Tutorial 1: Introduction to Radiology

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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.

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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

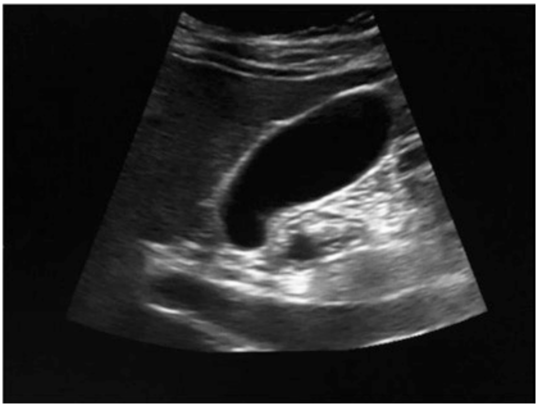


Fig. 2 US image of a healthy gallbladder in longitudinal plane. The gallbladder is filled with hypoechoic fluid (bile) and thus appears dark on B-mode image

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.

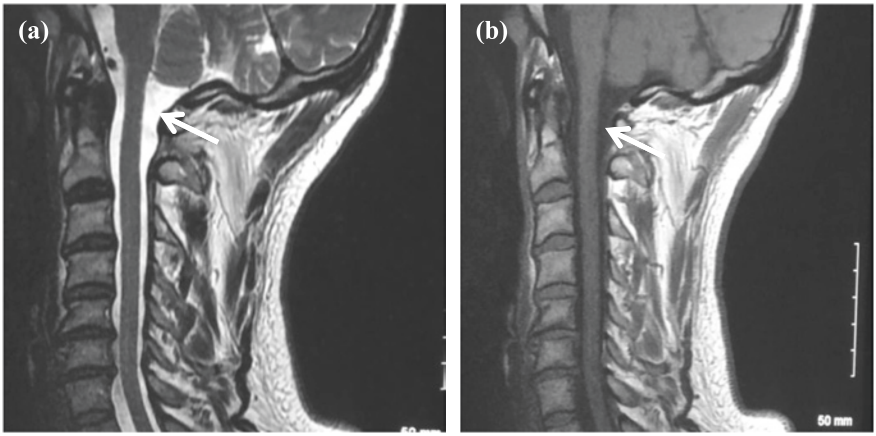


Fig. 3 MRI sagittal images of the cervical spine. The white arrows demonstrating the differences in the signal intensity of the cerebrospinal fluid in the spinal canal. This fluid is bright in image **a** (T2 weighted) and dark in image **b** (T1 weighted)

- 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.

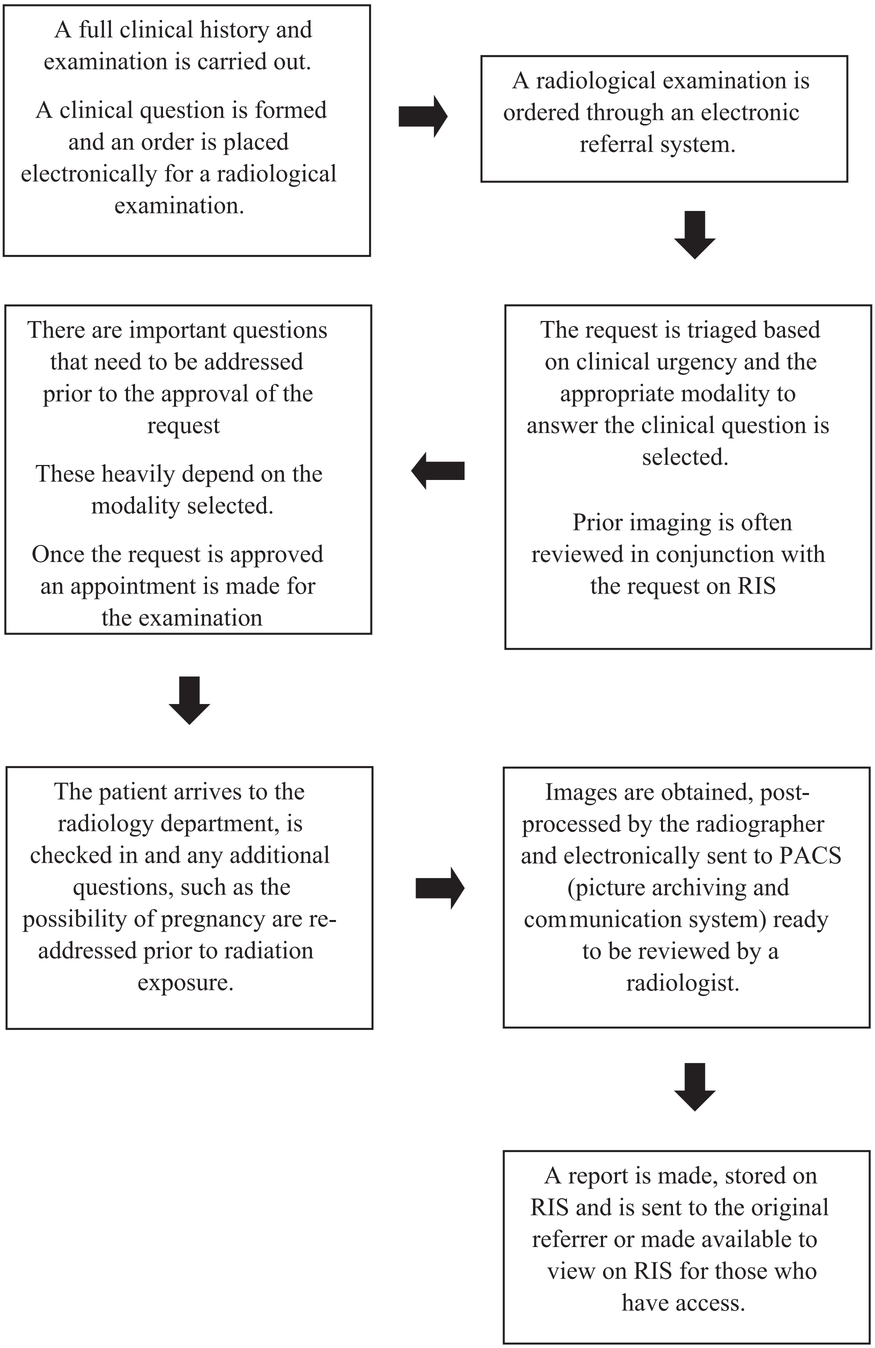
– Continually maintain and improve imaging protocols to provide high quality imaging and improved workflow.
– Mitigate the risks associated with unnecessary investigations, specifically those involving ionising radiation.

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

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