positive' screening tests may lead to unnecessary investigations and anxiety.
  - 'False negative' studies erroneously reassure patients who may then fail to seek advice if they become symptomatic.
- Early diagnosis of cancer from screening can result in the overdiagnosis of indolent cancers which may never have caused illness.
- Survival benefits of screening programmes can suffer from lead time bias.
  - Lead time bias is the systematic error of apparent increased survival from detecting disease at an early stage and must be considered when analysing the success of screening programmes (Fig. 2).
- For a screening programme to save lives, an increase in the proportion of early stage cancers diagnosed and decrease in proportion of late stage cancers diagnosed needs to be observed.
  - This is referred to as 'stage shift'.

Wilson-Jungner Criteria
• The condition being screened for is an important health problem
• Natural history of the condition is well understood
• There is a detectable early stage
• Treatment at early stage is of more benefit than at late stage
• There is a suitable test to detect early stage disease
• The test is acceptable to the target population
• Intervals for repeating the test have been determined
• Adequate health service provision has been made for the extra clinical workload resulting from screening
• Risks, both physical and psychological, are less than benefits
• Costs are worthwhile in relation to benefits gained

Fig. 1 Wilson–Jungner Criteria for population health screening

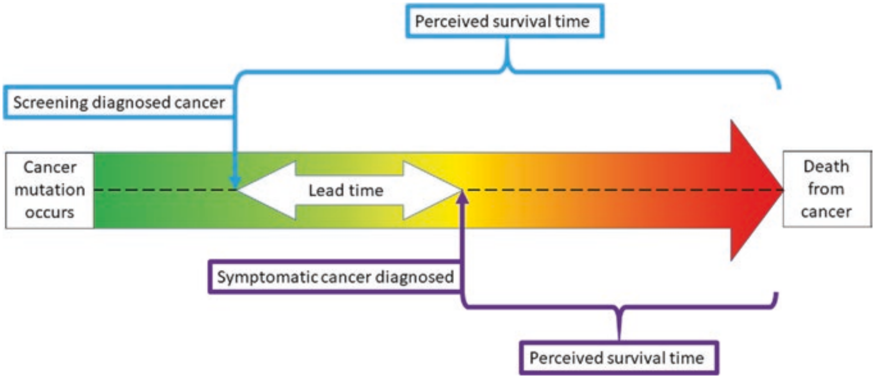


Fig. 2 Demonstration of 'lead time', the time between early diagnosis with screening and the time in which diagnosis would have been made without screening. Lead time bias occurs if testing increases the perceived survival time without affecting the course of the disease

Principles of diagnosis and staging:

- Diagnostic tests are performed when a patient presents with signs, symptoms or investigations which are suspicious for malignancy, including when a screening test has a positive result.
- Radiological staging is done to assess both the local extent of tumour and to identify metastatic disease.
- Standardised staging protocols for each cancer type are widely used to ensure more uniform reporting of the risk and stage of malignancy.
  - Variants of the 'TNM' (tumor, node, metastasis) protocol are frequently used.
- Staging is used to plan management at a multidisciplinary team meeting.
- Management options include surgery, interventional radiology, radiotherapy, and chemotherapy or other medical treatments.
  - These treatments can be used alone or in combination.
  - Can be for treatment with curative intent, for life extension or for palliation (symptom relief).

Principles of restaging:

- Restaging is performed in a patient with a known malignancy who is being monitored for response, stability, or progression of disease, usually while on or following treatment.

Principles of surveillance:

- Surveillance is performed in patients who have had presumed curative treatments to monitor for disease recurrence at an early and potentially treatable stage.

- Standardised surveillance protocols exist for many cancers but can vary according to cancer type and local preferences.

Radiologist's tip:

- Multidisciplinary Team (MDT) review including Radiology, Pathology, Medical Oncology, Radiotherapy and Surgery representatives is essential for optimal care decisions at all stages of cancer investigation, treatment and follow-up.

Radiological Modalities Utilised

Several modalities are used in varying combinations for oncology imaging depending on the type of malignancy and the timing of imaging.

Radiography:

- Many primary or metastatic lung tumours are first identified on chest radiograph.
- Malignancy can have numerous appearances on chest radiograph including:
  - Isolated mass, multiple lesions, lobar consolidation, lobar collapse, pleural effusion or hilar lymphadenopathy.
  - "Cannonball metastases" describes the appearance of multiple large rounded metastases throughout the lungs. This rare presentation is seen most often with renal cell carcinoma but can be seen in many metastatic cancers (Fig. 3).
- Other examples of malignancies seen on radiographs include:
  - Large bowel obstruction from colorectal cancer on abdominal radiograph.
  - Pathological fracture through a primary bone cancer or bone metastasis.

Computed Tomography (CT):

- This is the most common radiological investigation used for cancer investigation, diagnosis, staging, assessment for metastases, and surveillance (Fig. 4). It is widely available, reproducible and rapid to perform.
- Standard protocol for investigating suspected malignancy, staging, restaging and surveillance is IV contrast-enhanced CT of thorax, abdomen and pelvis, often referred to as "CT TAP".
- Limitations of CT include:
  - Lower sensitivity and specificity for lesions with similar density to surrounding tissue, such as within the liver and prostate.
  - Radiation exposure can be cumulatively high in patients undergoing many follow-up studies.
  - Sensitivity is markedly reduced in patients who can't receive intravenous contrast.

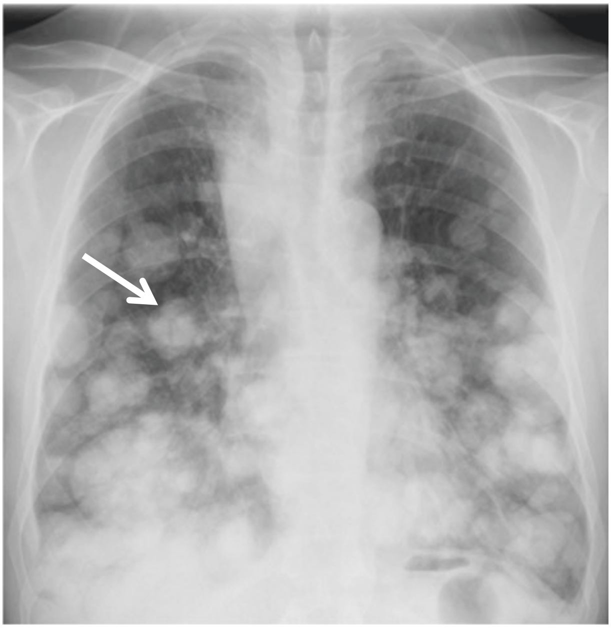


Fig. 3 Chest radiograph in a 57 year-old male with metastatic renal cell carcinoma demonstrating many large round tumours (example of tumour labelled with arrow) in both lungs, classically described as "Cannonball metastases"

CT Colonography:

- Used to assess the colon for polyps or cancers.
- Useful for patients in whom colonoscopy is incomplete or deemed unsuitable.
- Requires that the patient have low residue diet, a laxative and oral contrast for faecal tagging (to distinguish residual faeces from polyps) prior to the study.
- The bowel is distended by insufflation of carbon dioxide through a tube placed in the rectum at the time of scanning.
- The patient is scanned supine and prone to help distinguish faeces, which should be mobile, from polyps which will be fixed to the bowel wall.
- Has a high accuracy for polyps 6 mm or larger and tumours (Fig. 5).
- Limited by the inability to biopsy and obtain a tissue diagnosis.

MRI:

- Is superior to CT for identification and characterisation of small lesions surrounded by similar density tissues, for example in liver and prostate, and for bone and brain metastases.
- A wide variety of sequences aid in characterising a lesion.
- Useful sequences include:

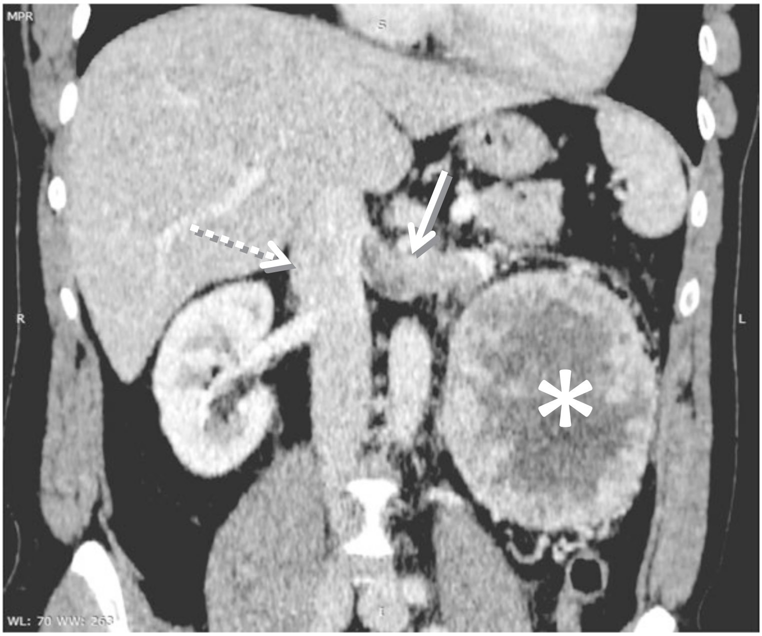


Fig. 4 A 62-year-old male presented with left flank pain and had a CT abdomen. Coronal portal venous phase CT image shows a large left renal cell carcinoma (Asterix), with tumour extending into the left renal vein (Arrow), almost reaching the inferior vena cava (Dotted arrow)

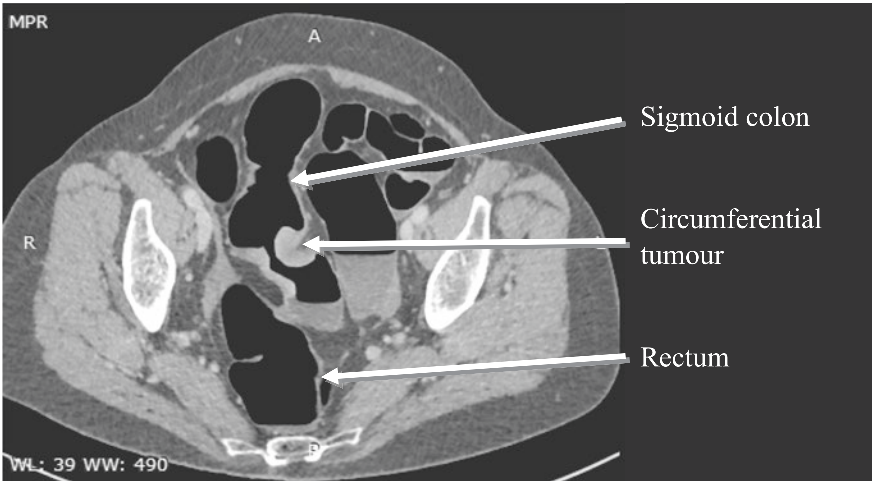


Fig. 5 A 68 year old man was referred with intermittent blood per rectum for CT colonography. Axial contrast-enhanced image through the mid-pelvis demonstrates a tumour in the sigmoid colon with circumferential mural thickening and narrowing of the bowel lumen. This corresponds to the 'Apple-core' appearance classically seen on barium enema, a study which has been replaced by colonoscopy and CT colonography

- Diffusion-weighted imaging measures Brownian motion in and out of cells. Highly cellular tissues as seen in many tumours can have restricted diffusion.
- Post contrast T1-weighted sequences use Gadolinium-based contrast to assess patterns of enhancement and washout of lesions.

- Limitations of MRI include:
  - Limited availability and higher cost compared with CT.
  - Patients with metallic foreign bodies (including pacemakers, surgical hardware, and piercings) may not be safe within the magnetic field.
  - Length of scan time, noise and limited space in MRI scanner can cause discomfort and claustrophobia.

PET-CT:

- Positron Emission Tomography (PET) is a form of nuclear medicine imaging whereby a radiopharmaceutical is given to the patient intravenously and the radiation emitted from the patient is recorded by the PET scanner.
- In most cases a CT is performed at the same time and the images obtained from both the PET and the CT studies are fused together using software. In this way, the functional information obtained from the radiopharmaceutical accumulation is fused to the anatomical information provided by CT.
- The most commonly used radiopharmaceutical is F-18 labelled Fluorodeoxygloucose (FDG). Fluorine-18 is a radioactive particle linked to Deoxyglucose, which is taken up by metabolically active cells that utilise glucose.
- As most cancers are more metabolically active than surrounding normal soft tissue, most tumours take up more FDG than their surroundings, and therefore appear 'hot' on a PET-CT scan.
- New radiopharmaceuticals are being continuously developed for cancer or biologic marker specific imaging.

Mammography:

- This is an X-ray test that utilises specialised imaging technique to differentiate normal breast tissue from benign or malignant lesions.
- Very high spatial resolution images are used to assess microcalcifications in breast tissue, which may have different characteristics in benign and malignant lesions.
- Typically, mammography involves two views of each breast—a cranio-caudal (CC) and mediolateral oblique (MLO) view (Fig. 6).
- Digital Breast Tomosynthesis is a variant of standard mammography which is emerging as an important tool for both screening and diagnostic studies.
  - Involves passing an X-ray source in an arc around breast and taking multiple low-dose images which are combined to give a semi-3D image.

– This can be very helpful in the assessment of asymmetries and potential distortions.

Ultrasound:

- Images are created by emitting sound waves and recording the pattern of echoes received from underlying tissues.
- Initial investigation for suspected testicular and gynaecological cancers (Fig. 7).
- Renal cell carcinomas and hepatic tumours (both primary and metastatic) are often first identified with ultrasound.
- Limitations:
  – Structures which are deep to bone, bowel gas or thick adipose tissue will be poorly seen as sound waves do not pass through these easily.
  – Quality of imaging is highly dependent on skill of the operator.

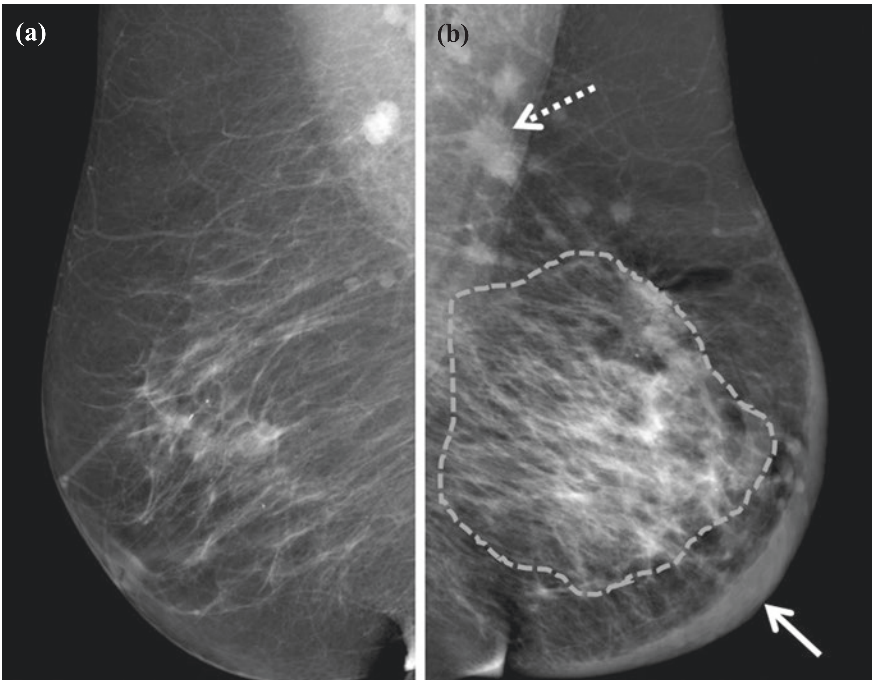


Fig. 6 MLO view mammograms in a 45-year-old female presenting with left breast swelling. **a** Normal right mammogram. **b** Abnormal increased central glandular and parenchymal thickening demarcated by the grey dotted line. Skin thickening (Arrow) and enlarged axillary lymph nodes (Dotted arrow) are also seen

Interventional Radiology:

- The histologic or cytologic diagnosis of many malignancies is obtained using image-guided biopsy or aspiration of a concerning lesion.
- Depending on the location and size of the lesion, and on patient-specific factors, biopsy can be guided by ultrasound, CT, mammography or MRI.
- Many oncologic therapies are delivered by interventional radiology, which can involve treatment of symptoms or complications, as well as curative or palliative ablation and embolisation.

Freqently Encountered Malignancies

Colorectal Cancer

Background:

- 2nd leading cause of cancer death with over 500,000 deaths per year worldwide.
- 20–25% of colorectal cancer (CRC) is metastatic at time of diagnosis.
- Clinical presentation can be with acute or chronic symptoms:
  - Acute: Large bowel obstruction or perforation, acute rectal bleed.
  - Chronic: iron deficiency anaemia, change in bowel habit or weight loss.
  - Left sided tumours are more likely to present with obstruction.

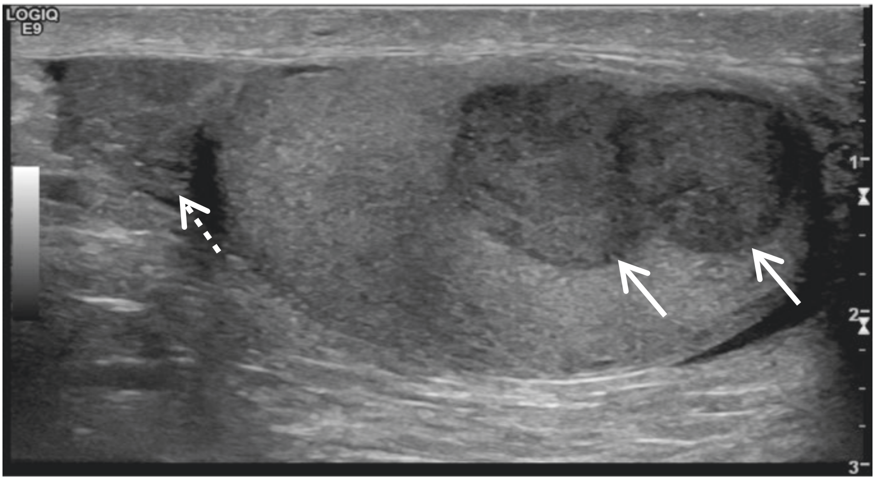


Fig. 7 Ultrasound of right testicle in a 20 year-old male showing a lobulated hypoechoic testicular mass in the lower pole (arrows) compatible with a seminoma testicular tumour. The head of epididymis (dotted arrow) is seen superior to the upper pole

Screening:

- National programmes are in place in many countries to screen asymptomatic populations within target age groups.
- Faecal immunochemical test (FIT) is performed at home on a stool sample to test for occult blood in stool.
  - Approximately 6% of screened population test positive and are offered a colonoscopy.
  - If colonoscopy is incomplete or the patient is unwilling or unfit to have colonoscopy, CT colonography can be performed.

Diagnosis and staging:

- Diagnosis is usually made at colonoscopy with biopsy of the primary lesion or from image-guided biopsy of a metastasis (usually liver, lung or nodes).
- Contrast-enhanced CT of thorax, abdomen and pelvis in the portal venous phase is the standard initial staging test.
- MRI rectum is performed for local staging of rectal cancers.
  - Decision to proceed straight to surgery or to perform neoadjuvant chemotherapy/radiotherapy first is based on how far beyond the bowel wall into the mesorectal fat the tumour has spread and the nodal status.
- If liver lesions are identified, contrast enhanced MRI liver with a liver specific MRI contrast agent is performed to characterise the lesions and to establish if treatment with surgical excision (metastasectomy) or IR ablation is feasible.
- PET-CT is performed if considering metastasectomy to exclude metastases elsewhere.

Restaging:

- Patients with liver metastases or locally advanced primary rectal cancers may receive neoadjuvant therapy in an attempt to reduce the disease burden to a level where resection can be considered and to reduce local recurrence rates post surgery.
- Following neoadjuvant therapy, repeat MRI of liver and/or rectum can be performed if considering surgical resection.
- PET-CT is often performed at restaging to confirm no new metastatic disease is present.

Surveillance:

- 80% of CRC relapses occur in first 3 years after initial surgery.
- Surveillance includes physical exam, serum carcinoembryonic antigen (CEA), colonoscopy and CT TAP, with the aim:
  - to identify small volume metastases at a resectable stage.
  - to identify local recurrence at an early and treatable stage.

- Most guidelines advise annual CT TAP for 3–5 years after curative therapy, although some reserve imaging only for patients with a high risk of recurrence.

> **Radiologist's tip**:
>
> - Metastatic colorectal cancer is potentially curable if there is a low volume of metastatic disease in the liver and/or lung, which is surgically resectable. PET/CT and MRI are crucial for fully evaluating a patient if surgical resection of metastases ("metastasectomy") is considered.

Lung Cancer

Background:

- Lung cancer is the leading cause of cancer death in both men and women.
- 2nd most common cancer in men after prostate and 2nd most common cancer in women after breast.
- Often first identified on chest radiograph as a mass, lobar collapse or a non-resolving consolidation.
- Presenting symptoms include cough, haemoptysis, chest pain, weight loss and paraneoplastic effects such as hypertrophic osteo-arthropathy, hyponatraemia or hypercalcaemia.
- At time of diagnosis, the cancer is often locally advanced or metastatic.

Diagnosis and staging:

- CT thorax is the primary investigation for screening, diagnosis, local staging and restaging and surveillance of lung cancers.
- PET-CT has an increasingly important role in the initial investigation, staging and follow up of lung cancer.
  - Used in the assessment of indeterminate pulmonary nodules measuring >8 mm to identify if increased metabolism is present.
  - Used routinely for staging in patients who may be operative candidates due to its ability to assess locoregional lymph node involvement and distant metastatic spread more accurately than CT.
- Histologic diagnosis is obtained through CT-guided biopsy of lung nodule, bronchoscopic fine needle aspiration (FNA) of an endobronchial mass or mediastinal/hilar nodes, or image-guided biopsy of metastases (Fig. 8).
- Tissue sampling is important for histologic confirmation of:
  - cancer type (primary lung vs. metastasis, small-cell vs. non-small-cell type)
  - genotyping (for example the presence of epidermal growth factor receptor mutation).

- Feasibility of CT-guided biopsy depends on the size and location of nodules and patient factors. Small size; position at lung bases, beside the heart, vessels or fissures; and background lung disease all increase the difficulty of the biopsy and therefore the risk of complications and obtaining a non-diagnostic sample.
- Contrast-enhanced CT or MRI brain should be considered as part of lung cancer staging when curative surgery is considered (assessment for brain metastasis).

Restaging:

- Restaging is with CT TAP.
- Frequency of restaging imaging is dictated by patient factors, tumour biology, treatment type and whether the patient is participating in a clinical trial.

Surveillance:

- Surveillance of incidentally detected pulmonary nodules follows guidelines such as those issued by the 'Fleischner Society' or 'British Thoracic Society'.
  - Guidance is based on nodule number, characteristics and size, and on patient risk factors such as smoking history.
- No consensus exists for surveillance imaging guidelines post primary resection or curative chemo-radiation.
  - an approximate guideline is a CT thorax every 6–12 months for 2–5 years. After this point, consider chest radiograph or low-dose CT thorax at annual clinic visit.

Radiologist's tip:

- New lung opacities seen on chest radiographs in the setting of infection should have follow up radiographs until the opacities resolve.
- If an opacity persists, a CT thorax should be performed to assess for a tumour.

Breast Cancer

Background:

- Breast cancer is the second leading cause of cancer death in women, exceeded only by lung cancer.
- One in eight women (12.5%) will develop invasive breast cancer during their lifetime.
- The death rates from breast cancer have been in decline since about 1989.

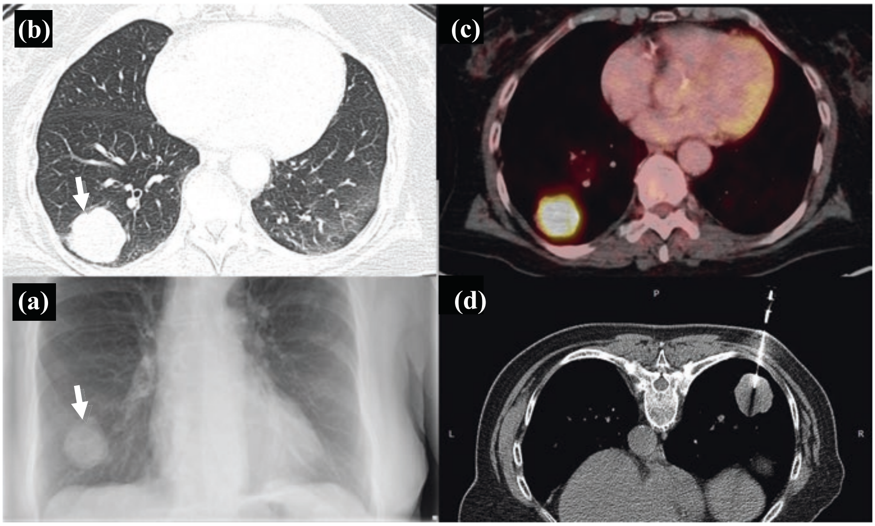


Fig. 8 A 70 year-old female presented with cough and haemoptysis and was referred for chest radiograph. **a** Chest radiograph shows a round mass-like opacity projected in the right lower lung (Arrow). **b** CT with lung windows shows a corresponding mass in the right lower lobe (Arrow). **c** Fused PET and CT images of thorax demonstrate increased activity in the mass, often described as appearing 'hot'. **d** CT guided biopsy of the mass with patient positioned prone, therefore appearing on the other side

  - This is the result of earlier detection through screening mammography and improved treatment.

- Prognosis and treatment are largely based on breast cancer stage at diagnosis.

Screening:

- Screening mammography performed in asymptomatic women allows the detection of in situ (pre-cancer) disease and early-stage breast cancer.
- Screening programmes vary depending on their target population. In general, mammograms are recommended every 2 years for all women within defined age groups.
- Screening may begin earlier in some high-risk women, for example carriers of genes with increased cancer risk such as BRCA1 and BRCA2.
- An abnormality is identified on approximately 5% of screening mammograms, requiring patients to be called back for further investigation.
  - These include spot compression views, magnification views, tomosynthesis and biopsy
  - Abnormalities visible on ultrasound are biopsied under ultrasound guidance
  - If no abnormality is seen on ultrasound in a region of concern, a stereotactic biopsy can be performed, using mammographic images to localise the abnormality and guide the biopsy needle.

- In certain settings, such as dense glandular breasts and in younger high-risk patients, screening may also incorporate contrast-enhanced MRI.

Diagnosis and staging:

- Diagnostic mammography is performed in symptomatic women (i.e. those with a breast lump, focal pain, nipple inversion, bloody nipple discharge).
- Ultrasound is used to assess abnormalities seen on mammography or palpable lesions found on self-examination or clinical examination.
- Contrast–enhanced breast MR imaging is used selectively to improve breast cancer staging (i.e. to detect multifocal tumours).
- CT, bone scintigraphy, and PET-CT can be used to evaluate asymptomatic patients at high risk for metastases or patients with signs or symptoms of metastatic disease.
- Accurate staging information will help to choose between:
  - breast conservation and mastectomy.
  - preoperative and postoperative chemotherapy or hormonal therapy.
  - sentinel lymph node biopsy (SLNB) and axillary lymph node dissection (ALND).
  - radiation therapy.
- Inflammatory breast cancer is a rare and aggressive form of breast cancer, presenting typically with pain, breast swelling and skin changes.
  - Usually progresses rapidly over weeks to months owing to tumour emboli obstructing flow in the dermal lymphatic vessels.
  - It may be difficult to detect a discrete breast mass at physical examination or on imaging because of the widespread involvement of the lymphatic system (Fig. 9).

Restaging:

- Performed in patients with known metastatic disease
- Involves CT TAP and bone scintigraphy.
- Also performed in patients receiving neoadjuvant treatment to downsize the tumour (often with breast MRI and PET-CT).
- PET-CT can be used for problem solving—for example when initial imaging studies are negative or equivocal and there is persistent concern for metastatic disease due to clinical or biochemical findings.

Surveillance:

- Following primary treatment of breast cancer, patients should be followed up to detect treatable early recurrence.

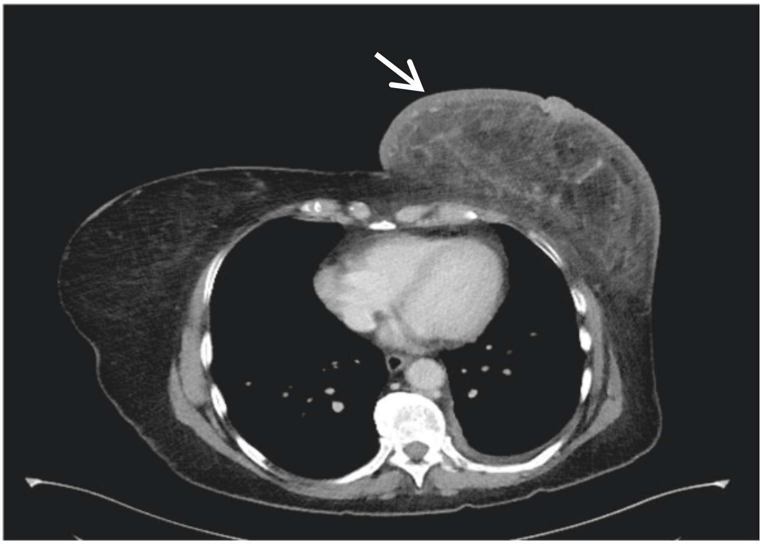


Fig. 9 A 45 year-old female presented with left breast pain and swelling. Mammogram and CT TAP were performed. Contrast enhanced axial CT image of the mid-thorax demonstrating an abnormal left breast and diffuse tumour infiltration. The skin is thickened (Arrow) and there is ill-defined increased density, compatible with oedema, without a focal breast mass

- Annual mammogram and/or digital breast tomosynthesis should be performed in all patients as well as regular history and examination.
- The use of routine cross-sectional (CT TAP) surveillance in asymptomatic breast cancer patients is controversial.
  - If performed, surveillance is usually discontinued at 5 years.

Prostate Cancer

Background:

- Prostate cancer is the most common cancer in men worldwide, excluding skin cancers.
- 6th most common cause of cancer-related deaths worldwide.
- Prevalence increases with age. It affects 40–73% of men in 80–90 year-old age group.
- Can present with local symptoms of urinary obstruction, however benign prostatic hypertrophy is a far more common cause of obstructive symptoms.
- Metastatic prostate cancer often presents as bone pain, due to the high frequency of spread of prostate malignancy to the bones.

- Wide spectrum of biologic behaviour ranging from indolent low-risk disease to highly aggressive castration-resistant prostate cancer.

Screening:

- Population screening for prostate cancer is not commonly performed.
- Asymptomatic screening mostly identifies 'low risk' prostate cancer groups.
  - 'Low risk' defined as PSA <10, Gleason score <6, and clinical T2a or less disease.
  - 'Low risk' cancer is usually managed with no treatment and active surveillance.
  - This is associated with very low prostate cancer related mortality.

Diagnosis and staging:

- Diagnosis has traditionally relied on prostate-specific antigen (PSA) levels, digital rectal examination (DRE), and systematic, non-targeted transrectal ultrasound (TRUS)-guided biopsy.
- MRI Prostate has recently emerged as a crucial part of investigation of suspected prostate cancer (Fig. 10):
  - When negative for suspected cancer, can potentially eliminate the need for biopsy.
  - Identifies likelihood of disease being present, potential aggressiveness of lesions, anatomic location of disease, extra-glandular extension and regional nodal involvement.
- Histologic diagnosis is usually obtained from TRUS biopsy, which can be non-targeted or can target a specific abnormal lesion seen on MRI.
  - Crucial for grading aggressiveness using 'Gleason Score'.
- CT TAP is used to assess for nodal and distant metastases including bone metastases.
- Bone scan assesses for bone involvement, as prostate cancer has a predilection for spreading to bone.
  - Bone metastases have increased radiotracer uptake, appearing 'hot' on bone scan (Fig. 11).

Restaging:

- Bone scan assesses for changes in bone metastases.
- CT TAP assesses for regional lymphadenopathy and distant metastases.

Surveillance:

- Active surveillance without treatment is a good management option for many low-risk and some intermediate-risk patients, particularly in patients who are older or have significant co-morbidities.

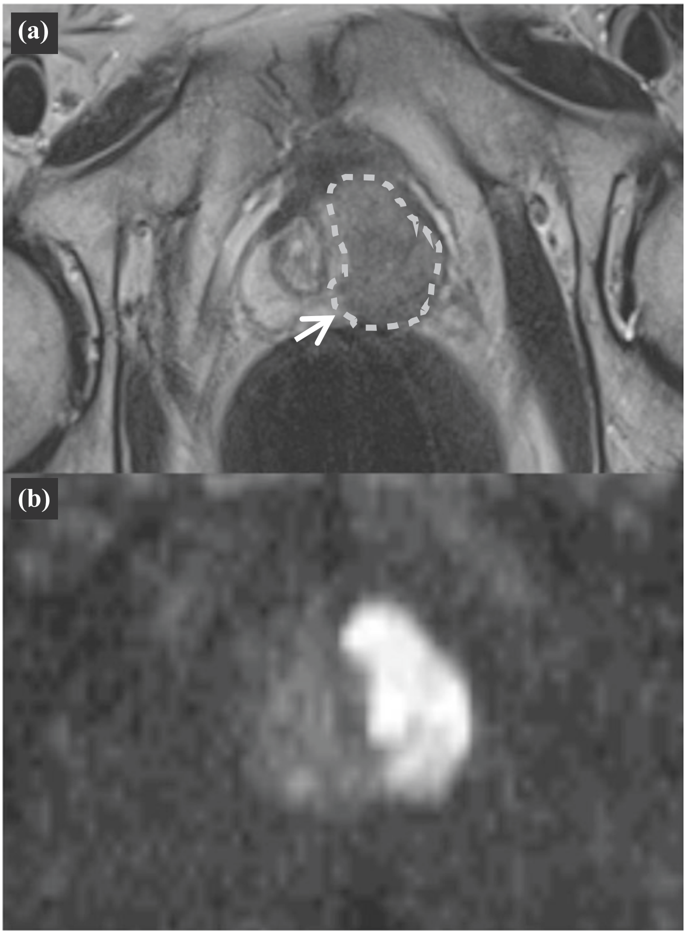


Fig. 10 A 55 year old man with family history of prostate cancer was found to have raised serum PSA level of 20 and referred for Prostate MRI. **a** Axial T2 sequence shows large area of low (dark) signal in left side of gland, with dotted outline. The normal prostate has bright signal on T2 (arrow). **b** Diffusion weighted images show high signal in the same region, compatible with a large prostate carcinoma replacing the left side of the prostate

- Serial evaluation of PSA is the mainstay of surveillance testing in men who have undergone definitive therapy for localized prostate cancer.
  – MRI, CT TAP and bone scintigraphy are standard investigations for rising PSA after prostatectomy.

Radiologist's tip:

- MRI Prostate has recently emerged as a crucial part of investigation of suspected Prostate cancer. If negative, prostate biopsy may be avoided and if positive, biopsy can be targeted to the site of abnormality instead of random tissue sampling.

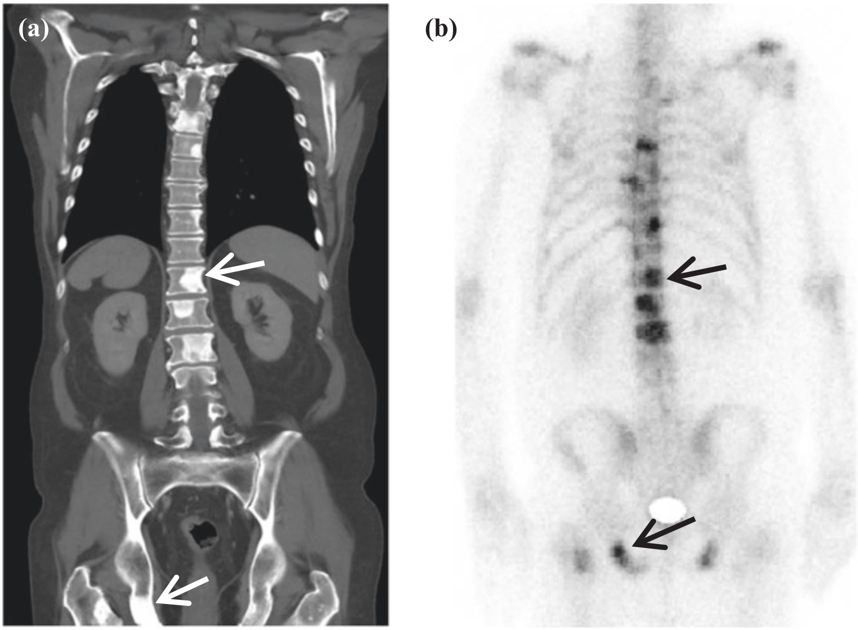


Fig. 11 The patient from Fig. 4 had TRUS biopsy of prostate and was found to have Gleason 9 Prostate cancer. He was referred for staging CT and Bone Scintigraphy. **a** Coronal CT in bone windows demonstrates multiple sclerotic lesions in thoracolumbar vertebrae and pelvis (White arrows). **b** Bone scintigraphy in same patient shows increased uptake in the same regions (Black Arrows), corresponding to osteoblastic action of prostate metastases

Pancreatic Cancer

Background:

- 4th leading cause of cancer death in western societies.
- Difficult to diagnose at an early stage. The majority of patients present with metastatic disease.
- Only 15–20% are candidates for surgical treatment at presentation.
  - Recurrence rates are high even after complete resection with negative margins.
- Presenting symptoms include jaundice, weight loss, epigastric or back pain, dyspepsia and nausea.
  - Many patients are asymptomatic and no reliable early warning signs have been established.
- Risk factors include smoking, obesity, diabetes and genetic causes such as BRCA carriers, Peutz–Jeghers syndrome and Hereditary Non-Polyposis Colorectal Cancer (Lynch Syndrome).

Screening:

- Average-risk population pancreatic cancer screening is not performed due to the low incidence of pancreatic cancer and lack of a cheap, easy and accurate screening test.
- Screening programmes are being trialled for patients with an increased lifetime risk in the range of 5–10%, however there is currently insufficient evidence that screening programmes improve survival.
- Screening tests include MRI and endoscopic ultrasound (EUS).

Diagnosis and staging:

- Pancreas protocol (triple phase) CT is the preferred initial imaging modality for diagnosing and staging pancreatic cancer and deciding resectability.
- Patients with suspected cancer on CT will usually undergo EUS.
- Local findings suggestive of pancreatic cancer include (Fig. 12):
  - A pancreatic mass
  - Pancreatic duct dilation and distal pancreatic atrophy
  - Common bile duct and intra-hepatic bile duct dilation.
- Histologic diagnosis is often obtained through EUS with fine needle aspiration of the pancreatic lesion.
- If a tumour surrounds a vessel by more than 180 degrees or occludes the SMV/portal vein without surgical options of reconstruction, then it is deemed unresectable.
- MRI has been shown to have equal sensitivity and specificity for pancreatic cancer but is mostly used when lesions are indeterminate on CT due to higher cost and lower availability.

Restaging:

- It is suggested that patients on active therapy should have initial restaging at 2–3 months with CT.
- Thereafter, clinical assessment, conducted frequently during visits for cancer-directed therapy, should replace imaging assessment.

Surveillance:

- Recommendations vary between oncology societies:
  - Some advocate no post-treatment surveillance.
  - Others advocate 3–6 monthly serum CA19-9 measurement and CT for 2 years post-resection, followed by annual testing.

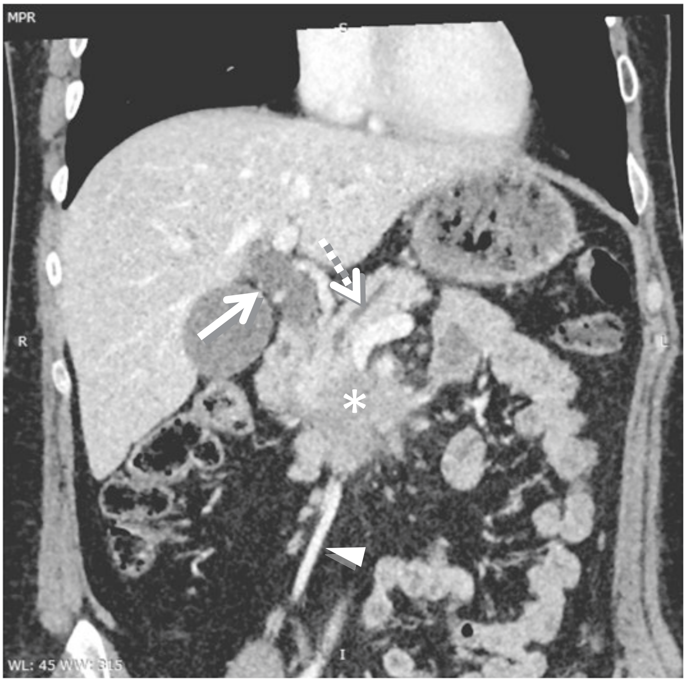


Fig. 12 A 76-year-old female had progressive epigastric pain and jaundice. Ultrasound demonstrated intrahepatic and extrahepatic bile duct dilation and she was referred for CT. Coronal portal venous phase CT image showing an ill-defined infiltrative mass in the head of pancreas (Asterix), causing obstruction and dilation of the common bile duct (Arrow) and pancreatic duct (Dotted Arrow) and encasing the superior mesenteric vein (arrowhead)

Pitfalls in Assessing Tumour Burden and Tumour Response

- Tumours can respond to treatment initially with oedema prior to a reduction in size. This is described as 'pseudoprogression'
  - This can result in unnecessary change or cessation of treatment if mistaken for true progression.
  - Most commonly seen in brain tumours, hepatocellular carcinoma and metastatic melanoma.
- "Incidentalomas"—Benign incidental lesions which are first seen at the time of cancer staging can be mistaken for metastases, which may prevent patients from undergoing curative treatments.
  - Investigation of the lesions may cause significant resource burden and stress for patients.
- Mixed treatment responses can be seen in many scenarios with different causes:

  - In a patient receiving chemotherapy and radiotherapy, there may be a response to radiotherapy at the focal site of treatment but progression of disease in metastases remote from radiotherapy site.

Imaging of Common Oncologic Emergencies

- Acute life-threatening conditions in oncology patients may develop either because of underlying malignancy or as a complication from treatment.
- Complications can include haemorrhage, thrombosis, embolus or mechanical obstruction or compression of airways, blood vessels, bowel, ureters, bile ducts or nerves.
- These may be suspected from clinical or biochemical assessments; however imaging is critical for timely diagnosis and management.
- CT and MRI are the most commonly used diagnostic modalities, depending on the suspected complication.
- Interventional radiology procedures often have a role in treating these complications, including, but not limited to:
  - Percutaneous nephrostomy or ureteric stenting for tumour obstruction of ureter.
  - Percutaneous biliary drainage or bile duct stenting for tumour obstruction of common bile duct or intra-hepatic ducts.
  - Embolisation of bronchial arteries for haemoptysis or visceral arteries in abdominal tumour haemorrhage.
  - Therapeutic drainage of malignant ascites or effusion.
  - Central venous catheter insertion for urgent chemotherapy.

Suggested Reading

- Barton H, Shatti D, Jones CA, Sakthithasan M, Loughborough WW. Review of radiological screening programmes for breast, lung and pancreatic malignancy. Quant Imaging Med Surg. 2018;8(5):525–34.
- Katabathina VS, Restrepo CS, Betancourt Cuellar SL, Riascos RF, Menias CO. Imaging of oncologic emergencies: what every radiologist should know. Radiographics. 2013;33(6):1533–53.
- Kalli S, Semine A, Cohen S, Naber SP, Makim SS, Bahl M. American joint committee on cancer's staging system for breast cancer, eighth edition: what the radiologist needs to know. Radiographics. 2018;38(7):1921–33.
- Lee SC, Jain PA, Jethwa SC, Tripathy D, Yamashita MW. Radiologist's role in breast cancer staging: providing key information for clinicians. Radiographics. 2014;34(2):330–42.

- Zhang L, Sanagapalli S, Stoita A. Challenges in diagnosis of pancreatic cancer. World J Gastroenterol. 2018;24(19):2047–60. https://doi.org/10.3748/wjg.v24.i19.2047. Review.
- Treadwell JR, Zafar HM, Mitchell MD, Tipton K, Teitelbaum U, Jue J. Imaging tests for the diagnosis and staging of pancreatic adenocarcinoma: a meta-analysis. Pancreas. 2016;45(6):789–95.
- Lim W, Ridge CA, Nicholson AG, Mirsadraee S. The 8(th) lung cancer TNM classification and clinical staging system: review of the changes and clinical implications. Quant Imaging Med Surg. 2018;8(7):709–18. https://doi.org/10.21037/qims.2018.08.02. Review.
- Tirumani SH, Kim KW, Nishino M, Howard SA, Krajewski KM, Jagannathan JP, Cleary JM, Ramaiya NH, Shinagare AB. Update on the role of imaging in management of metastatic colorectal cancer. Radiographics. 2014;34(7):1908–28. https://doi.org/10.1148/rg.347130090. Review.
- Andrea Laghi MD. CT Colonography: an update on current and future indications. Expert Rev Gastroenterol Hepatol. 2016. https://doi.org/10.1586/17474124.2016.1143358.
- PI-RADS version 2: a pictorial update. Radiographics. 2016;36(5):1354–72. https://doi.org/10.1148/rg.2016150234. Epub 2016 Jul 29. Review002E
- Wallitt KL, Khan SR, Dubash S, Tam HH, Khan S, Barwick TD. Clinical PET imaging in prostate cancer. Radiographics. 2017;37(5):1512–36. https://doi.org/10.1148/rg.2017170035. Epub 2017 Aug 11. Review.

Tutorial 13: Introduction to Paediatric Radiology

Caitriona Logan, Angela Byrne and Stephanie Ryan

Aims and Guidance for Tutors

Paediatric radiology is a subspecialty of radiology that covers all aspects of diagnostic imaging and image-guided treatment for children. The pathologies encountered in children are often different than those found in adults and paediatric radiology therefore differs in its approach and findings. Every imaging modality used in adult radiology is also used in paediatric radiology but with more emphasis on those with either low or no radiation, and on using distraction and pleasant environments to ease the process of acquiring images. After completing this tutorial students should be able to describe some of the reasons for specific modality choices when imaging children, and the important imaging features in a number of key pathologies.

Introduction

- Childhood injury and illnesses differ to the those seen in adults
- Children are more susceptible to the potential negative effects of medical ionising radiation than adults:

C. Logan (✉) · S. Ryan
Children's Health Ireland, Temple Street, Dublin, Ireland
e-mail: caitrionalogan@gmail.com

A. Byrne
Children's Health Ireland, Crumlin, Dublin, Ireland

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_13

  - Modalities that do not use radiation (ultrasound and MRI) are used more often in paediatric radiology than in adult radiology
  - When using modalities that use radiation, great care is taken to use the lowest dose necessary for diagnosis.

- Congenital and developmental pathologies are key, whereas degenerative pathologies are less frequent than in adult radiology.

Radiologist's tip: Imaging babies and young children

- One of the challenges in paediatric imaging is getting the patients to remain still enough to acquire diagnostic images.
  - Child-friendly staff, equipment and environments can help to successfully acquire imaging in an awake child, as well as the help of the parents.
  - A minority of children need to be imaged under sedation or general anaesthesia in order to obtain diagnostic quality imaging.
  - Anaesthesiology, nursing and specialist paediatric radiographers are key team members in a paediatric radiology department.

Radiological Modalities Used in Paediatric Radiology

- **Plain radiography**:
  - The most commonly used modality in the paediatric radiology department and is often first line for investigation of trauma, pneumonia or suspected bowel obstruction.
- **Ultrasound**:
  - Ultrasound scanning is a cornerstone of paediatric imaging due to the absence of radiation and due to its portability.
  - Children's small size and relatively low subcutaneous fat thickness provide excellent acoustic windows into almost the entire abdomen, with the exception of air-filled bowel.
  - The unossified anterior fontanelle of the still-developing skull, especially in the first 6 months of life allows the brain to be imaged with ultrasound in small babies.
  - It can also be used to rule out hip dysplasia and image the spinal cord in the neonate as the adjacent bones have still not fully ossified.
- **Magnetic resonance (MR) imaging**:
  - Relied heavily upon in paediatric imaging due to the absence of radiation.
  - Shows excellent soft tissue detail.
  - Requires long periods of stillness to produce high quality imaging.
  - Complex to acquire and interpret.

– Requires a team approach with nursing and anaesthesiology when sedation or general anaesthesia is necessary.
– MR Simulators can be used to help patients overcome their anxiety and potentially obviate the need for general anesthetic.

- **Fluoroscopy**:

– This modality uses pulsed x-rays to obtain real time imaging of the patient.
– It is particularly helpful in diagnosing potentially life threatening bowel malrotation as well as assisting in the reduction of intussusception.

- **Computed tomography (CT)**:

– This requires a higher radiation dose when compared with plain radiography or fluoroscopy but ongoing technical advances are continuing to allow doses to be reduced.

- **Nuclear imaging**:

– Imparts a radiation dose to the patient.
– Requires patients to lie still, sometimes for prolonged periods of time.
– Used to find pathology such as osteomyelitis in bones that may not be detectable on xrays.
– Used for measuring function in kidneys and for evaluation of obstructed kidneys.

- **Paediatric interventional radiology**:

– Uses imaging modalities such as ultrasound, fluoroscopy, CT and MRI to perform procedures in the paediatric population.
– Procedures include vascular catheter placement, tissue biopsy, tumour ablation and angiography.

Chest and Airway Imaging in Children

Causes of acute dyspnoea in newborn infants:

- **Transient tachypnoea of the newborn** is due to delayed clearance of fluid from the lungs. It is more common in small babies and in babies delivered by C-section owing to reduced mechanical squeeze from the birth canal to clear the fluid in the lungs. The retained fluid appears as interstitial oedema- fine lines-on chest radiograph, often with fluid in fissures. It classically resolves in 24 hours.
- **Meconium aspiration**: If a baby aspirates meconium stained liquor during delivery the meconium is very irritant to the bronchi. The meconium or the resulatant airway inflammation may obstruct airways or narrow them. This may appear on a chest x-ray as streaky densities due to atelecatasis and air-trapping. There is a high incidence of pneumothorax and pneumomediastinum in babies with meconium aspiration.

- **Respiratory Distress Syndrome (RDS)**: Neonates born as prematurely as 23 weeks can survive with modern neonatal ICU care. Surfactant, which keeps the alveoli of the lungs open to exchange gas, begins to be produced in an immature form in the lungs from 24 weeks. The administration of synthetic surfactant to treat Respiratory Distress Syndrome RDS or 'surfactant deficiency of prematurity' has led to markedly increased survival of premature infants. The typical appearance is of bilateral symmetrical alveolar densities with air bronchograms and low lung volumes (Fig. 1).
- **Neonatal pneumonia**: This can be caused by maternal systemic infection or acquired bacteria such as Group B Streptococcus. The most characteristic pattern is dense air space opacification with air bronchograms, but patterns may be variable and a high index of suspicion is required if there is a clinical deterioration.
- **Congenital diaphragmatic hernia**: The lung development is limited by a herniation of bowel into the thorax. These patients can have severe morbidity if the lung fails to develop due to mass effect from the hernia (Fig. 2).

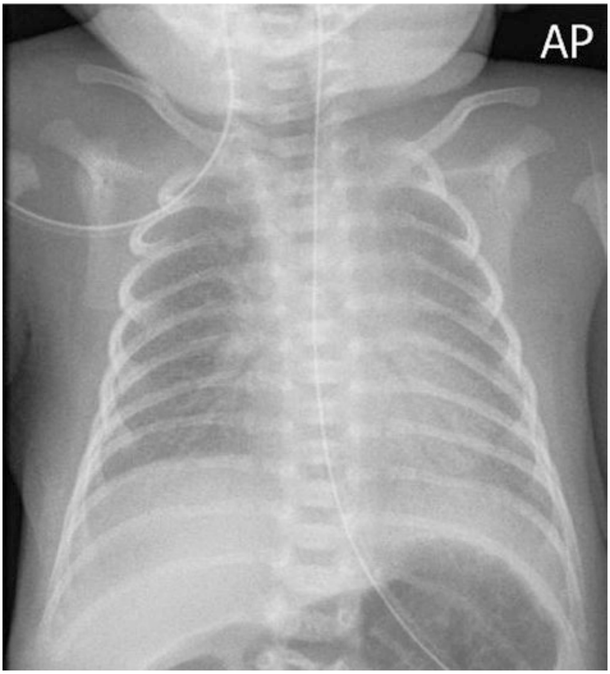


Fig. 1 Chest radiograph in a premature neonate which shows small lung volumes and a hazy opacification throughout the lungs in keeping with RDS

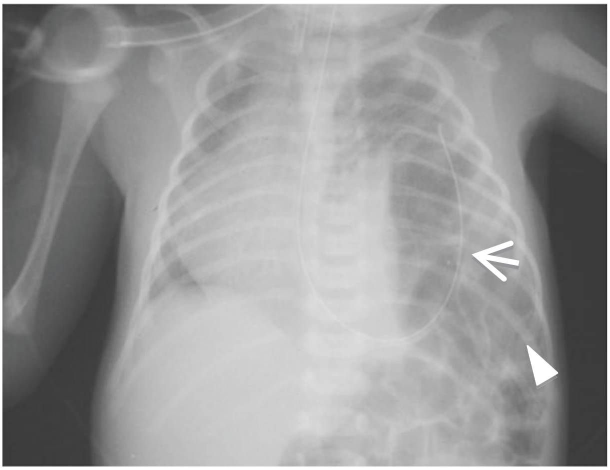


Fig. 2 Chest radiograph in a baby which shows bubbly lucencies in the left thorax in keeping with bowel loops (arrowhead). This is a left sided congenital diaphragmatic hernia. The nasogastric tube is in the thorax (arrow) instead of its expected position below the diaphragm

Causes of acute dyspnoea in children: lower respiratory tract.

- **Bronchiolitis** is common in children under 1 year and is caused typically by RSV (respiratory syncytial virus). The lungs are hyperinflated with bronchial wall thickening and can have bilateral areas of atelectasis. In severe cases the patient may need to be intubated in ICU.
- **Pneumonia** can look different in a child to an adult on a chest radiograph. An entity called round pneumonia is unique to children. If a child has clinical evidence of infection a mass on a chest radiograph can be treated as probable infection. A follow up radiograph must be done to confirm resolution.

Causes of acute dyspnoea in children: upper respiratory tract.

- **Croup** (acute laryngotracheobronchitis) which is a viral infection of the airway and the commonest cause of acute upper airway obstruction in children. The radiograph typically shows a "steeple sign" due to narrowing of the subglottic airway (Fig. 3).
- **Epiglottitis**, a potentially life threatening infection of the epiglottis caused by Hemophilus Influenza that should be diagnosed clinically without need for radiographs.
- **Foreign Body Inhalation or ingestion**: Children under 3 are most at risk for ingesting foreign bodies such as coins or batteries. These may be radio-opaque and can be seen on chest radiographs when the child presents with wheeze, stridor or respiratory distress. Some foreign bodies for example peanuts are not seen on a radiograph. Instead signs such as hyperinflation or air trapping on the side of the aspiration, collapse of the lung distal to the obstruction are sought on the radiograph. Figure 4 shows a hair clip lodged in the right main bronchus in a child.

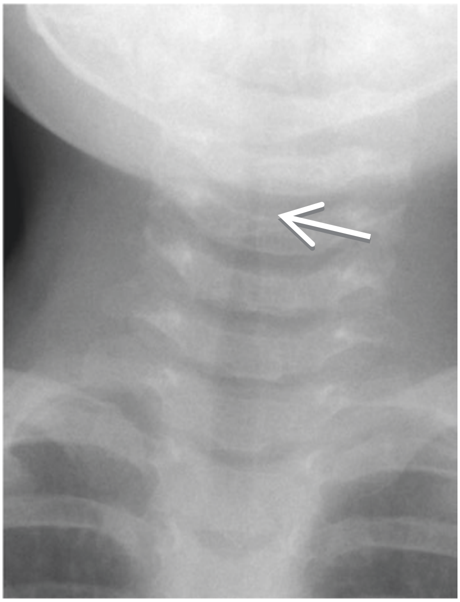


Fig. 3 Radiograph in a 2 year old presenting with stridor showing the 'steeple sign' of croup (arrow)

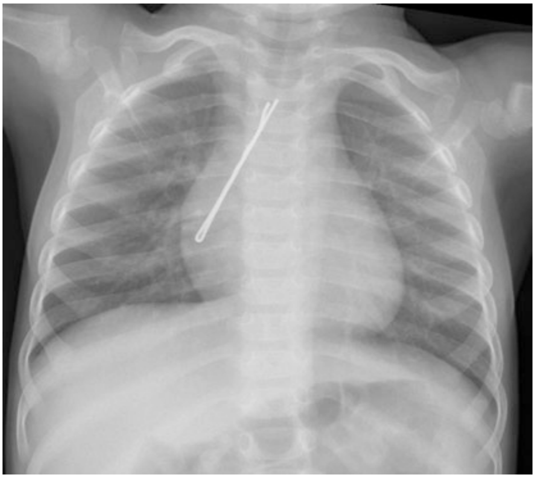


Fig. 4 Chest radiograph in a child who presented with stridor which shows a foreign body, a hair-clip, lodged in the right main bronchus

Radiologist's tip: Inhaled foreign body

- If a small child presents with stidor and one lung appears larger and more lucent than the other an **inhaled foreign body** must be considered. The foreign body itself may or may not be visible on a chest radiograph.

Cardiac Anomalies

- Cardiac anomalies are classified into groups according to whether they cause the child to be cyanotic (the blue infant) or non-cyanotic.
- In cyanotic **congenital heart disease** there may be no mechanical route for deoxygenated blood to reach the lungs for oxygenation as in the **Tetralogy of Fallot** where there is pulmonary stenosis.
- There may be no pumping ability of the heart to supply blood to the body as in **hypoplastic left heart syndrome**.
- In atrial or ventricular septal defects the atrial or ventricular septum are deficient leading to mixing of oxygenated blood and deoxygenated blood. A combined defect, **AVSD (atrio-ventricular septal defect)**, is associated with Trisomy 21 (Down Syndrome).

Gastrointestinal (GI) Imaging in Children

<u>**Upper GI obstruction in neonates**</u>.

Malrotation and volvulus:

- Bilious vomiting in a new-born implies there is obstruction below the level of the bile duct opening into the second part of the duodenum.
  - This presentation should raise concern for malrotation of the bowel with volvulus which is a true paediatric surgical emergency.

- Neonates born with malrotation are predisposed to volvulus due to a shortened mesentery.
- The plain radiograph may show a distended stomach and proximal duodenum with little or no gas beyond this.
- However radiographs are often normal or unhelpful. The best imaging modality to diagnose this is a flouroscopic upper GI contrast study.
- Volvulus results in compromise of enteric blood supply. The entire bowel can infarct and require resection which carries huge morbidity and mortality (Fig. 5).

Hypertrophic pyloric stenosis:

- A cause of non-bilious vomiting typically in a first born, male infant under 3 months of age and can be diagnosed with ultrasound.
- Ultrasound typically shows a thickened circular muscle of the pylorus with a distended stomach. Treatment is surgical with a pyloromyotomy.

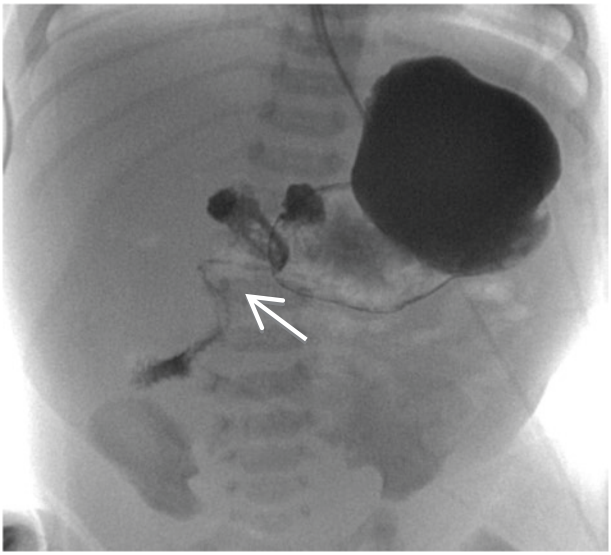


Fig. 5 An upper GI fluoroscopic study demonstrating the duodenal-jejunal flexure in an abnormal position to the right of the midline in keeping with malrotation. The bowel is tortuous distal to this due to volulus

Other causes of upper GI obstruction in a baby include:

- Oesophageal atresia which is often associated with a tracheoesophageal fistula.
- Duodenal atresia which is associated with Trisomy 21.

Lower GI obstruction in neonates:

- This is suspected clinically when vomiting is associated with abdominal distension and failure to pass meconium. The abdominal radiograph shows multiple dilated loops throughout the abdomen.
- Contrast enema is used for further assessment. The most common cause is Hirschprung disease. Other causes include imperforate anus, meconium ileus, meconium plug, ileal or colonic atresia.

Hirschsprung's disease:

- This is aganglionosis of the distal bowel typically involving the rectum and extending over a variable length of bowel.
- It can present in the newborn with failure to pass meconium or in childhood with chronic constipation. It is diagnosed definitively with rectal biopsy but the transition point may be delineated with a contrast enema.

Imperforate anus:

- These patients have no anal opening. The condition may be associated with other congenital anomalies such as oesophageal atresia and vertebral anomalies in the VACTERL syndrome (Vertebral, Anorectal, Cardiac, Tracheoesophageal fistula, Renal and Limb abnormalities).

Meconium ileus:

- This is small bowel obstruction in a newborn due to thick, inspissated meconium lodged in the distal ileum, causing obstruction and sometimes perforation. Meconium ileus occurs almost exclusively in babies with cystic fibrosis which will be diagnosed using a sweat test when the baby is at least one month old (Fig. 6).

<u>Other paediatric GI pathologies</u>:

Intussusception:

- Telescoping of one part of the bowel into the adjacent part through peristalsis which leads to obstruction. In children 90% are idiopathic and the usual age range is between 3 months and 3 years.
- Crying, pallor, drawing legs up to the abdomen are presenting features. Bloody (red currant jelly) stools, though classic, is a less common presenting feature.

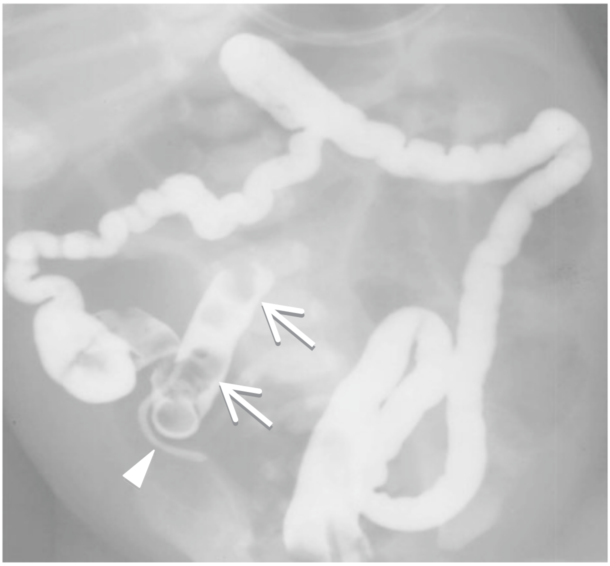


Fig. 6 Contrast enema in a neonate who failed to pass meconium. Thick plugs of meconium are seen obstructing the small bowel (arrows). Note the appendix filled with contrast (arrowhead)

- A mass may be felt within the right side of the abdomen. Ultrasound shows a donut appearance of the intussusception. An air-enema carried out by the radiologist successfully reduces the intussusception in approximately 85% of babies. The procedure has a 0.5% rate of perforation.

Appendicitis

- A common cause of abdominal pain presenting to the Paediatric ED. Ultrasound may show a thickened appendix. There may be inflammation of the surrounding mesentery and possibly an appendicolith.
- Children may form an inflammitory mass around an appendicitis that may be visible as an appendiceal mass on ultrasound.

Necrotising enterocolitis:

- This is an idiopathic colitis related to infection and ischemia affecting the premature infant in ICU. There may be nonspecific bowel dilatation with intramural air (pneumatosis) or, if the bowel perforates, pneumoperitoneum.
- Treatment is nil PO and antibiotics. This entity may be complicated by bowel strictures.

Renal Imaging in Children

- It is important to diagnose and promptly treat kidney and bladder infection in children as, if left untreated, the renal cortex may become scarred and non-functional.
- Ultrasound, micturating cysto-urethrograms (MCUG) and nuclear medicine studies may help to determine whether an infection is present, may detect any structural abnormality that could predispose to infection and may detect complications of infection, especially scarring.

Dilated renal collecting systems in the neonate:

- This may be identified on pre-natal ultrasound scanning. Post natal imaging is used to determine the cause of the dilated collecting system:
- **Pelviureteric junction (PUJ) obstruction**:
  - Obstruction of the proximal ureter. PUJ obstruction is the commonest cause of congenital hydronephrosis.
- **Posterior urethral valves**:
  - These are prominent folds in the lumen of the urethra that can block the passage of urine from the posterior urethra leading to bilateral hydronephrosis. Posterior urethral valves are diagnosed on MCUG.
  - Treatment of valves (Fig. 7) involves surgical fulguration.

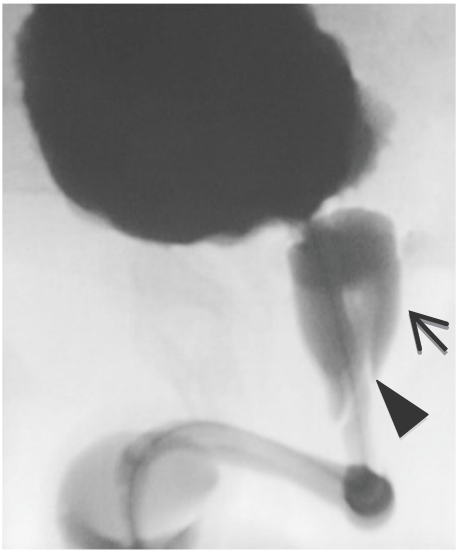


Fig. 7 Micturating cystourethrogram in a 2 month old boy who had hydronephrosis noted antenatally. Note the dilated posterior urethra (arrow) and the obstructing valves (arrowhead)

Radiologist's tips

- An ultrasound of the kidneys and bladder will diagnose dilated collecting systems (hydronephrosis) and malformed kidneys
  - A micturating cystourethrogram is a flouroscopic study that will diagnose **posterior urethral valves** and **vesoureteric reflux**.
  - Nuclear medicine studies: MAG3 is used to evaluate obstruction and DMSA scan to show scarring and differential function of each kidney.

Paediatric Neuroimaging

- It is possible to evaluate the neonatal brain by cranial ultrasound via the open fontanelle or sutures. As well as having no ionising radiation, it has the advantage of being very portable and can be used at the incubator in the neonatal intensive care unit for the sick newborn.

Intraventricular haemorrhage

- In the premature newborn, cranial ultrasound is used to detect intraventricular haemorrhage, (IVH) post haemmorhagic hydrocephalus and periventricular leukomalacia.
- IVH is more common in premature infants and tends to occur in the first week of life.

Neonatal encephalopathy:

- In the term infant this is usually secondary to a hypoxic ischaemic insult.
- Neonatal encephalopathy results in low APGAR scores, metabolic acidosis and, in severe cases, EEG abnormalities and seizures.
- This injury to the developing brain can lead to severe neurological deficits in later life.
- If suspected clinically it may be treated with cooling of the infant.
- MRI is the most sensitive investigation.

Spinal dysraphism:

- Also called spina bifida. This is caused by varying degrees of abnormal closure of the embryonic neural tube.
- It is the most common CNS congenital anomaly and can vary widely in severity from a dimple in the lower back to a **myelomeningocele**, which is a collection of CSF and spinal nerve roots lying exposed at the base of the spine.
- Patients may be functionally unaffected by milder forms but may be wheelchair-bound in more severe cases.

Paediatric Skeletal Imaging

- Children are prone to different types of musculoskeletal injuries than adults due to differences in bone structure and biomechanics.
- The presence of the growth plates or physis also makes childhood fractures different from those of adults (Fig. 8). The weakest link in the growing skeleton is at the physis. Fractures involving the physis are classified according to the Salter Harris classification system.

Developmental dysplasia of the hip

- Babies are clinically screened at birth for dislocation of the hip and for developmental dysplasia of the hip (DDH).
- Females, those born by breech delivery and those with a family history for DDH are more likely to have this condition which can be diagnosed on ultrasound in the first 8 weeks of life and with x-rays thereafter.
- Ultrasound or x-ray may show a dysplastic (shallow) acetabulum, subluxation or dislocation of the hip. These patients may need bracing or surgery.

Perthes disease

- This is an idiopathic avascular necrosis of the femoral head, and is most common in the 3–6 year age group.

Fig. 8 AP and lateral radiographs of the wrist demonstrating a fracture of the distal radius in a child which appears as a bump in the cortex (arrow) best appreciated on the lateral projection. This is known as a Buckle fracture. It occurs because developing bone falters with longitudinal compression resulting in a spectrum from buckle to greenstick to complete fracture

- Radiographs may be normal initially and later may show a smaller irregular femoral head which becomes progressively flatter and more deformed as the condition progresses (Fig. 9).
- Treatment is related to symptom control early in the disease.

Slipped upper femoral epiphysis (SUFE):

- This is a fracture of the physeal plate of the upper femur which needs orthopaedic fixation. This can be best seen on a frog-lateral view of the hips where the proximal femoral physis slips posteromedially.
- It is more common in overweight peripubertal boys (Fig. 10).

Non-accidenal injury

- Radiologists have important role in identifying cases of potential non-accidental injury.

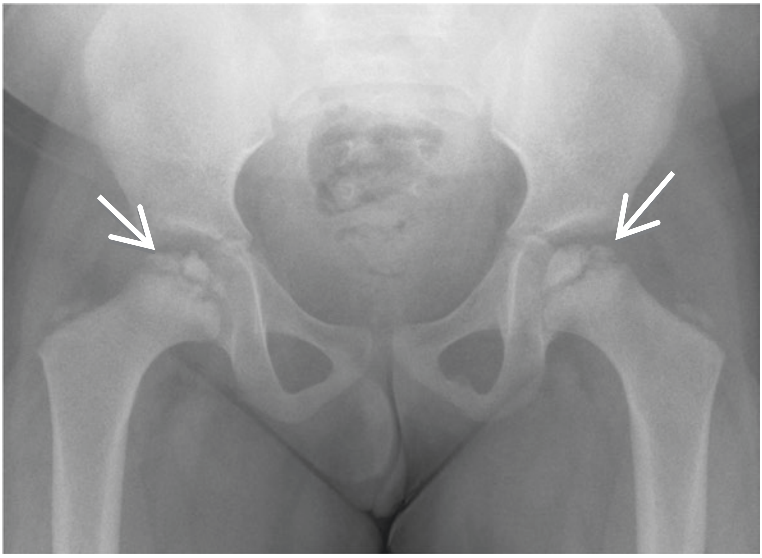


Fig. 9 A 4 year child presenting with bilateral hip pain. There is fragmentation and loss of height of the right femoral head and of the lateral aspect of the left femoral head in keeping with avascular necrosis or Perthe's disease

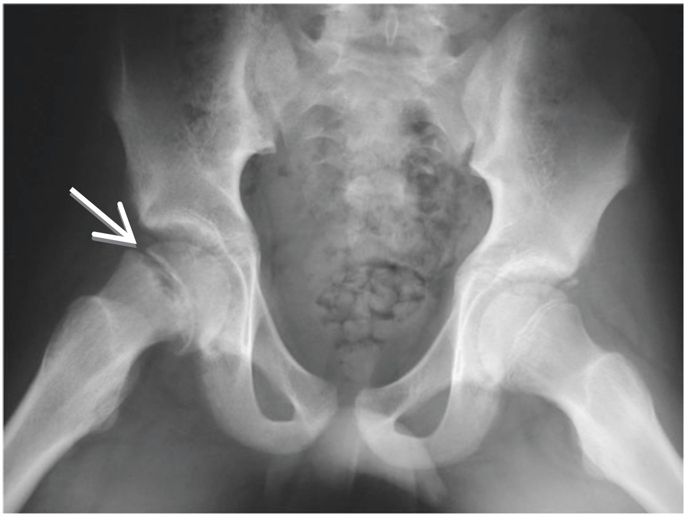


Fig. 10 Radiograph of the pelvis in an 11 year old with a painful right hip. It shows a right slipped upper femoral epiphysis. Notice the widened physis on the right (arrow) and the downward displacement of the femoral head

- Fractures of different ages on radiographs or that don't fit with the provided history should raise the suspicion of the radiologist and clinician for non-accidental injury.
- If this is suspected a full body series of radiographs called a skeletal survey can be carried out to check for other fractures. Certain fractures that are particularly suspicious include corner metaphyseal fractures, fractures of the posterior ribs, long bone fractures in a pre-ambulant child and multiple fractures at different stages of healing (Fig. 11).
- Subdural and intraparenchymal brain haemorrhages can also occur from abusive head trauma in 'shaken baby' syndrome. A CT brain is carried out on all suspected cases of NAI in the first year of life.

Radiologist's tip: Non accidental injury

- Certain fractures are particularly suspicious for non accidental injury:
  - corner metaphyseal fractures
  - fractures of the posterior ribs
  - long bone fractures in a pre-ambulant child
  - multiple fractures at different stages of healing.

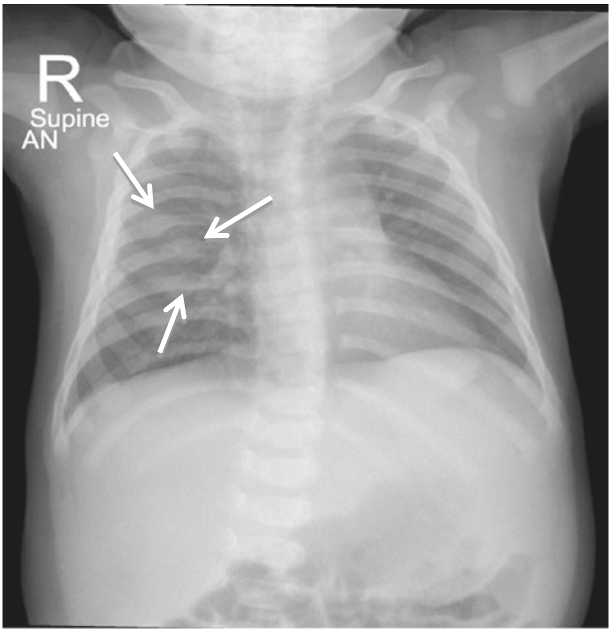


Fig. 11 A 3 month old baby who presented with a cough and fever. CXR showed multiple healing rib fractures. There was no history of trauma to account for these

Paediatric Oncological Imaging

- Paediatric oncology is a specialist branch of paediatrics which is treated in specialist centres. A multidiciplinary approach with oncologists, radiation oncologists, radiologists, pathologists and surgeons amongst others is key. Cases are often discussed on a global platform with experts from around the world to share knowledge and experience to improve outcomes.

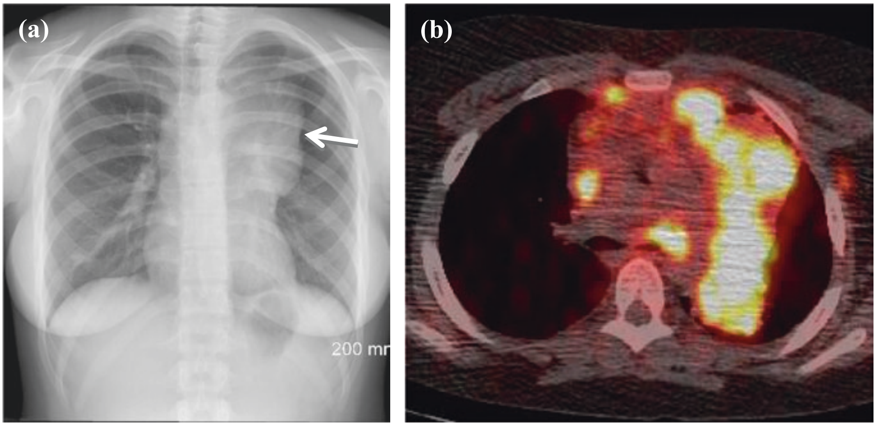


Fig. 12 Chest radiograph (**a**) in a teenager who presented with weight loss and night sweats. The left mediastinal border is markedly abnormal with mass-like enlargement. A PET CT scan (**b**) shows intense uptake of FDG in the tumour. This is a non-Hodgkin's lymphoma treated with radiotherapy and chemotherapy

Fig. 13 A coronal image from a CT chest and abdomen with contrast which shows a large mass (arrow) arising from the left kidney. Histology confirmed a Wilms tumour

- **Lukaemia**:
  - The most common childhood cancer accounting for approximately 30%. Abnormal leucocytes are produced in the bone marrow which supress the production of normal blood cells.
  - Imaging appearances of leukaemia are subtle and the diagnosis is usually made with blood tests and bone marrow biopsy.
- **Lymphoma**:
  - Accounts for 6% of childhood cancers and is a group of cancers characterised by reed Sternberg cells. 95% of cases are Hodgkin's Lymphoma.
  - Patients often present with lymphadenopathy, night sweats or weight loss (Fig. 12).
- **Wilms tumour**
  - The most common abdominal cancer in children.
  - It may present as abdominal mass in a child usually between the ages of 3–6 years. Cure rates are high with prompt recognition (Fig. 13).

Fig. 14 Radiograph of the left femur in a 10 year old in a child who presented with pain and swelling. There is an aggressive osteosarcoma in the mid femur with a "sunburst" perisoteal reaction

- **Osteosarcoma**
  - The most common malignant tumour of the bone in children. These are aggressive appearing tumours with periosteal reaction, tumour bone formation and soft tissue swelling (Fig. 14).

Suggested Further Reading

- Carty H, et al. Imaging children, 2nd ed. Churchill Livingstone;2005. ISBN-13: 978-0443070396.
- Donnelly LF. Paediatric imaging: the fundamentals. Saunders;2009. ISBN: 978-1-4160-5907-3.
- Applegate K, Anderson J, Klatte E, et al. Intestinal malrotation in children: a problem-solving approach to the upper gastrointestinal series. Radiographics. 2006;26 (5):1485–1500.
- Darras E, Roston A, Yewchuk L, et al. Imaging acute airway obstruction in infants and children. Radiographics. 2015;35 (7):2064–79.
- Fink K, Thapa M, Ishak G, et al. Neuroimaging of pediatric central nervous system cytomegalovirus infection. Radiographics. 2010;30 (7):1779–96
- Gordon I, et al. Guidelines for standard and diuretic renal imaging in Children. Eur J Nucl Med Mol Imaging. https://doi.org/10.1007/s00259-011-1811-3.
- Chao C, Zaleski C, Patton A, et al. Neonatal hypoxic-ischemic encephalopathy: multimodality imaging findings. Radiographics. 2006;26 (suppl_1):S159–S172
- Offiah A, van Rijn RR, Perez-Rossello JM, et al. Skeletal imaging of child abuse (non-accidental injury). Pediatr Radiol. 2009;39:461. https://doi.org/10.1007/s00247-009-1157-1.

Tutorial 14: Introduction to Nuclear Medicine

Anthony Cullen and Martin O'Connell

Aims and Guidance for Tutors

Nuclear medicine is an essential but sometimes poorly understood sub-specialty area of radiology and medicine. This chapter aims to familiarise students with the basic concepts of nuclear medicine imaging and modalities. The types and characteristics of radiopharmaceuticals will be described along with examples of common clinical applications. Upon completion of this tutorial, students should be able to describe the basic mechanisms of nuclear medicine imaging and recognise the appearance of several common pathologies on planar and hybrid imaging, including SPECT-CT and PET-CT.

Introduction

- Nuclear medicine allows the localisation and measurement of biochemical processes within the body using radiopharmaceuticals. Examples include evaluating organ function, such as myocardial perfusion or renal excretion studies. It also facilitates locating and measuring the activity of certain cancers. The information derived is different to that of anatomical imaging modalities such as CT or MRI.
- A key difference between nuclear medicine imaging and other types of diagnostic radiology is that the images are formed using radiation emitted from inside the patient, following injection of a radiotracer.

A. Cullen (✉) · M. O'Connell
Mater Misericordiae University Hospital, Eccles St, Dublin 7, Ireland
e-mail: cullen.2@gmail.com; anthonycullen@mater.ie

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_14

- Nuclear medicine images often have poor spatial resolution (the ability to distinguish between adjacent structures) and are frequently combined with anatomical imaging such as Computed Tomography (CT) to provide a more specific diagnosis.
- Radiopharmaceuticals can also be coupled with high energy sources of radiation to deliver therapeutic doses to certain types of cancer. Most often, a Beta-particle emitting atom is combined with a peptide or antibody which binds to a tumour cell and delivers radiation directly to the tumour.

Radiopharmaceuticals

- Radiopharmaceuticals are usually biologically active molecules combined with a source of radiation, a radionuclide, that accumulate in the organ or disease of interest. They are frequently called "radiotracers".
- A radionuclide is an unstable form of an atom which tries to become stable by emitting a charged particle or electromagnetic radiation. This spontaneous emission of radiation is called radioactivity.
- The most commonly used radionuclide in the nuclear medicine department is Technetium-99 m (^{99m}Tc).
- Technetium-99m is combined with various molecules or administered alone (called ^{99m}Tc Pertechnetate) depending on the imaging study required.
- The medical physics department play a key role in the creation and quality control of the radiopharmaceutical dose. They also calculate the estimated radiation dose to the patient based on factors such as the quantity and type of radiopharmaceutical administered, the biodistribution and the rate of excretion.
- Nuclear medicine facilities require a license from a regulatory body to use radiopharmaceuticals and are governed by laws in each country.

Imaging: General Considerations

- The radiopharmaceutical is usually administered intravenously, however some gastrointestinal or respiratory studies require the dose to be swallowed or inhaled.
- Imaging is performed according to the time it takes for biodistribution to the region of interest. This may take minutes or require the patient to return hours or days later.
- The imaging technique depends on the type of radioactive decay which occurs in the radionuclide. Beta decay occurs when a beta particle (an electron or positron) is emitted. Gamma decay occurs when a gamma ray is emitted and an atomic nucleus transitions to a lower energy state.
- Most imaging in the nuclear medicine department is performed with gamma radiation. Positron Emission Tomography (PET imaging) utilises positrons emitted during Beta decay.

- Gamma radiation is higher energy than diagnostic x-rays and requires a gamma camera system which is optimised to detect this range of energy.

Planar Imaging:

- Planar imaging is a technique in which non-tomographic (2D) planar images are created which show the accumulation of the radiopharmaceutical throughout the region of interest.
- Static or dynamic images can be obtained.
- This technique is commonly used for studies such as bone scans and thyroid scans. It is a reliable technique but is susceptible to artefact from overlapping regions of uptake.

Single-photon emission computed tomography (SPECT Imaging):

- In this technique the gamma cameras rotate around the patient acquiring images at intervals to allow 3D reconstruction of the radiotracer distribution.
- This technique takes longer than planar imaging but provides more accurate anatomical localisation.
- It is frequently combined with diagnostic CT images to provided co-registered hybrid imaging called SPECT-CT.
- A common use is the preoperative localisation of parathyroid adenomas using ^{99m}Tc-sestamibi SPECT-CT.

Positron emission tomography (PET Imaging):

Overview:

- PET radiopharmaceuticals decay by emitting positrons (Beta decay).
  - A positron is the antiparticle of an electron. It has the same mass but the opposite charge.
  - Positrons travel for approximately 2 mm before they annihilate with an electron.
- The destruction of the positron and electron releases two high energy gamma photons which travel in opposite directions.
- A PET scanner is comprised of a ring of scintillation crystals and photomultiplier tubes optimised to detect the high energy gamma radiation.
- PET scanners are integrated with CT scanners on the same machine. This allows fusion of the functional and anatomical imaging.
- The Standardised Uptake Value (SUV) is a ratio of radiotracer concentration in a lesion compared to whole body radiotracer concentration.
  - The maximum SUV value in a measured area (SUV Max) is quoted when measuring the distribution of radiotracer.

Radiopharmaceuticals:

- The most commonly used radiopharmaceutical is ^{18}F-Fluorodeoxyglucose (^{18}F-FDG).
- ^{18}F-FDG is a glucose analogue and is taken up by cells with high glucose requirements such as the brain and myocardium.
- Cancer cells also demonstrate increased uptake however this is not specific for cancer and increased uptake is also seen with infection and inflammation.
- The patient is required to fast before the scan as high blood glucose levels will interfere with scan quality.
- The patient should relax in a warm darkened room between the injection and scan to prevent uptake by brown fat and skeletal muscle.

Indications:

- Characterisation of lesions as benign or malignant, e.g. evaluating a solid solitary pulmonary nodule.
- Establishing the stage of a disease by detecting distant metastases.
- Assessing response to therapy and the presence of residual disease, e.g. in the treatment of lymphoma.
- Searching for occult malignancy e.g. a patient presents with a paraneoplastic syndrome.

Contraindications:

- Elevated blood glucose due to poor control of diabetes.
- Recent chemotherapy or radiotherapy.

Nuclear Medicine—Therapeutic uses:

Overview:

- Targeted radiotherapy can be administered using the same principles as diagnostic radiopharmaceuticals.
- Therapeutic radionuclides are used to deliver the radiation dose as close to the site of disease as possible.
- The most common therapeutic radionuclides are Beta particle emitters. These particles are emitted from the nuclei and are effective within millimetres.
- Alpha particles have a much larger mass than beta particles, containing two protons and two neutrons. They also travel a much shorter distance and deliver high energy to the site of disease resulting in cell death.
- Potential side effects are:
  - Acute—Most commonly nausea.
  - Sub-acute—Most commonly bone marrow suppression.

  - Late—Renal failure. Theoretical risk of radiation induced malignancy such as leukaemia.

- It is recommended to avoid close contact with patients post-treatment and some patients may require isolation.

Iodine-131 (^{131}I):

- I-131 ablates thyroid gland tissue and thyroid cancer cells with high-energy beta emissions.
- Gamma radiation emissions allow imaging of disease sites.
- It is effective for papillary and follicular thyroid cancers, Graves disease, toxic nodules.
  - It is not effective for anaplastic or medullary thyroid cancers due to poor iodine uptake.
- It is contraindicated in pregnancy.
  - Foetus receives high radiation dose from urinary excretion.
  - I-131 crosses the placenta and can ablate the foetal thyroid gland.
  - Also concentrates in lactating breast tissue, resulting in high breast dose.

Yttrium-90

- Yttrium-90 is a high-energy beta-emitting isotope with no primary gamma emission.
- Y-90 microspheres are used in Selective Internal Radiation Therapy (SIRT) for liver tumours such as unresectable hepatocellular carcinoma and colorectal liver metastases. The therapy is delivered intravascularly to the hepatic arteries by an interventional radiologist.

Radium-223 (Ra-223):

- α-particle radiopharmaceutical therapy that extends survival in patients with bone metastasis (3.6 month median survival advantage).
- Forms a complex with hydroxyapatite at sites of increased bone turnover.
- α-particle induces double-stranded DNA breaks.
- No radiation safety restrictions regarding contact with other people.
- Requires monitoring of blood count.

Case Review

See Figs. 1, 2, 3, 4, 5, 6 and 7.

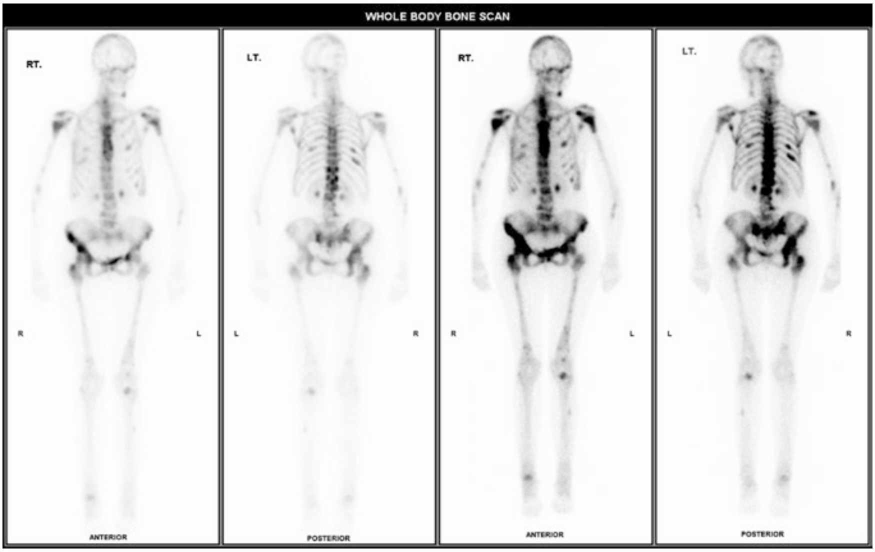


Fig. 1 Whole body bone scan in a 45 year old female with metastatic breast cancer. Technetium 99 m oxidronate was administered and 2D planar images acquired. There are multiple areas of areas of increased radiotracer activity in the axial and appendicular skeleton, most pronounced in the proximal humeri, ribs, vertebrae and pelvis

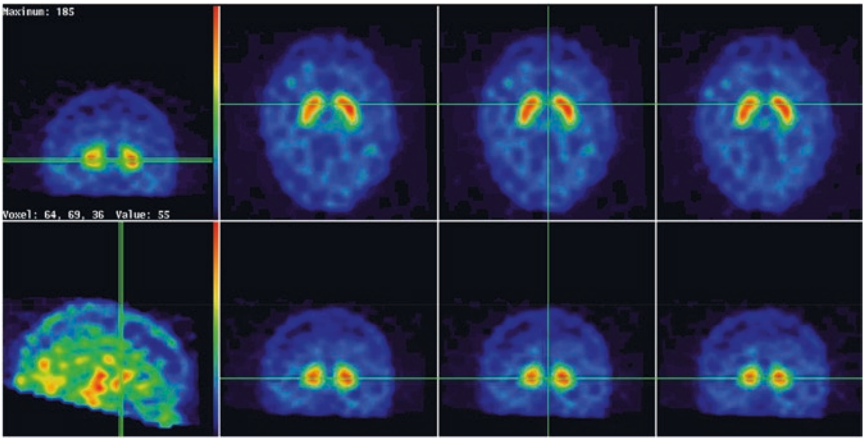


Fig. 2 SPECT brain imaging to assess the dopamine active transporter system (DAT scan). A DAT brain scan is often used to help distinguish Parkinson's disease from other causes of tremor or movement difficulties. Iodine-123—FPCIT (Ioflupane) was administered. There is normal uptake in the striatum—bilaterally

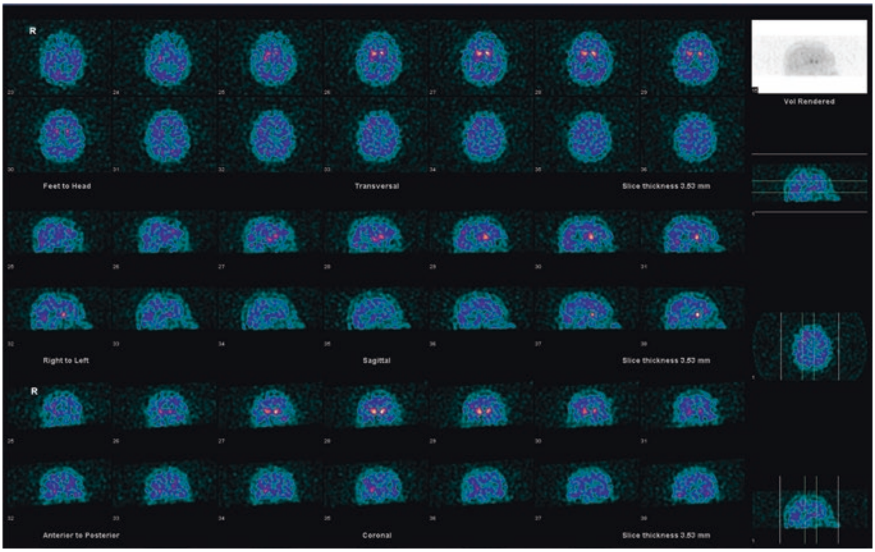


Fig. 3 SPECT DAT brain imaging in an 80-year-old male patient with clinical signs of Parkinson syndrome. The striatum demonstrates abnormally reduced uptake bilaterally, most pronounced in the posterior striatum. Findings are in keeping with neurodegenerative parkinsonism

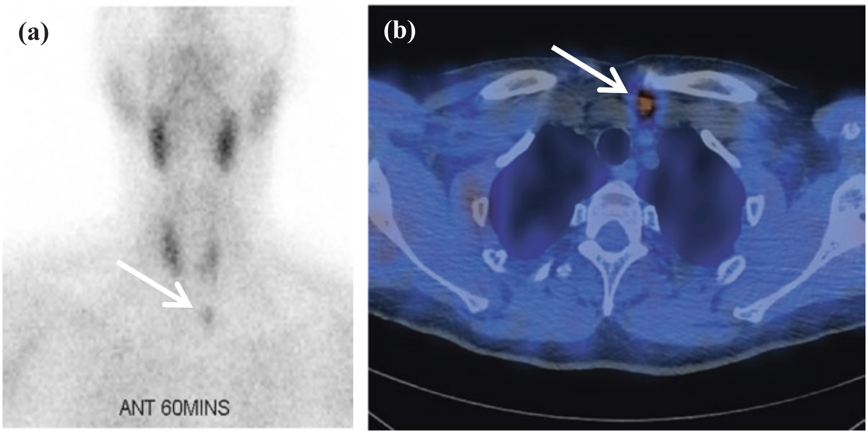


Fig. 4 A 49 year old male presented with symptoms of hyperparathyroidism. **a** Tecnetium-99 m- Sestamibi scan performed. Anterior planar imaging at 60 min demonstrated a focus of ectopic tracer uptake in the region of the left supra-sternal notch (arrow). **b** Exact location of lesion was provided by subsequently performed SPECT-CT which demonstrated a focus of uptake posterior to the left clavicle head and adjacent to the left brachiocephalic vein, consistent with an ectopic parathyroid adenoma (arrow)

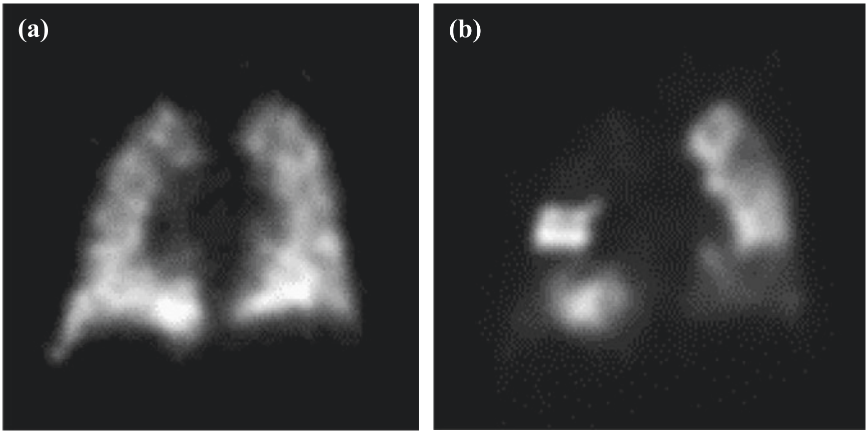


Fig. 5 A 54 year old male presented with pleuritc chest pain and new onset shortness of breath. He had a history of recurrent spontaneous pulmonary artery emboli and pulmonary hypertension. A Ventilation/Perfusion SPECT scan (V/Q scan) was performed with inhaled Technetium 99 m Pertechnetate and intravenous Technetium 99 m Macroaggregated Albumin. This image of the coronal ventilation (**a**) and coronal perfusion (**b**) studies demonstrates multiple mismatched perfusion imaging in the nuclear medicine department pulmonary artery emboli

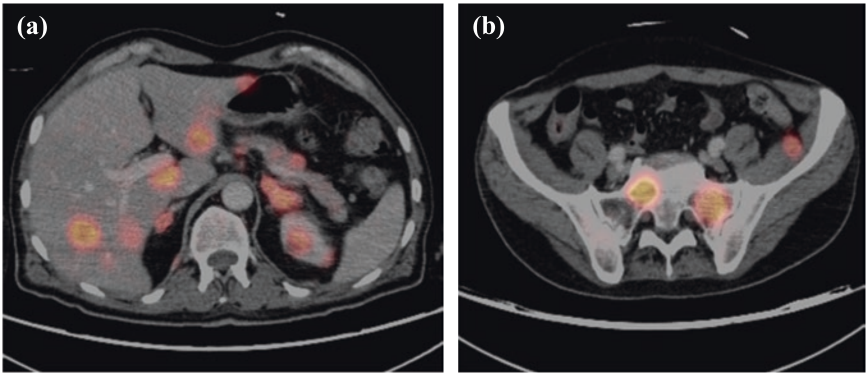


Fig. 6 A 53 year old man with a history of malignant melanoma and recent weight loss presented for a PET—CT scan to assess for recurrence. There is evidence of disseminated malignancy with multiple FDG avid areas including multiple hepatic, renal and adrenal metastases (**a**). Multiple intramuscular and osseous metastases are also present (**b**)

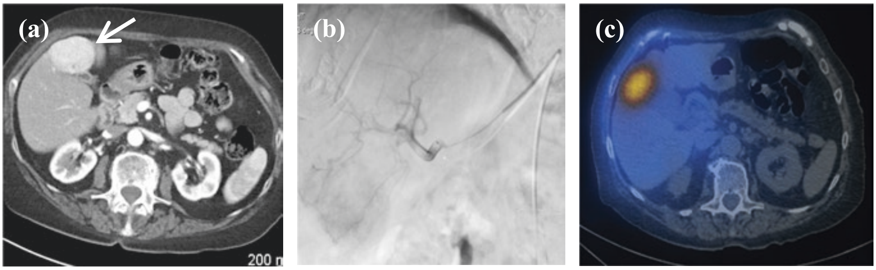


Fig. 7 An 83 year old female presented with hepatocellular carcinoma which had progressed despite recent therapy. **a** An arterially enhancing lesion liver is seen on coronal axial CT. **b** Selective Internal Radiation Therapy (SIRT) was performed by selectively delivering Yttrium-90 microspheres to the tumour via an intra-arterial catheter placed in the right hepatic artery. **c** Post treatment SPECT-CT images show excellent uptake within the tumour

Suggested Reading

- Mettler F, et al. Essentials of nuclear medicine imaging, 6th ed. Philadelphia: Saunders; 2012.
- Ziessman et al. Nuclear medicine–the requisites. 4th ed. Philadelphia: Saunders; 2014.
- European Nuclear Medicine Guide. European Association of Nuclear Medicine; 2018. https://www.nucmed-guide.app/#!/startscreen.

Tutorial 15: Emerging Imaging Technologies

Hong Kuan Kok and Hamed Asadi

Aims and Guidance for Tutors

Radiology is a rapidly evolving specialty of medicine with new technologies and innovations emerging at a constant pace. This tutorial provides a concise overview of future developments in imaging with a focus on artificial intelligence, radiation dose reduction and advances in imaging techniques.

Introduction

- Radiology is a specialty that has progressed at an unprecedented speed over the past two decades due to a variety of technological advances such as a transition from film-based to fully digitised reporting environments, increase in computational power and refinements in scanner technology and image processing techniques.
- In tandem with advances in diagnostic imaging, minimally-invasive Interventional Radiology (IR) procedures have also showed similar progress over this time and includes examples such as endovascular stroke thrombectomy, tumour embolisation and endovascular treatment of vascular diseases, made possible by new techniques and tools available to the Radiologist.

H. K. Kok (✉)
Interventional Radiology Service, Northern Health, Melbourne, VIC, Australia
e-mail: terrykok@gmail.com

H. Asadi
Interventional Neuroradiology Service, Austin Health and Monash Health, Melbourne, VIC, Australia

H. K. Kok · H. Asadi
School of Medicine, Deakin University, Geelong, VIC, Australia

© Springer Nature Switzerland AG 2020

C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_15

- Computational power has advanced to such a level that has allowed machines to run very complex algorithms which can assist the Radiologist in performing certain tasks such as semi-automated image interpretation, workflow optimisation and clinical decision making.

Artificial Intelligence/Machine Learning

- Artificial intelligence in its broadest sense is defined as the ability of computers to evaluate external data in the environment, learn from the data and respond to achieve a particular aim.
- Machine learning (ML) is a form of artificial intelligence and refers to a set of complex data modelling and analysis techniques with the potential to learn from experience. These algorithms can be supervised or unsupervised by the human operator.
- With ML, the process is semi-automated—the computer is provided the data, creates complex analytical models by utilising a learning framework to refine and optimise the accuracy of prediction.
- A wide array of ML algorithms exist, for which the specific details are beyond the scope of this chapter. However, some examples that may be encountered in the medical literature include different types of artificial neural networks and support vector machine. Readers are directed to recent review articles of ML in medicine for further detail.

Relevance to radiology:

- ML has attracted a lot of attention in Radiology due to the increasing volume and complexity of imaging work.
- As a speciality that deals with high level interpretation of large volumes of data in the form of digital images, reports and electronic clinical information, there is great potential for ML to support the growth of Radiology into the future.
- Pattern recognition and automated analyses of medical images by computers has emerged, partly due to the increase in number of imaging modalities and to the increased resolution and number of images generated from modern scanners, in an effort to reduce the workload within Radiology.
- Examples of ML applications include the automated detection, segmentation and analysis of lesions within an organ system (e.g. lung nodules, breast or liver lesions), either automatically generating a summary report or presenting these results to the reporting Radiologist for validation and cross checking.
- When used appropriately, ML has the potential to minimise error and improve reporting efficiency within Radiology departments—an important consideration given the exponential increase in demands on medical imaging, both in terms of volume and complexity.
- A potential future will see Radiologists engaging more in clinical work, supervising and validating ML assisted image reads and increasing their participation in ML assisted multidisciplinary meetings where management decisions are

made. The latter decisions will be based on multidimensional big data analysis resulting in a tailored management plan for each individual patient.

Examples of current applications in radiology:

- Imaging analytics and Computer Aided Detection of lesions (lung nodules, breast and liver lesions, automated analysis of brain perfusion imaging studies).
- Automated measurement of tumours in Oncologic imaging studies to accurately assess response to therapy and to improve reporting efficiency and reduce errors in the reproducibility of measurements.
- Worklist optimisation—ML algorithm continuously monitors new studies and prioritises patients with urgent clinical conditions (e.g. intracranial haemorrhage or stroke) to be presented next on the Radiologist's reporting workflow.
- Keyword detection in electronic medical records and radiology information systems—ML algorithm detects keywords relevant to the current imaging examination (e.g. Abdominal ultrasound in a patient with jaundice) and presents relevant clinical information (such as a history of cholestatic liver biochemistry results and cholecystectomy for gallstones) from the medical record to the Radiologist.
- Providing intelligent decision support for Interventional Radiology procedures incorporating data from imaging studies, patient demographics, risk factors and co-morbidities to present a selection of management strategies (e.g. management of intracranial aneurysms or peripheral vascular disease; Fig. 1).

Radiation Dose Reduction

- Many imaging tests involve exposure of a patient to ionising radiation with substantial differences in effective patient dose depending on the modality (e.g. conventional radiographs versus computed tomography [CT]) and sensitivity of the body part imaged to radiation (e.g. breast tissue versus bone).
- Due to the rapid expansion and utilisation of CT imaging, there has been increasing concern regarding radiation exposure, particularly in younger patients or those requiring repeated imaging studies over their lifetime (e.g. young patients with inflammatory bowel disease).
- Radiation dose reduction strategies are now incorporated in most modern CT scanners employing a combination of scanner based and image reconstruction techniques to reduce the dose to the patient.
- Scanner based strategies include the use of efficient imaging detectors and tailored x-ray tube output based on patient body habitus (e.g. lower x-ray beam kilovoltage and current setting based on body mass index or body part).
- Image reconstruction techniques make use of modern computing power allowing very complex algorithms to be used to produce diagnostic image quality for much lower radiation exposure parameters compared to older scanners. These techniques are commonly referred to as iterative reconstruction which represent a major advancement compared to older filtered back projection algorithms utilised since the early days of CT.

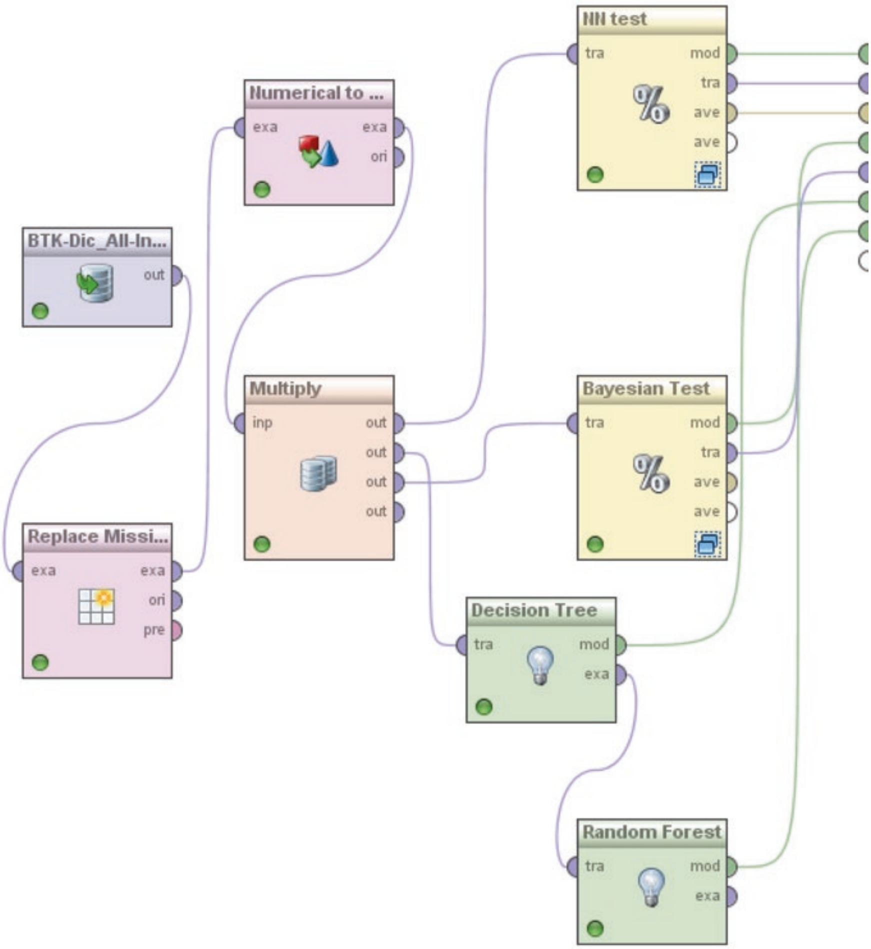


Fig. 1 Behind the scene of an example of a supervised learning ML algorithm to assist decision making for management of peripheral arterial disease. This algorithm consists of a number of 'nodes' and is programmed to study a database of patients with disease, risk factors and clinical outcomes. The aim in this example was to uncover complex relationships between patient and treatment variables using an artificial neural network to predict clinical outcomes and present it to the user in the form of a decision tree (not shown)

- Modern scanners are now able to acquire scans at very low dose—for example, CT coronary angiography can now be performed with doses of around 1 mSv on a modern scanner (based on prospective ECG acquisition, high scanner pitch, low tube exposure and iterative reconstruction) compared to 10–15 mSv on older scanners. Ultra-low dose chest CT can also be performed (Fig. 2) with some scanners and centres achieving doses comparable to a combined PA and lateral chest radiograph (0.2 mSv).

Advances in Imaging Techniques

- Innovative developments in CT technology has allowed imaging to expand beyond the traditional confines of anatomic imaging. It is now possible to gain further information on tissue characteristics or tissue blood flow (perfusion) through dual-energy CT scanning.
- Dual-energy CT exploits the principle of differing tissue interactions with x-ray beams of different energy levels (e.g. 80 and 140 kVp). These differences in tissue interaction allow tissues of different compositions to be characterised—for

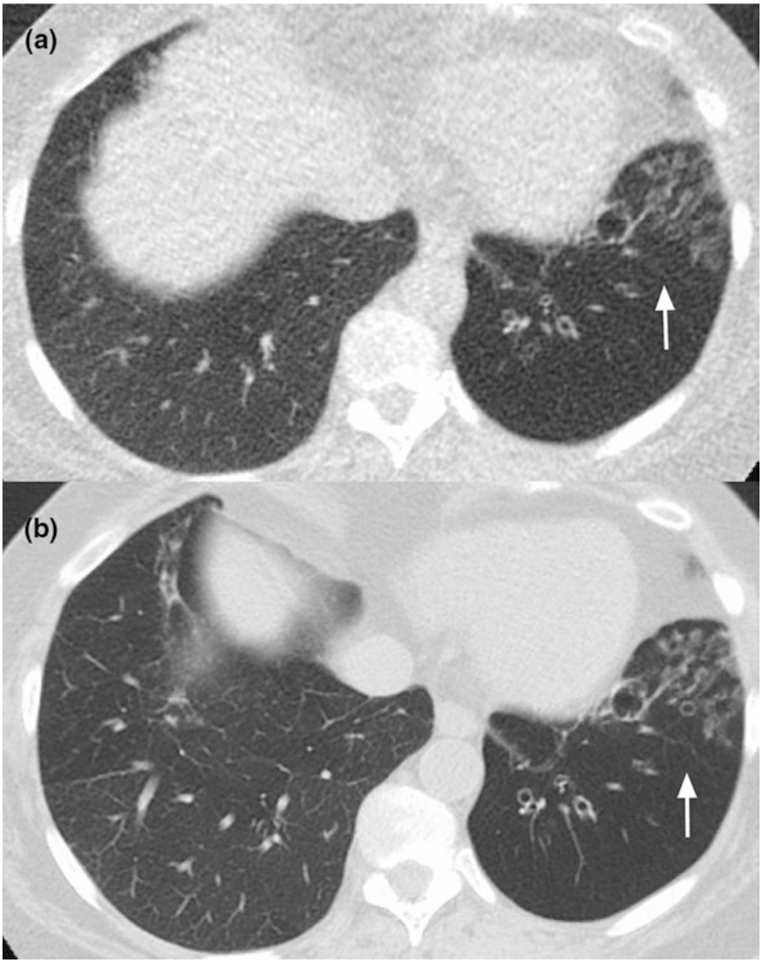


Fig. 2 **a** Ultra-low dose chest CT showing bronchiectasis in the left lower lobe (white arrow) at a dose of 0.2 mSv. **b** Previous study on an older CT scanner shows the same bronchiectatic changes (white arrow) at a dose of 2.5 mSv. There is increased image noise in the ultra-low dose scan, but image detail is sufficient for diagnosis

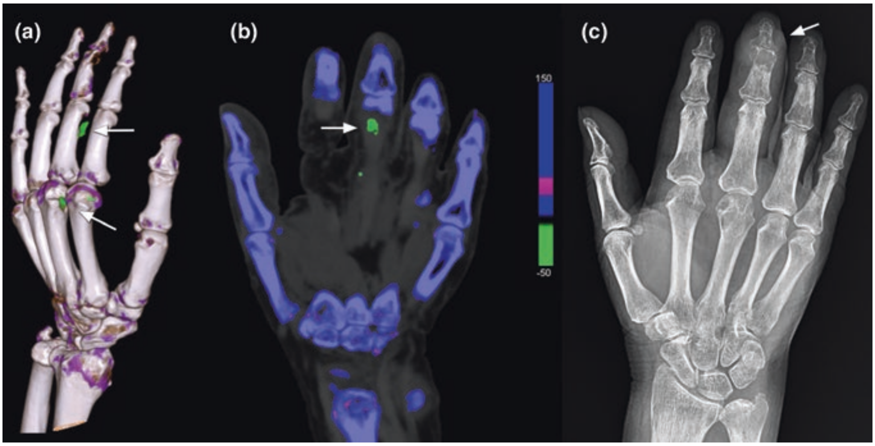


Fig. 3 **a** 3D volumetric reconstruction from a dual-energy CT study showing areas of uric acid deposition (white arrows) in a patient with gout. **b** Coronal dual-energy CT reconstruction showing uric acid deposition (arrow). **c** Hand radiograph of the same patient showing dactylitis of the middle finger (arrow) but no visible tophi

example, the composition of renal calculi detected on CT or the detection of uric acid deposition in periarticular soft tissues in patients with gout (Fig. 3).

- High field strength MRI scanners (7–9 Tesla) and ultra-high field strength scanners (ranging from 11–21 Tesla) are under development and some are starting to enter clinical use. Some of the advantages of higher field strength scanners include the ability to scan patients quicker or obtain images with superior spatial resolution and detail compared to current mainstream scanners which typically operate at a field strength of 1.5 or 3 Tesla.
- In addition to improvements in MRI scanner hardware, similar advances have been made in scanner software and sequences leading to a range of advanced imaging techniques. Recent examples include functional MRI which can measure brain activity based on the detection in blood flow alteration and oxygen consumption in different parts of the brain when activated.

Suggested Reading

- Handelman GS, Kok HK, Chandra RV, Razavi AH, Huang S, Brooks M, Lee MJ, Asadi H. Peering Into the black box of artificial intelligence: evaluation metrics of machine learning methods. AJR Am J Roentgenol. 2019;212 (1):38–43.
- Handelman GS, Kok HK, Chandra RV, Razavi AH, Lee MJ, Asadi H. eDoctor: machine learning and the future of medicine. J Intern Med. 2018;284 (6):603–619.

Tutorial 16: Sample Examination Cases

Ciaran E. Redmond, Eric Heffernan and Michael Lee

Aims and Guidance for Tutors

This chapter presents a collection of "examination style" cases. Each case has a clinical vignette and we suggest that students attempting these cases provide a description of the imaging findings and offer their favoured diagnosis. For each case there is a model answer and a summary of the key teaching points.

Radiologist's tips: Approach to radiology in examinations

- Take your time- carefully read the full question and take note of all images provided.
- The clinical vignette provided will often contain useful information and can hint towards the underlying pathology.
- Keep answers clear and concise- using a bullet point format can help with this.
- As a general rule try to avoid using acronyms.
- A suggested first step is to identify the modality and image plane
- Try to use correct radiological terminology in your description:
  - e.g. using terms such as "high attenuation" or opacification instead of "bright" or "white".
- Don't panic if you are initially unable to find an abnormality in the image, re-review it carefully and systematically.
- Try to think like a Radiologist would- at the end of your answer you can impress the examiner by making practical suggestions such as referring the patient for Multidisciplinary meeting discussion, further imaging or image-guided biospy.

C. E. Redmond (✉) · M. Lee
Academic Department of Radiology, Royal College of Surgeons in Ireland, Dublin 9, Ireland
e-mail: ciaranredmond1@gmail.com

E. Heffernan
Department of Radiology, St. Vincent's University Hospital, Dublin 4, Ireland

© Springer Nature Switzerland AG 2020

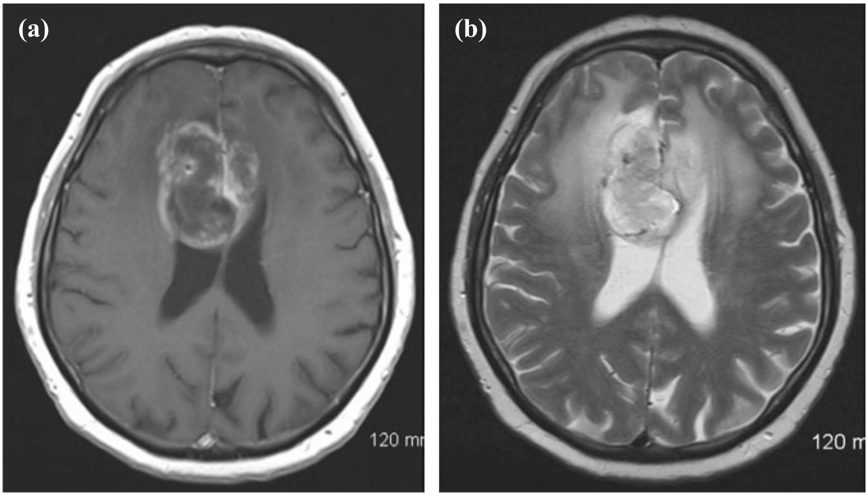
C. E. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students*, https://doi.org/10.1007/978-3-030-31893-2_16

Cases

Case 1: Unresolving headache.

Case vignette:
A 56-year man is brought to an emergency department after having a witnessed tonic-clonic seizure. He has no history of epilepsy or prior seizures. On questioning he reports recent intermittent headache and unintentional weight loss over the past three months. The patient's partner has noticed that he has been unusually emotionally labile over the same period.
Radiological investigations were performed as part of the patient's work-up.

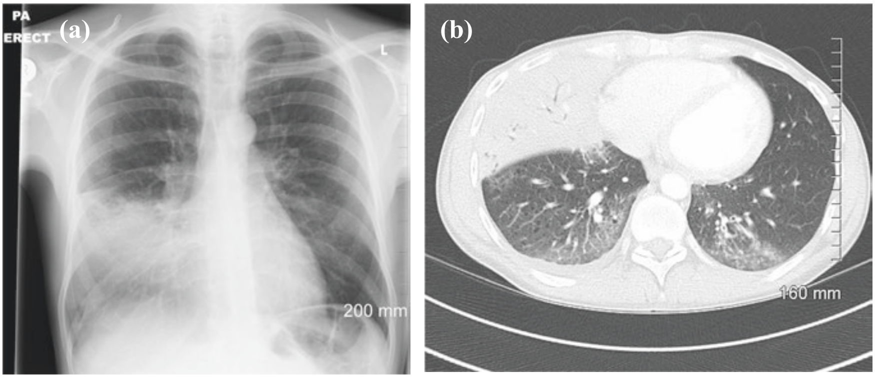
Radiological images:



Case 2: Cough and fever.

Case vignette:
A 61 year-old homeless man is referred to an Emergency Department with a two day history of productive cough, shortness of breath and fever. On examination there are decreased air entry and crepitations over the right lower chest. The patient's white cell count is elevated. A chest radiograph and CT thorax is performed.

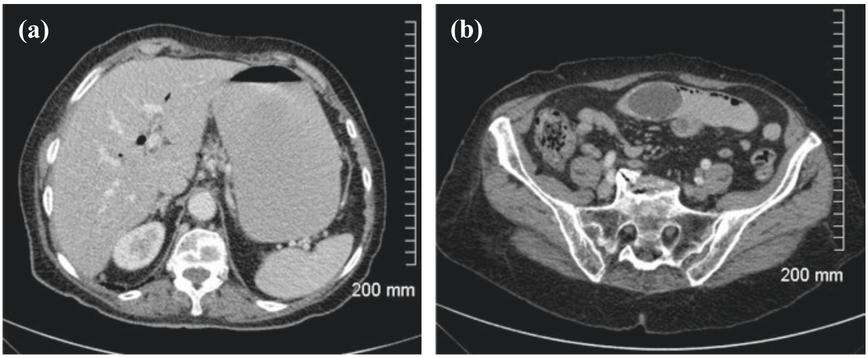
Radiological images:



Case 3: Abdominal pain.

Case vignette:
A 78-year old woman presents to an emergency department with a one day history of central abdominal pain associated with vomiting. The patient has known gall-stones. There is abdominal distension appreciable on examination.

Radiological images:



Case 4: Rheumatology clinic follow up.

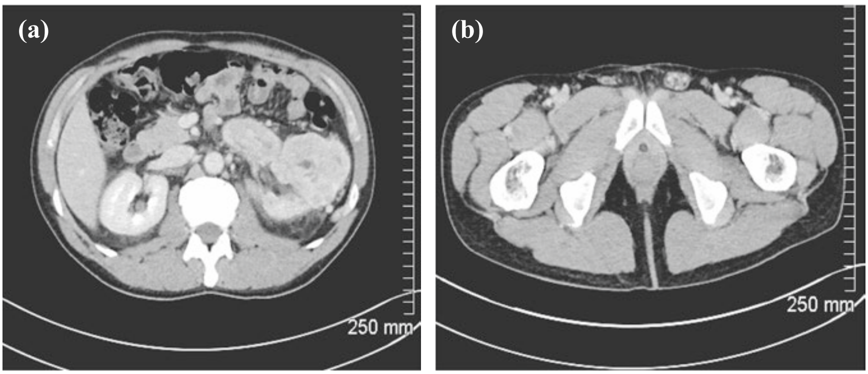
Case vignette:
A 68-year old woman with joint pain and stiffness attends for routine follow-up at a rheumatology clinic where she has been treated for a long period. She undergoes several radiographs, one of which is provided below.

Radiological image:

Case 5: New varicocoele.

Case vignette:
A 44-year old man presents to his general physician complaining of a new left sided scrotal swelling. On further questioning he also reports recent episodes of frank haematuria. On physical examination a left sided varicocele is evident, which the patient denied having previously. The patient is referred to a radiology department for investigation and a CT is performed.

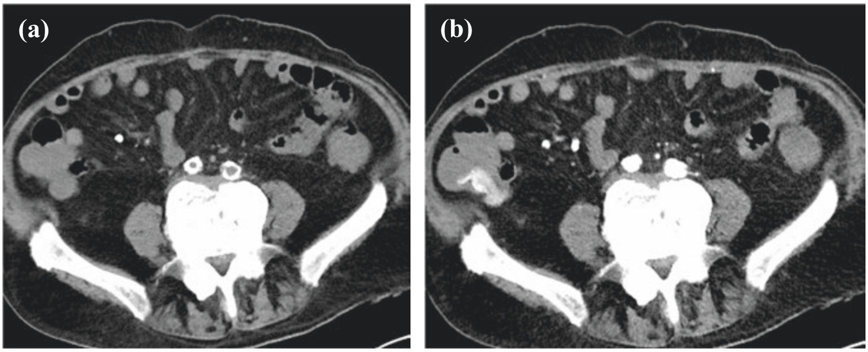
Radiological images:



Case 6: PR bleeding.

Case vignette:
An 80-year old man presents to an emergency department with acute onset large volume bright rectal bleeding. He has a history of atrial fibrillation and takes oral anticoagulant medication. On presentation the patient is haemodynamically unstable (tachycardiac and hypotensive). He undergoes an urgent CT.

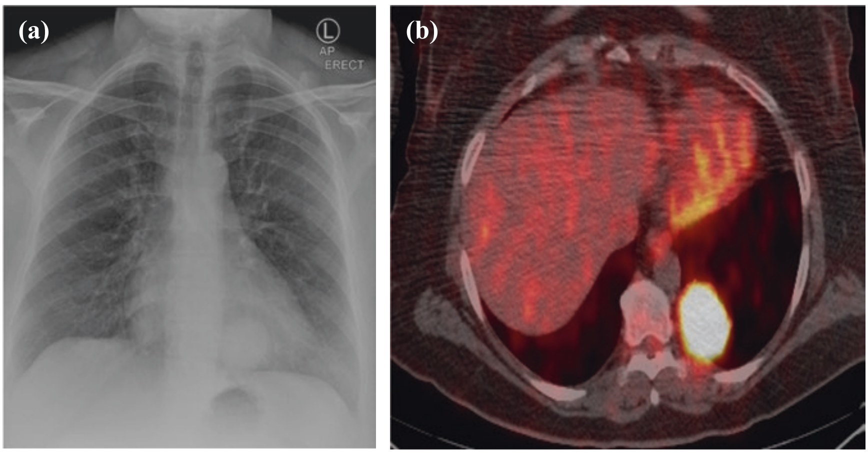
Radiological images:



Case 7: Haemoptysis.

Case vignette:
A 57-year old woman presents to a rapid access respiratory clinic with a history of recent haemoptysis. She is a smoker with a 60-pack year history. Further questioning reveals a six-month history of weight loss. On examination there is digital clubbing. As part of her work-up she undergoes a chest radiograph, a CT and a PET-CT.

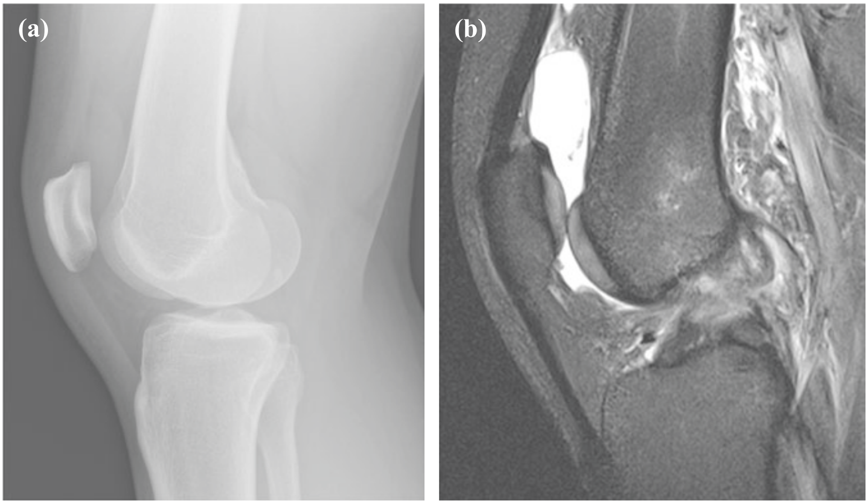
Radiological images:



Case 8: A knee injury.

Case vignette:
A 25-year old male sustains a left knee injury while playing soccer. He reports landing awkwardly from a jump and twisting his knee. He felt his knee "pop" and was unable to continue to play. On examination, the knee is swollen. There is a positive anterior drawer test. He undergoes radiography, followed by an MRI.

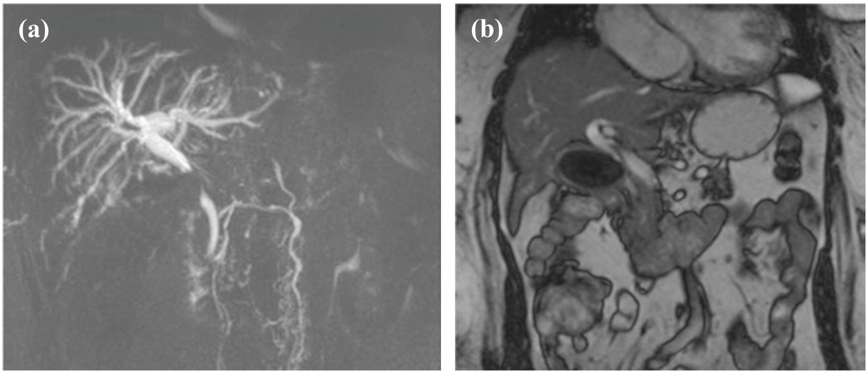
Radiological images:



Case 9: Severe abdominal pain.

Case vignette:
A 52-year old female with a history of known gallstones presents to the Emergency Department with acute onset right upper quadrant pain and jaundice. An ultrasound of the liver shows dilatation of the intrahepatic ducts. She is referred for further investigation with an MRCP.

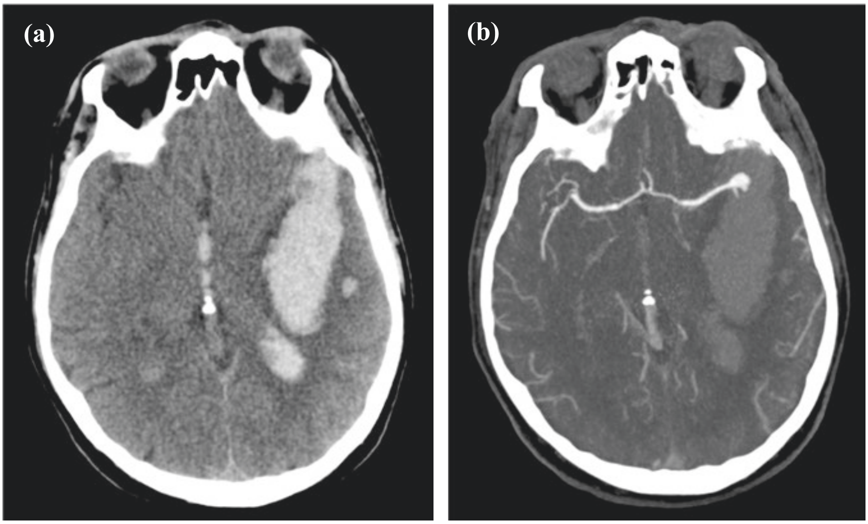
Radiological images:



Case 10: Headache.

Case vignette:
A 65-year old female is brought to the Emergency Department by ambulance. She reported a sudden onset severe headache. There was no history of trauma. Shortly after developing the headache she began vomiting. At time of arrival to hospital she has a reduced level of consciousness and a Glasgow Coma Scale of 12.

Radiological images:



Answers

Case 1: Unresolving headache.

Image findings:

- This is an MRI study of the brain- Image A is T1 weighted post intravenous contrast and image B is T2 weighted (notice how the fluid in the lateral ventricles is hyperintense on the T2 weighted).
- There is a ring enhancing mass involving both frontal lobes and protruding into both lateral ventricles.
- A considerable volume of cerebral oedema surrounds the mass- this is referred to as “vasogenic oedema”.

Diagnosis:

- Glioblastoma (GBM).

Teaching points:

- It is important to have a list of differential diagnoses for an intracranial ring enhancing lesion:
  - Brain tumour- primary (GBM) or secondary.
  - Cerebral abscess
  - TB
  - Multiple sclerosis
- Intracranial masses that encroach on the ventricular system, as in this case, can block flow of CSF through the ventricular system leading to hydrocephalus.
- The characteristic imaging appearance of vasogenic oedema is sparing of the gray matter at the periphery of the brain parenchyma.
- A glioblastoma that crosses along the corpus callosum to involve both cerebral hemispheres (as in this case) is known as a "butterfly glioma" due to the similarity in appearances with the wings of a butterfly.

Case 2: Cough and fever.

Image findings:
a:

- In this chest radiograph there is an area of consolidation in the right mid/lower zones.
- The adjacent right heart border is obscured. There is a horizontal line at the superior margin of the area of consolidation representing the horizontal fissure.
- The left lung is clear.

b:

- This CT thorax image confirms the presence of air bronchograms within the area of opacification.

Diagnosis:

- Right middle lobe pneumonia.

Teaching points:

- The loss of a well-demarcated silhouette of the right heart border indicates that the consolidation is in direct contact with the heart border. This is referred to as the "silhouette sign".
- An air bronchogram is when an air filled bronchus is made visible due to the presence of fluid or inflammatory exudate in the surrounding alveoli.

Case 3: Abdominal pain.

Image findings:
a:

- The stomach is very distended with fluid and oral contrast.
- There is gas within the intrahepatic biliary tree, this is referred to as pneumobilia.

b:

- There is an oval shaped structure impacted in the small bowel. The small bowel leading into this obstructing structure is dilated.
- There is no evidence of extra-luminal free air (pneumoperitoneum).

Diagnosis:

- Gallstone ileus.

Teaching points:

- Gallstone ileus is obstruction of small bowel due a large impacted gallstone.
- The term "ileus" is a misnomer in this instance, as an ileus refers to impairment of bowel function to a loss of normal peristalsis.
- The gallstone usually enters the bowel by a formation of a fistula between the gallbladder and the duodenum. The presence of this biliary-enteric fistula accounts for the presence of gas within the biliary tree.
- This case satisfies all three criteria for Rigler's triad which describes the common features of gallstone ileus: Small bowel obstruction, pneumobilia and an ectopic gallstone.

Case 4: Rheumatology clinic follow up.

Image findings:

- This radiograph of both hands demonstrates a severe erosive arthropathy, most marked at the metacarpophalangeal joints.
- There is sparing of the distal interphalangeal joints.
- Many of the metacarpophalangeal joints are subluxed with ulnar deviation of the fingers.

Diagnosis:

- Rheumatoid arthritis.

Teaching points:

- Patients with longstanding rheumatoid arthritis can develop deforming and debilitating disease in the hands.
- With improvements in modern treatment, cases like the one shown are becoming less common.

- A helpful method of differentiating osteoathritis (OA) and rheumatoid arthritis (RA) of the hands is to focus on the distal interphalangeal joints- these are spared in RA and frequently involved in OA.

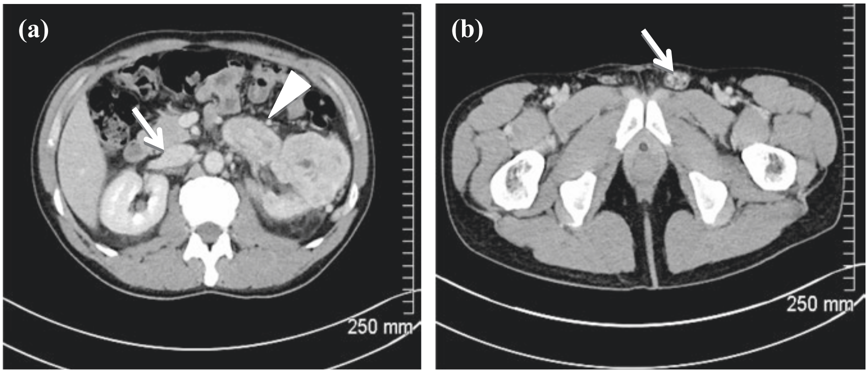
Case 5: New varicocoele.

Image findings:
a:

- This axial CT image of the abdomen demonstrates an aggressive looking mass in the left kidney- this is highly concerning for an malignancy.
- The left renal vein is severely abnormal- it is thrombosed and expanded. This vein has been invaded by tumour. The abnormal left renal vein is labeled in image A below (arrowhead). Notice how difference it appears to the normal right renal vein (arrow).

b:

- The upper part of the patients' varicocele was visualised at the lowermost image of the CT scan (labeled with arrow in image B below).



Diagnosis:

- Renal cell carcinoma with invasion of the left renal vein.

Teaching points:

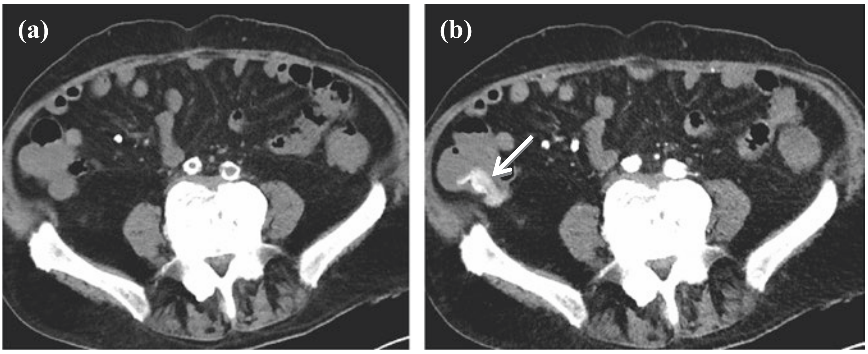
- The majority of large and enhancing renal lesions are renal cell carcinomas (RCC).
- Approximately 2/3 of patients present with frank haematuria.
- The investigation of frank haematuria includes a cystoscopy (assess bladder for malignancy) and a CT urogram (assess kidneys and ureters for malignancy).
- Advanced RCC can invade into the draining renal vein. When this occurs on the left side, obstruction of the gonadal vein (which drains into the left renal

vein) leads to development of a varicocoele. This does not occur with right renal vein involvement as the right gonadal vein drains directly into the inferior vena cava.

Case 6: PR bleeding.

Image findings:

- This is a CT angiogram of the abdomen (A: non-contrast phase, B: arterial phase).
- In the arterial phase image, there is dependent hyperattenuating material within the caecum, which was not present in the non-contrast phase. This is active extravasation of contrast media from a bleeding colonic vessel (labeled with arrow in image below).



Diagnosis:

- Gastrointestinal bleed (the cause for this was not certain but the patient's anticoagulant therapy was likely a causative factor).

Teaching points:

- CT plays an important role in the investigation of patients presenting with acute and unstable gastrointestinal haemorrhage. The CT protocol involves administering intravenous contrast and acquiring multiple phases to help identify a site of active extravasation of contrast.
- Potential causes for colonic haemorrhage:
  - colonic neoplasm
  - angiodysplasia

  – diverticular disease

- Patients presenting with gastrointestinal haemorrhage, as in this case, can be treated non-operatively in Interventional Radiology with embolisation of the supplying artery.

Case 7: Haemoptysis.

Image findings:
a:

- In the left lower zone, there is a well-rounded opacity located behind the heart. Given the patients smoking status the appearances are concerning for lung cancer.
- The lungs appear otherwise normal.

b:

- This is an axial image of a PET CT of the lower thorax.
- The lesion on the chest radiograph corresponds to a mass in the left lower lobe. The mass in contact with the posterior chest wall. It demonstrates avid FDG uptake indicative of a hypermetabolic process such as a malignant tumour.

Diagnosis:

- Primary lung cancer (adenocarcinoma).

Teaching points:

- Patients with haemoptysis or a concerning lesion on a chest radiograph should be referred urgently for respiratory assessment.
- Chest radiography has a suboptimal sensitivity for the detection of lung cancer-tumours projected over the cardiac shadow can be challenging to identify.
- In cases where tumours are peripherally located, as in this case, CT guided lung biopsy is performed to obtain a histopathological diagnosis.
- PET CT plays a role in the staging of lung cancer and to help identify patients who have resectable tumours.

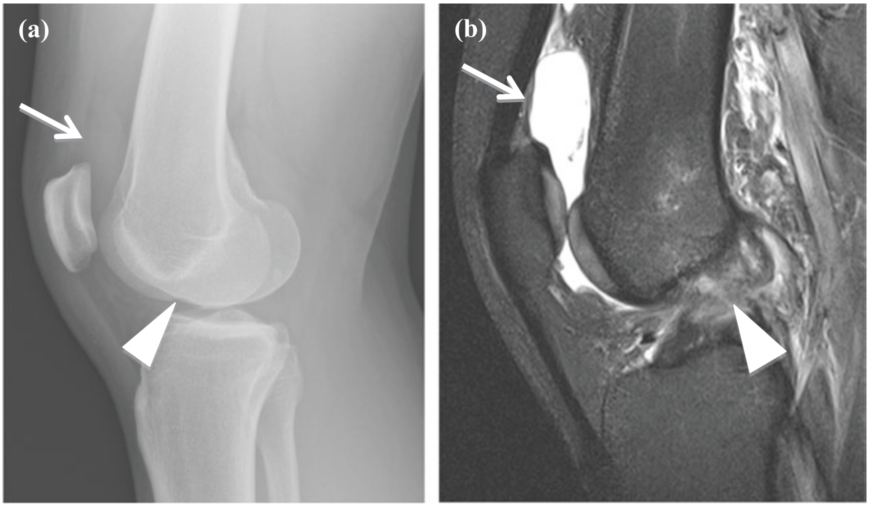
Case 8: A knee injury.

Image findings:
a:

- This lateral radiograph demonstrates a large knee joint effusion (labeled with arrow in image below). There is evidence of a depression in the lateral femoral condyle (labeled with arrow head)- this is known as the deep lateral femoral notch sign and is due a small impaction fracture.

b:

- In this sagittal MR image, the presence of a knee joint effusion is confirmed (labeled with arrow below). A complete tear of the anterior cruciate ligament is present (labeled with arrow head).



Diagnosis:

- Anterior cruciate ligament tear.

Teaching points:

- The anterior cruciate ligament (ACL) is the most commonly injured ligament of the knee joint- female athletes are at higher risk of ACL injury than male athletes.
- While the mechanism of injury and examination can be quite suggestive, the diagnosis is confirmed using MRI. If MRI is unavailable or contraindicated, CT is also highly sensitive.
- The simultaneous occurrence of tearing of the ACL, medial collateral ligament and medial meniscus is known as the “O’Donoghue unhappy triad”.

Case 9: Severe abdominal pain.

Imaging findings:
a:

- This is a maximal intensity projection image of the MRCP demonstrating the entire biliary tree. The intrahepatic ducts are dilated down to the level of the common hepatic duct.

b:

- This further coronal MRCP image shows a large oval structure compressing the common hepatic duct. This structure is similar in appearance to that seen in case 3 and is also a large gallstone.

Diagnosis:

- Mirizzi syndrome.

Teaching points:

- Mirizzi syndrome is a rare presentation caused by extrinsic compression of the common hepatic duct by a gallstone within the cystic duct or gallbladder.
- In patients presenting with right upper quadrant pain and jaundice, calculi in the common bile duct (choledocholithiasis) is a much more common cause.
- Patients with Mirizzi syndrome are treated with cholecystectomy.

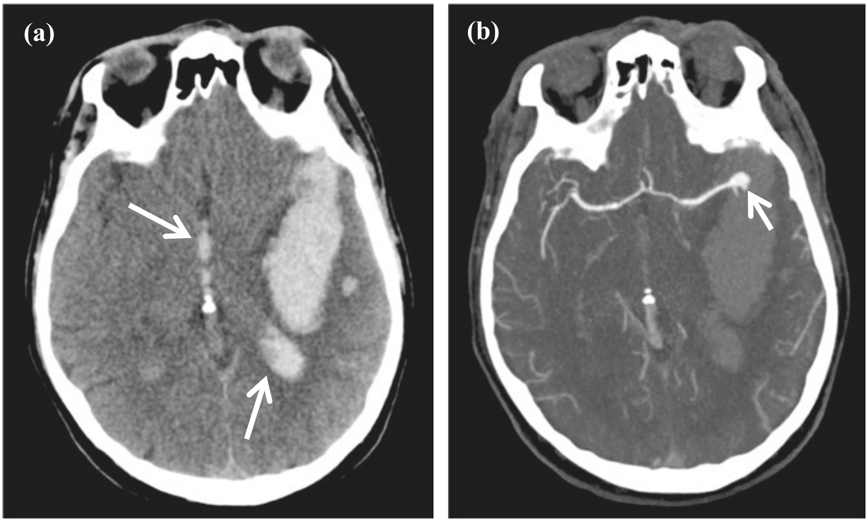
Case 10: Headache.

Image findings:
a:

- This axial image of a CT brain demonstrates a large acute haemorrhage in the left cerebral hemisphere. There is some extension of blood into the ventricular system (labeled with arrows in image below).

b:

- This is an image from a CT angiogram, performed immediately after the CT brain.
- The cause of the haemorrhage is identified and due to a ruptured aneurysm of the left middle cerebral artery (labeled with arrow below).



Diagnosis:

- Acute intracranial haemorrhage due to ruptured cerebral aneurysm.

Teaching points:

- In patients who are diagnosed with acute atraumatic intracranial haemorrhage, it is very important to perform a CT intracranial angiogram to help identify a potentially treatable cause for the haemorrhage.
- As well as the usual cardiovascular risk factors, there are several patient groups who have a predisposition for cerebral aneurysm formation:
  - Polycystic kidney disease
  - Marfan syndrome
  - Ehlers-Danlos syndrome
- The three most common site for cerebral aneurysms are the anterior communicating artery, the posterior communicating artery and the middle cerebral artery.
- Patients with ruptured cerebral aneurysms are often treated by coil embolisation in Interventional Radiology.

Index

© Springer Nature Switzerland AG 2020

C. Redmond and M. Lee (eds.), *Tutorials in Diagnostic Radiology for Medical Students,* https://doi.org/10.1007/978-3-030-31893-2