Cross Sectional Imaging
Made Easy®
To

My loving daughter
Jassim Singh
Preface

Explosion
Bang on radiology
With CT, PET-CT, MRI, Doppler, SPECT, sonology
Baffling, mystifying, bewildering, perplexing
Comprehend, amalgamate, understand
Get un bamboozle

Corroborate it with patients’ state
The diagnosis is made
The treatment is concocted

Vigor and strength rejuvenated
All is well and invigorated
The value of radiology cannot be measured
It can only be treasured.

– Hariqbal Singh

The advent of multiple modalities for Cross Sectional Imaging over last four decades has revolutionized the field of medicine leading to mystifying ways to image the patient.

I express my gratitude to Prof MN Navale, Founder President, Sinhgad Technical Educational Society’s and Dr Arvind V Bhore, Dean, Smt Kashibai Navale Medical College for their kind permission in this endeavor.

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Hariqbal Singh
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SECTION ONE

Computed Tomography
Physical Principle of CT Scan Imaging

CT was invented in 1972 by British Engineer, Sir Godfrey Newbold Hounsfield in Hayes, United Kingdom at EMI Central Research Laboratories using X-rays. EMI Laboratories is best known today for its music and recording business. About the same time South Africa-born American Physicist, Allan McLeod Cormack of Tufts University in Massachusetts independently invented a similar process, and both shared the 1979 Nobel Prize.

The first clinical CT scan was installed in 1974. The initial systems were dedicated only to head scanning due to small gantry, but soon this was overcome and whole body CT systems with larger gantry became available in 1976. Basic principle is to obtain a tomogram having thickness in millimeters of the region of interest using pencil beam X-radiation. The radiation transmitted through the patient is counted by scintillation detector. This information when fed in the computer is analyzed by mathematical algorithms and reconstructed as a tomographic image by the computer so as to provide an insight into the structure being studied.
DEVELOPMENTS IN CT TECHNOLOGY

Conventional Axial CT

Table 1.1 gives various generations of CT scan.

<table>
<thead>
<tr>
<th>Generation of CT scan</th>
<th>Motion of X-ray tube-Detector system</th>
<th>Stationary detectors</th>
<th>X-ray beam type</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>Translate-Rotate</td>
<td>Two detectors</td>
<td>Pencil beam</td>
</tr>
<tr>
<td>Second</td>
<td>Translate-Rotate</td>
<td>Multiple detectors</td>
<td>Narrow fan beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>up to 30°</td>
<td>(10°)</td>
</tr>
<tr>
<td>Third</td>
<td>Rotate-Rotate</td>
<td>Multiple detectors</td>
<td>Wide fan beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>up to 750°</td>
<td>(50°)</td>
</tr>
<tr>
<td>Fourth</td>
<td>Rotate-Fixed</td>
<td>Ring of 1500-4500</td>
<td>Fan beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>detectors</td>
<td></td>
</tr>
</tbody>
</table>

Spiral/Helical CT

Spiral CT uses the conventional technology in conjunction with slip ring technology, which simultaneously provides high voltage for X-ray tube, low voltage for control unit and transmits digital data from detector array. Slip ring is a circular instrument with sliding bushes that enables the gantry to rotate continuously while the patient table moves into the gantry simultaneously, thus three dimensional volume rendered image can be obtained. The advantages over the conventional scanner are the reduced scan time, reduced radiation exposure and reduced contrast requirement with superior information.

Electron Beam CT (EBCT)

In EBCT both the X-ray source and the detectors are stationary. High energy focused electron beam is magnetically steered on the tungsten target to emit X-rays
which pass through the subject on to the detectors and image is acquired. EBCT is particularly used for faster imaging in cardiac studies.

**Multislice/Multidetector CT (MDCT)**

Spiral CT uses single row of detectors, resulting in a single slice per gantry rotation. Multislice CT, multiple detector arrays are used resulting in multiple slices per gantry rotation. In addition, fan beam geometry of spiral CT is replaced by cone beam geometry.

The major advantages over spiral CT are improved spatial and temporal resolution, reduced image noise, faster and longer anatomic coverage and increased concentration of intravenous contrast.

**Dual Source CT**

The dual energy technology of the new Flash CT provides higher contrast between normal and abnormal tissues making it easier to see abnormalities while reducing radiation. With its two rotating X-ray tubes, enhanced speed and power allows children to be screened more effectively. It turns off the radiation when it comes close to sensitive tissue areas of the body like thyroid, breasts, or eye lens. Pediatric patients benefit because they do not need to hold breath or lay completely still during the examination and they do not have to be sedated.

**Hounsfield Units**

CT numbers recognized by the computer are from (-) 1000 to (+) 1000, i.e. a range of 2000 Hounsfield units which are present in the image as 2000 shades of gray, but our eye cannot precisely discriminate between these 2000 different shades.
Hounsfield scale assigns attenuation value of water as zero (HU 0). And other media attenuation value as compared to water is listed in Table 1.2:

<table>
<thead>
<tr>
<th>Media</th>
<th>Attenuation value in HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>(-) 1000</td>
</tr>
<tr>
<td>Lung</td>
<td>(-) 400 to (-) 800</td>
</tr>
<tr>
<td>Fat</td>
<td>(-) 40 to (-) 100</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
</tr>
<tr>
<td>Fresh blood</td>
<td>55 to 65</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>40 to 80</td>
</tr>
<tr>
<td>Bone</td>
<td>400 to 1000</td>
</tr>
</tbody>
</table>

**Window Level (WL) and Window Width (WW)**

To permit the viewer to understand the image, only a restricted number of HU are put on view and this is accomplished by setting the WL and WW on the console to an suitable range of Hounsfield units, depending on the tissue, for interpreting the image. The expression WL represents the central Hounsfield value of all the Hounsfield numbers within the WW. Tissues with CT numbers outside this array are shown as either black or white. Both the WL and WW can be set on the displayed image as desired by the viewer. On CT examination of the chest, a WW of 300 to 350 and WL of 35 to 45 are chosen to image the mediastinum (soft tissue window where as WW of 1500 and WL of 0 is used to assess the lung window.
Image Reconstruction

The acquisition of volumetric data using spiral CT means that the images can be postprocessed in ways appropriate to the clinical situation.

Multiplanar reformatting (MPR) is by taking standard axial images and subject to the three-dimensional array of CT numbers obtained with a series of contiguous slices; and can be viewed sagittal, coronal, oblique and paraxial planes (Figs 1.1A to C).
Figs 1.1A to C: Bilateral renal cysts seen in axial section (A) are reformatted into sagittal (B) and coronal (C) planes
Three-dimensional Imaging

Many fractures like fracture of the mandible associated frontal bone with or without walls of sinuses can be reconstructed into a three-dimensional image (Figs 1.2A to D).

Figs 1.2A to D: Fracture of body of mandible and frontal bone. With bilateral maxillary hemosinus
CT Angiography

CT angiography (CTA) sequence is created subsequent to intravenous contrast, images are acquired in the arterial phase and then reconstructed and exhibited in 2D or 3D format. This performance is used for imaging the aorta, renal, cerebral, coronary and peripheral arteries (Figs 1.3 to 1.5).

Figs 1.3A to D: CT abdominal angiography
Physical Principle of CT Scan Imaging

Fig. 1.4: Volume rendered image posterior coronal plane

Fig. 1.5: Volume rendered image posterior oblique coronal plane
CT is readily available in most hospitals and stand alone CT centers. It is fast imaging modality and provides with cross sectional high resolution images. Data acquired on axial scans can be used for multiplanar and 3D reconstructions. It detects subtle differences between body tissues. However it uses X-rays radiation which has radiation hazards, CT need contrast media for enhanced soft tissue contrast. Contrast is contraindicated in asthma, cardiac disease, renal and certain thyroid conditions.
Extradural hematoma occurs as the result of laceration of a meningeal vessel or dural sinus following trauma and requires urgent intercession, patients generally present with a period of lucency followed by a diminished level of consciousness. In extradural or epidural hemorrhage, blood accumulates between dura and the inner table of the skull. Bleeding is generally from the middle meningeal artery. It results in a high attenuation biconvex collection compressing the brain parenchyma.

The swirl sign is an ominous sign of epidural or extradural hemorrhage and has two components, an active component and a more chronic one (Figs 2.1A and B). The active component is usually a small rounded lesion that is isoattenuating to the brain and that represents actively extravasating unclotted blood. The chronic component is the hyperattenuating extra-axial hematoma collection, which typically measures 50-70 HU. CT is the imaging modality of choice in the extradural hematoma, it shows a high attenuation biconvex collection compressing the brain parenchyma.
Figs 2.1A and B: CT brain shows acute extradural hemorrhage as hyperdense biconvex lens shaped collection in the right frontoparietal region, it is extending to interhemispheric fissure. Hypodense areas in it suggest fresh bleed into the subdural hematoma due to swirling of blood and is called ‘the Swirl sign’
SUBDURAL HEMATOMA (SDH)

Hemorrhage that occurs in between dura mater and arachnoid mater surrounding the brain is called SDH. Bleeding occurs due to damage of the bridging veins within the subdural space, resulting in the formation of a SDH. CT scan is the investigation of choice and presents a concavoconvex appearance and does not cross the midline (Figs 2.2A to D).

**Figs 2.2A to D:** Plain CT brain shows chronic (hypodense) right subdural hematoma causing mass effect in the form of compression of right lateral ventricle and contralateral shift of midline structures. In addition, there is a small acute bleed (hyperdense) in left frontotemporoparietal region (arrow) and also within the right chronic hematoma (oblique arrow).
**SUBARACHNOID HEMORRHAGE**

Subarachnoid hemorrhage (SAH) is bleeding into the subarachnoid space, the area between the arachnoid membrane and the pia mater surrounding the brain (Figs 2.3A to D). This may occur spontaneously, usually from a ruptured cerebral aneurysm or may result from head injury.

*Figs 2.3A to D:* (A) Diffuse subarachnoid hemorrhage (SAH) along the cisterns; (B) SAH in the interhemispheric fissure and in the left cerebral sulcus; (C and D) SAH in left cerebellopontine angle cistern and hemorrhagic contusion in left temporal lobe
Symptoms of SAH include thunderclap headache (severe headache of rapid onset), vomiting, confusion, lowered level of consciousness and/or seizures. The diagnosis is confirmed on CT.
INTRACRANIAL BLEED

Intracranial bleed is described as a bleed into the brain parenchyma. It may be impossible to distinguish traumatic intracerebral from spontaneous intracerebral hemorrhage, at times the history may be unhelpful. Unenhanced CT is the imaging modality of choice. A 35-years-old hypertensive male presented with sudden onset right sided hemiparesis. Axial unenhanced CT shows evidence of intraparenchymal hemorrhage on left side in temporoparietal region, having CT value 55-60HU, with adjacent edema of cerebral parenchyma (Fig. 2.4).

Fig. 2.4: Plain axial CT brain shows fresh intracranial hemorrhage seen as hyperdense area in left temporoparietal region
Cerebral infarction is caused by blockage of arteries of the brain. Atherosclerosis is the most common predisposing factor. Cerebral infarction most commonly occurs in the middle cerebral artery territory, lacunar infarction occurs in the basal ganglia and the internal capsule.

Unenhanced CT is the initial imaging modality, due to its availability and promptness in diagnosis. Within the first 6 hours CT may show no abnormality. If early diagnosis of cerebral infarct is vital, MRI (perfusion and diffusion sequences) is the investigation of choice. It can detect the cerebral infarct at a very early stage.

The cardinal sign of infarction on CT is an area of decreased attenuation within the cerebral substance (Figs 2.5A to C). Typical locations are within the known territory of a major vessel (e.g. the middle or posterior cerebral arteries), or in the basal ganglion or internal capsule.

Figs 2.5A and B: Right MCA infarct is seen as hypodense area in right cerebral hemisphere. The mass effect has caused compression on ipsilateral lateral ventricle with minimal midline shift.
Fig. 2.5C: Plain CT shows hyperdense appearance of MCA-‘Hyperdense MCA sign’, which is the earliest indicator of impending cerebral ischemia/infarct. This patient had left side hemiparesis of sudden onset.

The area of diminished density accompanied by mild mass effect, may be seen as early as 6 hours after the onset of symptoms but in many cases it may not be clearly visible for the first 24 hours. Brain tissue once infarcted the dead neurons slowly undergo gliotic change. Normal brain has a CT attenuation value of more than 30 HU. A fresh infarct has CT value 25-30 HU. An old infarct has a further reduction in CT value 10-15 HU. An old infarct ultimately appears as area of gliosis with loss of volume and finally is replaced by CSF density fluid and this is known as cystic encephalomalacia or porencephalic cyst.

In infarction the occluded artery may appear denser than surrounding brain due to acute intraluminal thrombus-the ‘hyperdense artery sign’ (Fig. 2.5B). This is the earliest indicator of impending cerebral ischemia or infarct.
TUBERCULOMA BRAIN

Common pathological conditions leading to ring enhancing lesions on CT of the brain are granuloma, abscess, some primary brain tumors, resolving hematoma and infarct.

Figs 2.6A to D: Precontrast (A and B) and postcontrast (C and D), CT brain images show conglomeration of intensely enhancing ring lesions with perilesional edema in right frontal lobe
Tuberculoma is usually formed by conglomeration of several miliary tubercles, which form around the outer sheaths of the small cerebral blood vessels (Figs 2.6A to D). The center of the conglomeration becomes caseous and gets inspissated and sometimes liquified. A thick capsule may form around these lesions.
TEMPORAL LOBE ABSCESS

Cerebral abscess results from local or hematogenous spread, resulting from cardiac, paranasal sinus or aural disease (Figs 2.7A and B).

Figs 2.7A and B: (A) Scout image of CT brain shows loculated air in the cranium with air fluid level. (B) Contrast CT brain shows right temporal abscess with air-fluid level with enhancement of wall of the abscess
GLIOBLASTOMA MULTIFORME

This case was confirmed to be a glioblastoma multiforme on histopathology. Glioblastoma multiforme rarely calcifies. It is one of the most malignant forms of glioma and is the most common primary brain tumors (Figs 2.8A and B). It is known to occur in multifocal pattern in about 5% cases.

Figs 2.8A and B: (A) CT shows a mass with hyperdense areas of calcification in left parietal lobe. It is causing mass effect in the form of compression of left lateral ventricle and a significant shift of midline structures to contralateral side. (B) Contrast CT shows the enhancing components of the mass and the mass effect caused by it.
Primary tumors that metastasize to the brain include melanoma, sarcomas, tumors arising in the kidney, colon and lung. In addition, unknown primaries sometimes present with brain metastases. The incidence of brain metastasis is far more prevalent than primary brain cancer (Figs 2.9A and B).

Figs 2.9A and B: Contrast CT brain show multiple enhancing metastases with primary being a solitary pulmonary nodule in right lung
RETINOBLASTOMA

Retinoblastoma arises from primitive neuroectodermal cells in retina. It may be hereditary or sporadic and may be bilateral. Over 80% of retinoblastoma show evidence of calcification on CT scan. In patients under three years of age in whom a retinoblastoma is suspected, the presence of calcification on CT scan is virtually diagnostic (Fig. 2.10).

Fig. 2.10: Two years old boy with proptosis left eye. Contrast CT orbits revealed calcification in the enhancing retinal soft tissue mass
ANTROCHOO ANAL POLYP

Antrochoanal polyps are benign tumor of the maxillary sinus more common in children. Allergy has been implicated as etiology. These polyps originate in the lining of the maxillary antrum and gradually prolapse through the natural or an accessory ostium into the nasal cavity and enlarge towards the posterior choana and nasopharynx. They cause nasal obstruction and serous otitis media if they occlude the eustachian tube (Figs 2.11A to D). Radiographic examination
Computed Tomography

with CT scan and more rarely MRI helps the diagnosis. Surgery remains the mainstay of treatment and the endoscopic approach should be used in first intention.
Mucoceles are benign, mucus-filled lesions lined with columnar or cuboidal epithelium. They are most frequently found in the frontal and ethmoid sinuses causing expansion of the sinuses. The typical radiographic appearance of mucoceles is a fully opacified sinus with evidence of rounded or ovoid expansion and bone erosion (Fig. 2.12).

Fig. 2.12: Adult male presented with proptosis, CT scan revealed a mucocele in the right anterior ethmoidal sinus.
AMELOBLASTOMA OF MANDIBLE (FIGS 2.13A TO D)

Ameloblastoma is a benign tumor of odontogenic epithelium (ameloblasts) most common in mandible than maxilla, however most common site is posterior body and angle of the mandible. On X-ray it appears as a lucency in the bone of varying size often as a multiloculated “soap bubble” appearance.

Figs 2.13A to D: (A) Pantomogram shows multiseptated expansile lucency involving the body of mandible on right side with loss of adjacent teeth. (B) Contrast CT shows mildly enhancing soft tissues occupying the lesion. (C and D) CT in bone window shows the expansile lucency with thinning of mandibular cortex. A large left maxillary polyp is also present.
FACIAL FRACTURES

The mandible is a frequent site for fractures due to assaults, accidents or underlying pathology with myriad methods for repairing this bone (Figs 2.14A to F).

Figs 2.14A to F: Plain CT shows fractures of (A) Mandible on left side. (B) Hard palate on left side. (C) Walls of left maxillary sinus with hemosinus. (D) Left zygomatic arch and walls of left maxillary sinus. (E) Left lateral orbital floor. (F) Reconstructed 3D CT image shows most of the fractures.
FRACTURE OF VERTEBRAL BODY

Compression fracture of vertebral body may be associated with localized hemorrhage seen as paravertebral soft tissue mass similar to that seen in abscess.

Wedge compression fracture of body of L1 vertebra is seen with retropulsion of the body and bony fragment is seen encroaching on the spinal canal. In addition, L2 and L3 vertebrae are also fractured (Figs 2.15A to D).

Figs 2.15A to D: Axial (A), Sagittal reformatted (B) and volume rendered (C and D). CT images in a patient with history of fall from height
MILIARY TUBERCULOSIS

Discrete nodules 1-2 mm in diameter are distributed throughout both lungs; these nodules may coalesce and enlarge (Figs 2.16A to C).

Miliary tuberculosis infection in the lung results from erosion of the infection into a pulmonary vein. Once the infection enters a pulmonary vein, it is carried throughout the lung, leading to the development of small nodules that can be seen on imaging studies.

Figs 2.16A to C: (A) Scout image shows miliary shadows in both lungs. (B) CT chest mediastinal window shows pericardial effusion. (C) CT thorax lung window shows bilateral multiple miliary opacities.
bacteria reach the left side of the heart and enter the systemic circulation, they seed the organs such as the liver and spleen. Alternately, the bacteria may enter the lymph node and drain into a systemic vein and eventually reach the right side of the heart and seed to the lungs, causing miliary tuberculosis.
CENTRILOBULAR OPACITIES IN PULMONARY KOCH’S

Endobronchial spread in pulmonary Koch’s on CT appear as poorly defined centrilobular rosettes of nodules, 2 to 10 mm in diameter, branching centrilobular opacities, described as “tree-in-bud” (Fig. 2.17).

Fig. 2.17: Centrilobular opacities in pulmonary Koch’s
FUNGAL BALL

Fungal lung infection, when it occurs, is probably from hematogenous spread (Figs 2.18A to C).

Figs 2.18A to C: 43 years old male presented with cough fever and weight loss with loss of appetite since two months. (A) Radiograph of chest PA view, demonstrates a well-defined cavity in right lower zone with fairly well-demarcated opacity seen in it. (B) CT chest shows a thick-walled cavity in the right lower lobe with a fungal ball inside the cavity. (C) Fungal ball moved to the dependent position when CT chest was performed in prone position. This fungal ball was caused by Candida albicans as confirmed by transbronchial biopsy.
IDIOPATHIC PULMONARY FIBROSIS

Idiopathic pulmonary fibrosis (IPF) is chronic, progressive interstitial lung disease. It is a chronic fibrosing interstitial pneumonia characterized with abnormal and excessive deposition of fibrotic tissue with minimal associated inflammation (Figs 2.19A to C).

Figs 2.19A to C: (A) High-resolution CT chest scout image shows reticular prominence and cystic spaces. It is not possible to judge whether the cystic appearance is due to bronchiectasis or due to honeycombing. (B and C) Show abundant areas of subpleural honeycombing and interstitial thickening. These features are seen in idiopathic pulmonary fibrosis. The patient presents with breathlessness and dry cough.
PULMONARY EMBOLISM

The diagnosis of pulmonary emboli can be made by CT scanning if a filling defect outlined by a thin rim of contrast is visualized within the lumen of the vessel (Figs 2.20 and 2.21). Another common finding in the more peripheral arteries is the complete cut-off sign; this is produced when the thrombus completely occludes the lumen.

Figs 2.20A and B: Axial CT Pulmonary angiography images show pulmonary embolism in both right and left pulmonary arteries
Figs 2.21A and B: Coronal reformatted image from contiguous axial from CT pulmonary angiography images shown in Figs 2.20 A and B to show the entire extend of pulmonary embolus in both right and left pulmonary arteries.
PULMONARY ARTERIAL HYPERTENSION (PAH)

77 years old male had breathlessness for 15 days. X-ray chest shows enlarged cardiac silhouette and round paracardiac opacities.

Main pulmonary artery (MPA) diameter in this case measures 4.5 cm (Figs 2.22A to D). Values for MPA greater than 3.37 cm is suggestive of pulmonary arterial hypertension, when viewed in an unenhanced axial 10 mm section on standard mediastinal window.

Figs 2.22A to D: CT shows dilated pulmonary arteries which resulted in paracardiac opacities on X-ray chest (A)
THYMOMA

Thymoma is a lymphoepithelial neoplasm. 15-30% are malignant. They usually arise in the superior anterior mediastinum, but may project into the adjacent middle mediastinum. CT scan shows a homogeneous density with uniform enhancement, may occasionally be cystic. Invasion of the adjacent structures may be identified with malignant thymomas (Fig. 2.23). Thymic hyperplasia usually enlarges the gland but maintains its normal pyramidal shape.

Fig. 2.23: Contrast CT image shows invasive thymoma with invasion of superior vena cava and left pulmonary artery
HODGKIN’S LYMPHOMA

Intrathoracic group of nodes are involved in patients with lymphoma, the most common are: (a) Prevascular and paratracheal group, (b) Hilar group and (c) Subcarinal nodes. Lymph node enlargement is most common in Hodgkin’s than in non-Hodgkin’s lymphoma (Fig. 2.24). In most cases the involvement is bilateral and asymmetrical. The posterior mediastinal nodes are infrequently involved.

Fig. 2.24: Contrast CT in a proven case of Hodgkin’s lymphoma shows a large mediastinal lymph node mass. There is compression of mediastinal structures. Pleural calcification is present.
NEUROFIBROMA

Nerve sheath tumors are the most common posterior mediastinal masses and neuroblastomas being the most common. They are classified according their origin:

a. Peripheral nerves (neurofibroma, schwannoma and their malignant counterparts) (Fig. 2.25).

b. Sympathetic ganglia (ganglioneuroma, ganglioneuroblastoma, neuroblastoma).

Fig. 2.25: Neurofibroma
NORMAL CT CORONARY ANGIOGRAPHY
(FIGS 2.26 TO 2.29)

Fig. 2.26: Volume rendered image axial plane

Fig. 2.27: Volume rendered image coronal plane
Fig. 2.28: Volume rendered image posterior coronal plane

Fig. 2.29: Volume rendered image posterior oblique coronal plane
REDUNDANT TORTUOUS AORTA

Tortuous aorta is a pathological condition where the aorta is tortuous and redundant may have irregular shape (Figs 2.30A and B). It can affect blood flow from the heart to the body tissues.

Figs 2.30A and B: Scout CT image of chest shows prominent descending aorta raising a suspicion of aneurysm. Aortic reconstruction following contrast CT chest shows no aneurysm but only tortuous dilatation of thoracic aorta.
COARCTATION OF AORTA

In coarctation of aorta there is a characteristic shelf-like narrowing of the aorta which usually occurs just beyond the origin of the left subclavian artery (Figs 2.31A to D). The severity of coarctation or narrowing can vary considerably and it is this severity which determines the age of presentation (Figs 2.31E to G).

**Figs 2.31A to D:** CT aortic angiography in a case of postductal coarctation of aorta. (A) Aortic arch shows reduction in diameter of descending aorta as compared to ascending. (B and C) The diameter of ascending aorta (upright arrow) is maintained but that of descending aorta (down pointing arrow) has abruptly reduced. (D) Return of normal caliber of descending aorta.
Figs 2.31E to G: (E and F) Coronal and sagittal reformatted image shows the actual site of coarctation. (G) Color coded CT angiogram shows exact location of narrowing.
HEPATIC TRAUMA

Liver is most frequently injured abdominal organ after spleen. Most often due to deceleration injuries, often seen in association with right-sided rib fractures, right-sided pneumothorax, right lung contusion and injuries to the right kidney or adrenal gland. Posterior segment of right lobe is most frequent site (near spine and ribs). Lacerations extending to bare area may only have retroperitoneal finding (Figs 2.32A to C).

Figs 2.32A to C: (A) Contrast CT abdomen shows small contusions in liver. (B) Contrast CT abdomen shows lacerated liver. (C) CT images in a patient with diaphragmatic rupture with herniation of liver in the thorax
SIMPLE HEPATIC CYST

Liver cysts are benign congenital malformations resulting from isolated aberrant biliary ducts. The cyst contents are usually clear serous fluid. They do not invade biliary or vascular elements, but may cause obstruction or compression atrophy of the liver parenchyma when they attain a large size. Complications are hemorrhage, rupture, torsion and infection (Figs 2.33A and B).

Figs 2.33A and B: (A) Plain and (B) contrast CT abdomen show a large thin walled hypodense (12 HU) cystic lesion in the liver with smooth margins. No septae or calcifications seen
HYDATID CYST LIVER

Hydatid cyst is caused by the parasite *Echinococcus granulosus*.

Though commonly found in liver, the lung and mediastinum are also involved. Calcification may be seen. Other features which aid in diagnosis are:

a. *Meniscus sign*: Radiolucent crescent in the uppermost part of the cyst.

b. *Air-fluid level*: Rupture of cyst walls with air entering in the endocyst.

c. *Water-lily sign*: Completely collapsed cyst membrane floating on the cyst fluid (Fig. 2.34).

![CT scan shows a large cystic lesion occupying most of the right lobe of liver. It has multiple daughter cysts](Hydatid Cyst)
HEMANGIOMA LIVER

Hemangioma is the most common benign tumor of the liver. The classic findings of hemangioma on CT show hypoattenuation similar to that of vessels; on dynamic contrast-enhanced CT peripheral globular enhancement and a centripetal fill-in pattern with the attenuation of enhancing areas identical to that of the aorta and blood pool (Figs 2.35A to D).

Figs 2.35A to D: Well-defined hyperdense lesion is seen in liver (A) that shows peripheral enhancement (B and C) in arterial phase and progressive centripetal fill in delayed phases (D)
HEPATIC CIRRHOSIS

Cirrhosis results from chronic liver disease characterized by replacement of liver tissue by fibrosis, scar tissue and regenerative nodules leading to loss of liver function. Alcoholism, hepatitis B and C, fatty liver and unknown causes are the etiology factor (Figs 2.36A and B).

Figs 2.36A and B: Shrunken liver with nodular contour, esophageal and splenoportal collaterals (arrow) are seen along with massive ascites indicating portal hypertension.
HEPATOCELLULAR CARCINOMA

The mass was excised and confirmed to be a hepatocellular carcinoma (Figs 2.37A to D).

Figs 2.37A to D: Elderly female had right upper quadrant pain. (A) Plain CT abdomen shows mass in liver. (B) Arterial phase CT shows enhancement in the mass. A hypodense scar is also seen (arrow). (C) Venous phase CT shows enhancement in the mass as well as the scar (arrow). (D) In delayed phase CT shows persistence of contrast in the scar. This differentiates it from fibronodular hyperplasia
HEPATIC METASTASES

Colorectal cancer, carcinoid, islet cell tumors, renal cancer, lymphoma, sarcoma, adenocarcinoma, bronchogenic carcinoma, breast, pancreas, ovarian cancer or cyst-adenocarcinoma can all result in hepatic metastases (Figs 2.38A to D).

Figs 2.38A to D: (A) Contrast CT abdomen shows differential enhancement in the left lobe and an ill-defined low density mass which was hepatic metastases from mucinous carcinoma of transverse colon. (B to D) Enlarged liver shows multiple round hypodense metastatic lesions in both the lobes. Those of which are more hypodense in center indicate onset of necrosis.
CARCINOMA STOMACH

Atrophic gastritis predisposes to the development of carcinoma stomach. A sequence of events which may follow atrophic gastritis are development of intestinal metaplasia, dysplasia and to neoplasia (Figs 2.39A to D).

Figs 2.39A to D: (A) CT shows diffuse thickening of walls of stomach with narrowing of lumen in a case of gastric lymphoma. (B) CT image in right lateral recumbent position shows circumferential thickening of pylorus with the growth extending into antrum and duodenum. Prepyloric lymph node is seen (arrow) in a case of carcinoma of the pylorus. (C) Homogeneously enhancing circumferential thickening of almost the entire stomach wall is seen in this case of carcinoma of stomach. Few enlarged lymph nodes are also present. (D) Ascites and bilateral ovarian deposits (Krukenberg tumor) in a previously operated case of carcinoma stomach
SMALL BOWEL OBSTRUCTION

Strangulating obstruction means mechanical small bowel obstruction caused when two limbs of a loop are incarcerated by a band or by hernia compromising the blood supply (Figs 2.40A and B).

Figs 2.40A and B: A patient presented with abdominal pain. Scout CT image: (A) Shows radially distributed dilated bowel loops. Coronal recon CT image. (B) Confirms the same. Exploratory surgery confirmed strangulated small bowel obstruction.
SUPERIOR MESENTERIC ARTERY (SMA) SYNDROME

Normal distance between aorta and SMA is more than 13.5 mm and normal angle between aorta and SMA is > 28°. When either the distance is less than 10 mm or the angle becomes less than 20° third portion of duodenum undergoes extrinsic vascular compression so that the patient presents with abdominal cramps and repeated vomiting (Figs 2.41A and B). This compression is characteristically relieved in prone or elbowknee position.

Figs 2.41A and B: (A) Normal superior mesenteric artery. (B) Superior mesenteric artery syndrome
APPENDICITIS

CT signs of appendicitis include an appendix measuring greater than 6 mm in diameter, failure of the appendix to fill with oral contrast or air up to its tip, an appendicolith, enhancement of its wall with intravenous contrast with or without surrounding inflammatory changes include increased fat attenuation, fluid, inflammatory phlegmon, thickening of caecum, abscess, extraluminal gas and lymphadenopathy (Figs 2.42A to C).

Figs 2.42A to C: (A) Plain CT scan with oral contrast shows contrast filled normal non-inflamed appendix. (B) Contrast CT abdomen shows enlarged inflamed appendix and adjacent fat stranding. (C) Contrast CT abdomen shows enlarged inflamed appendix with gas in lumen and early stage of appendicular lump formation.
SIGMOID DIVERTICULITIS

Diverticulosis is the presence of acquired pulsion diverticula. These are mucosal herniations through vascular entry sites into pericolic fat. Diverticulitis implies super-imposed inflammation (Fig. 2.43).

Fig. 2.43: CT pelvis shows inflamed diverticuli of sigmoid colon (horizontal arrows) and pericolic abscess (vertical arrow)
CHOLECYSTITIS

In cholecystitis the mechanism probably involves inflammatory mediators released because of ischemia, infection or bile stasis. Sometimes an infecting organism can be identified (Figs 2.44A to D).

Figs 2.44A to D: CT scan of different patients show: (A) Calculus cholecystitis. (B) Acalculus cholecystitis. (C) Emphysematous cholecystitis. (D) Obstructive biliopathy due to worm infestation
CHOLELITHIASIS IN PORCELAIN GALLBLADDER

Porcelain gallbladder means the wall of the gallbladder has been calcified to a hard bluish white texture resembling porcelain ceramic. This medical condition primarily results from a chronically inflamed organ (Figs 2.45A and B). When many gallstones collect in the gallbladder, it becomes irritated, and precipitates calcification that might necessitate surgery.

Figs 2.45A and B: (A) Plain CT abdomen shows hyperdense appearance in the dependent part of gallbladder due to multiple small calculi. There is calcification of the wall (Porcelain gallbladder). (B) In right lateral decubitus position the calculi have shifted to the now dependent position.
PANCREATIC DUCT CALCIFICATION

Chronic pancreatitis usually is envisioned as an atrophic fibrotic gland with dilated ducts and calcifications (Figs 2.46 A and B).

Figs 2.46A and B: (A) CT showing necklace of pancreatic duct calcification involving the body and tail. (B) CT shows dilated pancreatic duct in another patient having terminal obstruction due obstructive biliopathy
ACUTE PANCREATITIS

Acute pancreatitis leads to irregular, heterogeneous, swollen pancreas with associated fat stranding (Figs 2.47A to D) and may undergo necrosis, and may lead to impaired permeability.

Figs 2.47A to D: Images show irregular, swollen pancreas with associated fat stranding in acute pancreatitis
Spleen is the most frequently injured abdominal organ. Mirvis et al. Radiology 1989;171:34 gave the following CT based criteria and severity grading of blunt splenic injury.

A. *CT Grade I*: Capsular avulsion, laceration(s), or subcapsular hematoma < 1 cm diameter.

B. *CT grade II*: Laceration(s) 1-3 cm deep, central/subcapsular hematoma 1-3 cm diameter.

C. *CT grade III*: Laceration(s) 3-10 cm deep, central/subcapsular hematoma > 3 cm diameter.

D. *CT grade IV*: Laceration(s) > 10 cm deep, central/subcapsular hematoma > 10 cm diameter, massive lobar maceration or devascularization.

E. *CT grade V*: Bilobar tissue maceration or devitalization.

**Figs 2.48A to C**: Splenic trauma grade I, II and III
Figs 2.48D and E: Splenic trauma grade IV and V
WILMS’ TUMOR (NEPHROBLASTOMA) WITH HEPATIC METASTASIS

A case of Wilms’ tumor of right kidney shows another 3 × 2.4 cm heterogeneously enhancing lesion in postero-inferior segment of right lobe of liver (Figs 2.49C and D). Filling defect is noted in right renal vein which is stretched out possibly tumor thrombosis (Figs 2.49A to D). Wilms’ tumor constitutes 90% of renal tumors in children under 5 years with peak incidence at 3-4 years of age.

**Figs 2.49A to D**: Six years old male child presented with gradually increasing lump abdomen. CT show a large well-defined enhancing mass lesion with few areas of necrosis, involving the right kidney, sparing its upper pole. Medially, the lesion is seen to displace the pancreas and great vessels to left side with compression of IVC. Cranially, the lesion is seen insinuating the inferior surface of liver and inferiorly extend up to iliac crest.
RENAL CELL CARCINOMA WITH PULMONARY METASTASES

In renal cell carcinoma, common sites for distant metastases include lung, liver, bone, brain and soft tissues throughout the body (Figs 2.50A to D).

Figs 2.50A to D: (A, B) CT abdomen shows a heterogeneous enhancing left renal mass proved on histopathology as a renal carcinoma. (C, D) Show bilateral multiple lung metastases.
URETERIC CALCULUS

Spiral CT is increasingly replacing the IVU in the investigation of ureteric colic and can be regarded as the investigation of choice (Fig. 2.51). It is performed without injection of contrast medium and provides rapid result.

Fig. 2.51: Ureteric calculus with obstructive uropathy
CYSTITIS

Chronic cystitis results in structural and pathological changes (Fig. 2.52). There may be gross wall thickening, reduction in bladder capacity and development of vesicoureteric reflux.

Fig. 2.52: CT image in cystitis shows thick irregular enhancing urinary bladder wall
CARCINOMA URINARY BLADDER

Urinary bladder mass shown in Figs 2.53C and F was histopathologically proved as low grade transitional cell carcinoma bladder. Direct involvement of the bladder by malignancy in adjacent organs (rectum, cervix and prostate) is not uncommon.

Figs 2.53A to F: 55 years old female presented with hematuria. (A) Scout image shows staghorn calculus right renal pelvis. (B) Plain CT shows staghorn calculus with small renal calyceal calculi. (C) A growth is seen within the bladder on right side. (D and E) Contrast CT shows uptake of contrast by renal parenchyma and excretion by both kidneys. (F) Delayed contrast CT shows contrast opacified right ureter coursing through the mass in urinary bladder.
INTRADIVERTICULAR BLADDER CARCINOMA

Carcinoma arising within urinary bladder diverticula has a poorer prognosis than the neoplasms that originate from the main bladder as a result of early transmural tumor infiltration (Figs 2.54A to D).

Figs 2.54A to D: CT show a diverticulum communicating with the bladder and at two site from wall arises the neoplasm confirmed as multicentric intradiverticular bladder carcinoma
UNDESCENDED TESTICLE (CRYPTORCHIDISM)

Right testes is in normal position, left side of scrotal sac is empty. Undescended left testes is lying in proximal end of inguinal canal (arrow) and is smaller in size.

If the testicle cannot be located within the scrotum, it is undescended. An undescended testicle most commonly lies in the inguinal canal or it may lie higher up along the normal line of descent in the abdominal.

Figs 2.55A to D: Right testes is in normal position, left side of scrotal sac is empty. Undescended left testes is lying in proximal end of inguinal canal (arrow) and is smaller in size.
If testicles fail to descent by the age of 3 years, it is associated with abnormal development and this is severe at puberty as a result undescended testes may be atrophic with poor spermatogenesis.

Ultrasound is regarded as the initial investigation to locate an undescended testicle.

If not identified on ultrasound, a more extensive search is desired by MRI.

If possible CT be avoided because of radiation. On MR testicle shows a high signal on T2-weighted and STIR sequences.
CARCINOMA PROSTATE

Carcinoma prostate metastasize to bones, lymph nodes, liver and lungs (Figs 2.56A to D).

Figs 2.56A to D: Prostate is enlarged with irregular contours (A). The fat plane with urinary bladder is lost (B). Enhancing metastasis is seen in liver (C). Small cyst is seen in right kidney. Malignant left pleural effusion is present (D). The spine shows degenerative changes (D)
CT GUIDED PRECISION BIOPSY

CT guided precision robotic assistance biopsy with automated planner (Figs 3.1 and 3.2) reduces the number of needle passes, time spent and number of check scans which leads to significant reduction to patient’s radiation dosage.

Figs 3.1A and B: (A) Plan for posterior straight approach biopsy (red line) for a 12 mm nodule in right lung; (B) Check scan shows precise positioning of needle in the nodule
Figs 3.2A and B: (A) Posterior approach biopsy plan for a 9 mm left para aortic lymph node at a depth of 127 mm; (B) The needle held in robotic arm is in the process of moving in to the left para aortic lymph node at a depth of 127 mm.
ARTIFACTS

An artifact is an abnormal looking/appearing false finding in an image and is unrelated to the patient. It is thus a ghost appearance and in reality it does not exist.

Artifacts occur due to patient’s motion, implants or ornaments and give rise to streak artifacts or beam hardening artifacts due to which adjacent structural details are obscured. Ring artifacts occur due to problems in detectors. When a partial volume is sampled or included in the field of view of imaging it gives rise to partial volume artifact.

• Angulation artifact seen as the asymmetric appearance of frontal horns of lateral ventricles as head was not symmetrically positioned. In reality, both ventricles are equal in size and are symmetrical (Fig. 4.1A).

• Ring artifacts occur as a result of detector malfunction which could either be due to improper calibration or due to detector-data ring mismatch. The center of the detector arc is the most sensitive region where ring artifacts can occur (Fig. 4.1B).

• Motion artifact due to accidental motion. The patient has moved the right arm from side to the anterior part of abdomen (Fig. 4.1C) resulting in motion artifact.

• Streak artifacts due to metallic implant in tibia (Fig. 4.1D).
Figs 4.1A to D: (A) Angulation artifact, (B) Ring artifact, (C) Motion artifact and (D) Streak artifact due to metallic implant
EXTRINSIC ARTIFACT

Scout image shows right thigh in Thomas splint (Fig. 4.2A). Axial image shows hyperdense streaks on the pelvic structures due to reverberation artifacts from proximity of metallic Thomas splint (Fig. 4.2B).

Fig. 4.2A: Thomas splint being metallic on CT scans will produce reverberation artifact from the metal
Fig. 4.2B: Hyperdense streaks on the pelvic structures due to reverberation artifacts from proximity of metallic Thomas splint
PARTIAL VOLUME ARTIFACT

Symmetric hyperdensities seen in the frontal region are due to partial volume of the bone (Figs 4.3A and B).

Partial volume artifacts seen when tissues with different absorption properties occupy the same voxel, the beam is attenuated on basis of average of attenuation values of all those tissues. This volume averaging leads to partial volume artifacts. Common sites are posterior fossa and lung diaphragm interface.

Fig. 4.3A: Partial volume artifact seen because of frontal bones and frontal brain parenchyma occupying the same voxels
Fig. 4.3B: Partial volume artifact seen in frontal region
Xenon-CT is a noninvasive technique for measuring blood flow by xenon-enhanced CT scan. For this non radioactive xenon gas is inhaled, and the enhancement so produced is measured by sequential CT imaging. Time dependent concentration of xenon in various tissues is used to provide blood flow data which is mapped.

Cerebral blood flow (CBF) is important to the neurosurgeons, neurologists and psychiatrists. Xenon-CT is effectively used to provide CBF in cerebrovascular diseases, tumors, head injury, neuropsychiatric disorders and in brain death.

Normal CBF in cortical gray matter is about 80 ml/100 g/min, white matter has mean CBF of about 20 ml/100 g/min and areas containing both gray and white matter have a mean flow of 40–60 ml/100 g/min.

The range of blood perfusion in renal cortex is between 150 to 280 ml/100 cc/min and hepatic tissue perfusion blood flow is from 80 to 120 ml/100 cc/min.

- Axial CT (Fig. 5.1A) of a 67-year old male presented with cognition and behavior dysfunction, dyspraxia and loss of short-term memory. Neurological investigations including CT scan were normal.
- Axial xenon-enhanced CT (Fig. 5.1B) shows reduced cerebral blood flow in the right posterior temporal lobe (arrows) consistent with the patient’s dysfunctions. The color scale represents cerebral blood flow (Fig. 5.1B).
**Fig. 5.1A:** Normal CT scan

**Fig. 5.1B:** Axial xenon-enhanced CT shows reduced cerebral blood flow in the right posterior temporal lobe
IODINATED INTRAVASCULAR AGENTS

Intravascular radiological contrast media are iodine containing chemicals which add to the details to any given CT scan study and thereby aid in the diagnosis. Contrast overall enhances the body tissues. It helps to show the lesion which could not be appreciated on plain scan or shows the lesion better than what was seen in the plain scan. Contrast was first introduced by Moses Swick. Iodine (atomic weight 127) is an ideal choice element for X-ray absorption because the korn (K) shell binding energy of iodine (33.7) is nearest to the mean energy used in diagnostic radiography and thus maximum photoelectric interactions can be obtained which are a must for best image quality. These compounds after intravascular injection are rapidly distributed by capillary permeability into extravascular-extracellular space and almost 90% is excreted via glomerular filtration by kidneys within 12 hours.

Following iodinated contrast media are available:
1. Ionic monomers, e.g. Diatrizoate, Iothamalate, Metrizoate.
2. Nonionic monomers, e.g. Iohexol, Iopamidol, Iomeron.
3. Ionic dimer, e.g. Ioxaglate.
4. Nonionic dimer, e.g. Iodixanol, Iotrolan.

The amount of contrast required is usually 1-2 ml/kg body weight. Normal osmolality of human serum is 290
Computed Tomography

mOsm/kg. Ionic contrast media have much higher osmolality than normal human serum and are known as High Osmolar Contrast Media (HOCM), while nonionic contrast media have lower osmolality than normal human serum and are known as Low Osmolar Contrast Media (LOCM).

Side effects or adverse reactions to contrast media are divided as:
1. Idiosyncratic anaphylactoid reactions.
2. Nonidiosyncratic reactions like nephrotoxicity and cardiotoxicity.

Adverse reactions are more with HOCM than LOCM. So LOCM are preferred. Delayed adverse reactions although very rare are, however, more common with LOCM and include iodide mumps, systemic lupus erythematosus (SLE) and Stevens-Johnson syndrome. Principles of treatment of adverse reaction involves mainly five basic steps: ABCDE

A—Maintain proper airway.
B—Breathing – Support for adequate breathing.
C—Maintain adequate circulation. Obtain an IV access.
D—Use of appropriate drugs like antihistaminics for urticaria, atropine for vasovagal hypotension and bradycardia, beta agonists for bronchospasm, hydrocortisone, etc.
E—Always have emergency back-up ready including ICU care.

Following intravascular iodinated agent arterial opacification takes place at approximately 20 seconds with venous peak at approximately 70 seconds. The level then declines and the contrast is finally excreted by the kidneys. These different phases of enhancement are used to image various organs depending on the indication. Spiral CT, being faster is able to acquire images during each phase, thus provide much more information.
ORAL CONTRAST

The bowel is usually opacified in CT examinations of the abdomen and pelvis as the attenuation value of the bowel is similar to the surrounding structures and as a result pathological lesions can be obscured. Materials used are barium or iodine based preparations, which are given to the patient to drink preceding the examination to opacify the gastrointestinal tract.

Barium Sulphate

Barium sulphate preparations are used for evaluating gastrointestinal tract. Barium (atomic weight 137) is an ideal choice element for X-ray absorption because the K shell binding energy of barium (37) is near to the mean energy used in diagnostic radiography and thus maximum photoelectric interactions can be obtained which are a must for best image quality. Moreover, barium sulphate is nonabsorbable, nontoxic and can be prepared into a stable suspension. For CT scan of abdomen, 1000-1500 ml of 1-5% w/vol barium sulphate suspension can be used. Severe adverse reactions are rare. Rarely mediastinal leakage can lead to fibrosing mediastinitis while peritoneal leakage can cause adhesive peritonitis.

Iodinated Agents

Iodine containing oral contrast agents like Gastrografin and Trazograf are given for evaluating gastrointestinal tract on CT scan.

AIR

Air is used as a negative per rectal contrast medium in large bowel during CT abdomen and during CT colonography.
CARBON DIOXIDE

Rarely carbon dioxide is used for infradiaphragmatic CT angiography in patients who are sensitive to iodinated contrast.
Radiation is a form of energy which can travel from one place to another even in vacuum. Radiation hazards are the harmful effects that can occur to the body due to radiations. Heat and light are the form of radiations that can be felt by the senses. Although X-rays are ionizing radiations, they cannot be felt by the skin. Hence, it is important to be aware of radiation hazards and radiation protection.

Natural sources of radiation are radon and cosmic rays. Artificial sources of radiation are:

a. Diagnostic radiation in the form of radiography, CT scan, PET scan and nuclear scan,
b. Therapeutic radiation in the form of brachytherapy and teletherapy.

**UNITS OF RADIATION**

As per the International System of units, dose of ionizing radiation is measured in unit called as gray (Gy). One Gy is defined as that quantity of radiation which results in energy deposition of one Joule per kilogram in the irradiated tissue. Gray has replaced the earlier unit known as the rad. 1 Gy is equal to 100 rad.

Effective dose of radiation is different for different tissues and is measured in terms of a unit called as Sievert’s (Sv). This depends on the quality factor (Q) of the tissue which
permits passage of energy. Dose equivalent (Sv) = Quality factor (Q) × Dose (Gy).

**EFFECTS OF RADIATION**

Stochastic effects of radiation are the ones whose probability of occurrence increases with increase in dose and include cancer and genetic effects. Deterministic effects are the ones which increase in severity with increase in dose and include cataract, blood dyscrasias and impaired fertility.

Irradiation *in utero* can lead to developmental abnormalities (8-25 weeks), cancer which can be expressed in childhood or in adults due to DNA damage by radiation.

Preconception maternal irradiation in therapeutic doses gives rise to defects in 1 out of 10 exposed children. Nonurgent radiological testing should not be done between 8-17 weeks of gestation, which is the most sensitive period for organogenesis. Children are 10 times more sensitive for hazards of radiations than adults. Hence, radiography with high kV and low mA technique is recommended in children.

Acute radiation syndrome is said to occur when high doses kill so many cells that tissues and organs are damaged immediately. The higher the radiation dose, the sooner the effects of radiation will appear and higher will be the probability of death. This was seen in atomic bomb survivors in 1945 and emergency workers responding to the 1986 Chernobyl nuclear power plant accident who received radiation to the tune of 800 to 16,000 mSv. Acute radiation at doses in excess of 100 Gy to the total body, usually result in death within 24 to 48 hrs from neurological and cardiovascular failure. This is known as the cerebrovascular syndrome. Chronic radiation causes radiation pneumonitis and even permanent scarring that results in respiratory compromise.
AVERAGE EFFECTIVE DOSE IN MILLISIEVERTS (mSv)

- X-ray Chest 0.03
- CT Orbits 0.8
- CT Temporal bone 1.0
- CT Head 2.0
- CT Spine 3.0
- CT Chest 8.0
- CT Abdomen and pelvis 10.0
- Whole body PET/contrast-enhanced CT 23.0 to 23.0
- Coronary angiography (diagnostic) 5.0 to 15.0

The International Commission of Radiation Protection (ICRP) was formed in 1928 on the recommendation of the first International Congress of Radiology in 1925 which formed the International Commission on Radiation Units (ICRU). The National Commission for Radiation Protection (NCRP) in America and the Atomic Energy Regulatory Board (AERB) in India are the regulatory bodies that recommend norms for permissible doses of radiation for radiation workers and for the general public. Atomic Energy Regulatory Board (AERB) which is the Indian Regulatory Board was constituted on November 15, 1983 by the President of India by exercising the powers conferred by Section 27 of the Atomic Energy Act, 1962. The Regulatory Authority of AERB is derived from the rules and notifications promulgated under the Atomic Energy Act, 1962 and the Environmental (Protection) Act, 1986. Radiation safety in handling of radiation generating equipment is governed by Section 17 of the Atomic Energy Act, 1962 and the Radiation Protection Rules, 1971 issued under the Act.

The overall objective of radiation protection is to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure.
Atomic Energy Regulatory Board (AERB) recommends and lays down guidelines regarding the specifications of medical X-ray equipment, for the room layout of X-ray installation, regarding the work practices in X-ray department, the protective devices and also the responsibilities of the radiation personnel, employer and Radiation Safety Officer (RSO). It is the authority in India which exercises a regulatory control and has the power to decommissioning X-ray installations and also for imposing penalties on any person contravening these rules.

**BENEFIT RISK ANALYSIS**
Since radiation exposure entails inherent risks of radiation effects, no decision to expose an individual can be undertaken without weighing benefits of exposure against potential risks that is, making a benefit risk analysis.

**PRINCIPLES OF RADIATION PROTECTION**
1. Justification of a practice  
2. Optimized protection  
3. Dose limitation

**RADIATION PROTECTION ACTIONS**
The triad of radiation protection actions comprise of “time distance-shielding”. Reduction of exposure time, increasing distance from source, and shielding of patients and occupational workers have proven to be of great importance.

**SHIELDING**
Shielding implies that certain materials (concrete, lead) will attenuate radiation (reduce its intensity) when they are placed between the source of radiation and the exposed individual.
Radiation Safety Measures

Source Shielding
X-ray tube housing is lined with thin sheets of lead because X-rays produced in the tube are scattered in all directions, to protect both patients and personnel from leakage radiation. AERB recommends a maximum allowable leakage radiation from tube housing not greater than 1 mGy per hour per 100 cm².

Structural Shielding
The lead lined walls of radiology department are referred to as protective barriers because they are designed to protect individuals located outside the X-ray rooms from unwanted radiation.
1. Primary barrier is one which is directly struck by the primary or the useful beam.
2. Secondary barrier is one which is exposed to secondary radiation either by leakage from X-ray tube or by scattered radiation from the patient.
   The room housing X-ray unit is not less than 18 m² for general purpose radiography and conventional fluoroscopy equipment and that of the CT room housing the gantry of the CT unit should not be less than 25 m².
   Wall of the X-ray rooms on which primary X-ray beam falls is not less than 35 cm thick brick or equivalent. Walls of the X-ray room on which scattered X-rays fall is not less than 23 cm thick brick or equivalent. The walls and viewing window of the control booth should have material of 1.5 mm lead equivalent.

Personnel Shielding
Shielding apparel should be used as and when necessary which comprise of lead aprons, eye glasses with side shields,
hand gloves and thyroid shields. The minimum thickness of lead equivalent in the protective apparel should be 0.5 mm. These are classified as a secondary barrier to the effects of ionizing radiation as they protect an individual only from secondary (scattered) radiation and not the primary beam.

**Patient Shielding**

Thyroid, breast and gonads are shielded to protect these organs especially in children and young adults. The responsibility for establishing a Radiation Protection Program rests with the hospital administration/owners of the X-ray facility. The administration is expected to appoint a Radiation Safety Committee (RSC) and a Radiation Safety Officer (RSO). Every radiation worker prior to commencing radiation work and at subsequent intervals not exceeding 12 months shall be subjected to the medical examinations. Radiation Safety Officer (RSO) should be an individual with extensive training and education in areas such as radiation protection, radiation physics, radiation biology, instrumentation, dosimetry and shielding design. Duties of RSO include assisting the employer in meeting the relevant regulatory requirements applicable to the X-ray installation and ensuring that all radiation measuring and monitoring instruments under custody are properly calibrated and maintained in good condition.

**RECOMMENDED DOSE LIMITS**

Once pregnancy is established the dose equivalent to the surface of pregnant woman’s abdomen should not exceed 2 mSv for the remainder of the pregnancy. Ten Day Rule states that all females of reproductive age who need an X-ray examination should get it done within first 10 days of menses to avoid irradiation to possible conception.
Radiation Safety Measures

As a general principle radiation exposure should be less than 20 mSv/year for radiation workers and less than 1 mSv/year for general public. Optimization of protection can be achieved by optimizing the procedure to administer a radiation dose which is as low as reasonably achievable (ALARA), so as to derive maximum diagnostic information with minimum discomfort to the patient.

DETECTION OF RADIATION

Following methods of detecting radiation-based on physical and chemical effects produced by radiation exposure are available:

1. **Ionization**: The ability of radiation to produce ionization in air is the basis for radiation detection by the ionization chamber.
2. **Photographic effect**: The ability of radiation to blacken photographic film is the basis of detectors that use film.
3. **Luminescence**: When radiation strikes certain materials they emit light that is proportional to the radiation intensity.
4. **Scintillation**: Here radiation is converted into light, which is then directed to a photomultiplier tube, which then converts the light into an electrical pulse.

Personnel dosimetry is the monitoring of individuals who are exposed to radiation during the course of their work. It is accomplished through the use of devices such as the pocket dosimeter, the film badge or the thermoluminescent dosimeter (TLD). The dose is subsequently stated as an estimate of the effective dose equivalent to the whole body in mSv for the reporting period. Dosimeters used for personnel monitoring have dose measurement limit of 0.1-0.2 mSv (10-20 mrem).
Thermoluminescent dosimeter can measure exposures as low as 1.3 μC/kg (5 mR) and the pocket dosimeter can measure up to 50 μC/kg (200 mR). The film badge however cannot measure exposures < 2.6 μC/kg (10 mR). TLD can withstand a certain degree of heat, humidity, and pressure; their crystals are reusable; and instantaneous readings are possible if the department has a TLD analyzer. The greatest disadvantage of a TLD is its cost.
SECTION TWO

PET-CT Imaging
Positron emission tomography – computed tomography (PET-CT) has revolutionized field of medical diagnosis, PET alone lacked anatomic localization and CT lacked functional aspect of imaging. PET-CT has the advantages of both modalities, i.e. PET and CT. Patient is subjected to both the modalities in the same session and images are acquired. The system combines the images into superimposed images. In this way, functional imaging obtained by PET, which depicts the distribution of metabolic or biochemical activity in the body is aligned to the anatomic image obtained by CT.

PET-CT is used for early diagnosis of malignant diseases, its staging and follow up, surgical planning and radiation therapy and response to treatment. It determines the location and extent of cancer indicating spread to other areas of the body such as lymph nodes, liver, bones or brain in the form of metastatic disease. It distinguishes between malignant and benign tumors and recurrent cancer from scar tissue or fibrosis.

PET-CT is also used to study brain function in epilepsy, diagnosing Alzheimer’s disease and other types of dementia, evaluating viability of heart muscle and study of coronary artery disease.
2-Deoxy-2-(18f), fluoro-deoxy-glucose or 18F-FDG, is a radioactive form of glucose and is the most common radiopharmaceutical used in PET. 18F-FDG has a half-life of approximately 110 minutes, so it is quickly expelled from the body. It is produced by cyclotron (Fig. 10.1). Other radioisotope-positron emitters which can be used are carbon-11, nitrogen-13 and oxygen-15, having much shorter half life.

Patient is kept fasting for at least 4 hours prior to scan. 10 mCi (370 MBq) of 18F-FDG is injected and imaging is done after one hour. Normal PET image shows more uptake in brain and cardiac muscles where there is increased metabolism. Pelvicalyceal system and urinary bladder show high uptake due to excretion.

Standardized uptake value (SUV) enables comparison within and between different patients and diseases.

\[
\text{SUV} = \frac{\text{Radionuclide distribution in region of interest}}{\text{Radionuclide dose injected/Patient’s weight in Kg}}
\]

Table 8.1 lists standardized uptake value (SUV) in normal tissues.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Region</th>
<th>SUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soft tissue</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>2</td>
<td>Liver</td>
<td>2.2-2.5</td>
</tr>
<tr>
<td>3</td>
<td>Kidneys</td>
<td>3.3-3.5</td>
</tr>
<tr>
<td>4</td>
<td>Neoplasm</td>
<td>5.0-20.0</td>
</tr>
</tbody>
</table>
PET-CT GANTRY (FIG. 9.1)

First the patient is put through CT gantry and CT scan is done and patient is shifted further into the PET gantry. Thus first the CT images are acquired followed by PET images and these images are then fused by software resulting in PET-CT images.

Fig. 9.1: PET-CT gantry
Cyclotron (Fig. 10.1) is the equipment with the help of which 18F-FDG glucose is prepared in 5 hours. FDG glucose is tagged to fluorine molecule resulting in 18F-FDG glucose molecule used for PET imaging.

Fig. 10.1: Cyclotron which help to prepare 18F-FDG glucose
Normal PET images showing more uptake in brain and cardiac muscles where there is increased metabolism. Pelvicalyceal system and urinary bladder show high uptake due to excretion of 18F-FDG (Fig. 11.1).
Fig. 11.1: Normal PET images showing more uptake in brain, cardiac muscles, kidneys and urinary bladder
Clinical Illustrations

LUNG METASTASIS

Postoperative case of carcinoma of anal canal in this CT scan shows a small nodule in left upper lobe of lung. Corresponding PET image shows increased uptake with a SUV of 8, confirming it to be a malignant nodule (Fig. 11.2).

SUV is standardized uptake value of tissue. Higher the SUV value more is the tissue metabolism and higher are the chances of it being malignant.

Fig. 11.2: PET-CT shows a small malignant nodule in left upper lobe of lung
8 years male with urinary symptoms was subjected to limited PET-CT abdomen which shows mass in upper pole of right kidney.

PET image shows increase uptake but can be mistaken for pelvicalyceal system so CT scan is mandatory in renal pathologies.

PET-CT image shows increased uptake with void in central area corresponding to the necrosis on CT (Fig. 11.3).

**Fig. 11.3:** PET-CT abdomen shows a mass in upper pole of right kidney
Clinical Illustrations

SOFT TISSUE SARCOMA

34 years male with dull pain in left thigh gradually progressing with tenderness and swelling.

PET-CT for staging, CT shows ill-defined soft tissue lesion in medial compartment of the left thigh with necrotic areas and was confirmed as soft tissue sarcoma on histopathology.

PET shows very high uptake with clear delineation of extent of tumor.

PET-CT image shows corresponding increase uptake with void area in the center corresponding to the necrotic area on CT (Fig. 11.4).

Fig. 11.4: PET-CT shows a soft tissue sarcoma on medial compartment of the left thigh
PET image of pre and post treatment in a case of lymphoma shows complete response. Increased focal uptake in post therapy images is seen in region of heart due to higher metabolism and in the region of urinary bladder due to excretion.

Increased uptake seen in liver and intra-abdominal lesions of lymphoma in pre-therapy images is not seen in post therapy images indicating good response (Fig. 11.5).

PET can thus be used for monitoring response to treatment in cases of malignancy as it shows changes at metabolic level. It is more sensitive and specific than CT scan.

Fig. 11.5: Pre and post treatment PET-CT in a case of lymphoma shows complete response
Magnetic resonance imaging (MRI) is based on the principle of electromagnetic character of atomic nuclei which was first described by physicist Felix Bloch and Edward Purcell in 1946. They received a Noble prize for this in 1952. However it was long after this that nuclear magnetic resonance was used for imaging. In 1973, Lauterbur showed that images of human body could be acquired by placing a magnetic field around it. First human images were published by Damadian et al in 1977. Since then use of MRI for medical imaging has seen an exponential growth and now it is a mainstay in the field of medical diagnostics.

Electromagnetism is at the core of MRI physics. When current is passed through a wire, a magnetic field is created around it. Similarly, in a nucleus with odd number of protons or neutrons, the electrons rotating around the nucleus produce a field around them. This gives a “charge” to the nucleus, also called as the spinning charge or “the spin”. Thus these nuclei behave as tiny magnets. Hydrogen proton is the most favorable nucleus for MRI as it is widely available in the water molecules present in the body.

When these nuclei are placed in an external magnetic field (B₀), they either align along the magnetic field or against it. When the number of nuclei along the magnetic field is more as compared to those against the field, a net magnetization is created in the direction of the field.
In order to generate a signal from these spinning nuclei they have to be tipped out of alignment with $B_0$ (i.e. out of the longitudinal plane and towards the transverse plane). The signal generated by each rotating nucleus is much stronger if the nuclei precess in unison with each other at 90 degrees to the main magnetic field. For this a second magnetic field is introduced and it is referred to as $B_1$. This $B_1$ should be applied perpendicular to $B_0$, and it has to be at the resonant frequency. Radiofrequency (RF) coils are used to transmit $B_1$. If sufficient RF pulse is applied the spins are flipped into the transverse plane. This is the $90^\circ$ RF pulse and it generates the strongest signal. However as this is a high energy state, the signal starts decaying quickly and is called free induction decay (FID). This decay or relaxation is of two types:

T1 relaxation is the relaxation in the longitudinal plane due to the spins returning to the normal equilibrium state and aligning with the main magnetic field. In T2 relaxation there is dephasing in the transverse plane ($90^\circ$ degree plane). Each individual proton precesses at slightly different speed. After a while, the signal from protons in transverse plane degrades as protons start precessing out of phase with each other. This is T2 relaxation.

In human tissue T1 is usually 10 times longer than T2 which means that T2 decay occurs before T1 recovery. In actual practice the T2 dephasing time is much quicker than the ‘natural’ T2 due to inhomogenities in the magnetic field $B_0$. This reduced T2 is called $T2^*$. 

T1W and T2W images result by manipulating the manner and frequency in which RF pulses are applied (Repetition to Time), and by changing time to start signal acquisition after RF has been applied (Time to Echo), T1-weighted or T2-weighted images can be obtained.
Physical Principle of Magnetic Resonance Imaging

Pulse sequences:

1. Partial saturation (PS): It is also known as gradient echo or field echo and it uses a 90° RF pulse.
2. Spin echo (SE): A 90° pulse is followed by 180° refocusing RF pulse.
3. Inversion recovery (IR): 180° pulse is followed by a 90° pulse.

In a typical image acquisition the basic unit of each sequence (i.e. the 90°-180°-signal detection) is repeated hundreds of times. By altering the time to echo (TE) or time to repetition (TR), i.e. the time between successive 90° pulses, the signal contrast can be altered or weighted. For example if a long TE is used, inherent differences in T2 times of tissues will become apparent. Tissues with a long T2 (e.g. water) will take longer to decay and their signal will be greater (or appear brighter in the image) than the signal from tissue with a short T2 (e.g. fat). In a similar manner TR governs T1 contrast. Tissue with a long TR (water) will take a long time to recover back to the equilibrium magnetization value, therefore a short TR interval will make this tissue appear dark compared to tissue with a short T1 (fat). When TE and TR are chosen to minimize both these weightings, the signal contrast is only derived from the number or density of spins in a given tissue. This image is said to be proton density weighted (PDW). Table 12.1 gives time to echo and time to repetition for MR sequences and Table 12.2 lists the signal intensity of various tissues at T1, T2 and proton density imaging.

<table>
<thead>
<tr>
<th>Table 12.1: Time to Echo and Time to Repetition for MR sequences</th>
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<tbody>
<tr>
<td><strong>Echo Time TE</strong></td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>T1 Weighted</td>
</tr>
<tr>
<td>T2-Weighted</td>
</tr>
<tr>
<td>Proton Density Weighted or PDW</td>
</tr>
</tbody>
</table>
### Table 12.2: Signal intensity of various tissues at T1, T2 and proton density imaging

<table>
<thead>
<tr>
<th>Tissue</th>
<th>T1</th>
<th>T2</th>
<th>Proton Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>Bright</td>
<td>Bright (less than T1)</td>
<td>Bright</td>
</tr>
<tr>
<td>Water</td>
<td>Dark</td>
<td>Bright</td>
<td>Intermediate bright</td>
</tr>
<tr>
<td>Cerebral Gray matter</td>
<td>Gray</td>
<td>Gray</td>
<td>Gray</td>
</tr>
<tr>
<td>Cerebral White matter</td>
<td>White</td>
<td>Dark</td>
<td>Dark</td>
</tr>
<tr>
<td>TR value</td>
<td>TR &lt; 500</td>
<td>TR &gt; 1500</td>
<td>TR &gt; 1500</td>
</tr>
<tr>
<td>TE value</td>
<td>TE 50-100</td>
<td>TE &gt; 80</td>
<td>TE &lt; 50</td>
</tr>
</tbody>
</table>

Air is black in all sequences because of very few protons and cortical bone is always black due to no mobility of protons.

Each volume element in the body has a different resonant frequency which depends on the protons present within it. This produces a signal which is specific to the resonant frequency of that volume element. This signal is analyzed by the computers using a mathematical technique called as Fourier analysis.

Magnet forms the main component of the MRI, it is of two types: 1. Permanent or resistive magnet used in low field scanners and are usually referred to as open MRI 2. Superconducting magnet – used in all scanners above 1.0 Tesla. It is wound from an alloy (usually Nb-Ti) that has zero electrical resistance below a critical temperature. To maintain this temperature the magnet is enclosed and cooled by a cryogen containing liquid helium which has to be topped-up on a regular basis.

RF coils are needed to transmit and/or receive the MR signal. The RF coil should cover only the volume of interest.
This gives an optimal signal-to-noise ratio (SNR). To achieve this there are various types of RF coils with trade-offs in terms of coverage and sensitivity. For example, Head coil being smaller in size provides better SNR. Body coil is integrated into the scanner bore and is not seen by the patient. Both these coils act as transceivers, i.e. they transmit and receive. Surface coils are used for imaging anatomy near to the coil. They are simple loop designs and have excellent SNR close to the coil but the sensitivity drops off rapidly with distance from the coil. These are only used as receivers, the body coil acting as the transmitter. Quadrature or circularly-polarized coils comprise of two coils 90° apart to improve SNR by a factor of 2½.

Advanced applications include diffusion imaging, perfusion imaging, functional MRI, spectroscopy, interventional MRI.

Possible adverse effects of MRI can be due to static magnetic field, gradients, RF heating, noise and claustrophobia.

Caution needs to be exercised while selecting patients for MRI. Patients with pacemakers, metallic implants, aneurysm clips should be excluded. Metallic objects should not be taken near the magnet as they can be injurious to the patient, personnel and equipment.

SPECIAL SEQUENCES

Short Tau Inversion Recovery (STIR) Sequence

It is heavily T2 weighted imaging, as a result the fluid and edema return high signal intensity and it annuls out the signal from fat. The resultant images show the areas of pathology clearly. The sequence is useful in musculoskeletal imaging as it annuls the signal from normal bone marrow.

Fluid Attenuated Inversion Recovery (FLAIR)

This is an inversion-recovery pulse sequence that suppresses or annuls out the signal from fluid. The sequence is useful to
show subtle lesions in the brain and spinal cord as it annuls the signal from CSF. It is useful to bring out the periventricular hyperintense lesions, e.g. in multiple sclerosis.

**Gradient Echo Sequence**

These sequences reduce the scan times. This is achieved by giving a shorter RF pulse leading to a lesser amount of disruption to the magnetic vectors. The sequence is useful in identifying calcification and blood degradation products.

**Diffusion-weighted Imaging**

‘Diffusion’ portrays the movement of molecules due to random motion. It enables to distinguish between rapid diffusion of protons (unrestricted diffusion) and slow diffusion of protons (restricted diffusion). GRE pulse sequence has been devised to image the diffusion of water through tissues. It is a sensitive way of detecting acute brain infarcts, where diffusion is reduced or restricted.

**MR Angiography**

The most common MR angiographic techniques are time-of-flight imaging and phase contrast. In these sequences, multiple RF pulses applied with short TRs saturate the spins in stationary tissues. This results in suppression of the signal from stationary tissues in the imaging slab. In-flowing blood is unaffected by the repetitive RF pulses, as a result, as it enters the imaging slab, its signal is not suppressed and appears hyperintense compared with that of stationary tissue. Time-of-flight imaging may be 2D, with section-by-section acquisition, or 3D, with acquisition of a larger volume. MRA can also be performed with intravenous gadolinium the vascular phase of enhancement.
MRI CONTRAST

Intravenous Contrast Agents

In MRI the most commonly used intravenous contrast agents are gadolinium chelates, the paramagnetic property of gadolinium provides contrast. It has the ability to alter the magnetic characteristics of neighboring tissues. The effect of this is shortening of the T1 and T2 relaxation times. Shortening of T1 effects are exploited since shortening of T1 relaxation time leads to an increase in signal intensity.

Gadolinium containing contrast agents available are gadodiamide (Omniscan), gadobenic acid (Multihance), gadopentetic acid (Magnevist), gadoteridol (Prohance), gadofosveset (Ablavar), gadoversetamide (OptiMARK), gadoxetic acid (Eovist or Primovist).

Other MRI contrast agents gaining recognition are superparamagnetic agents, i.e. iron oxide and manganese.

Two type’s of iron oxide contrast agents exist: Superparamagnetic iron oxide (SPIO) and ultrasmall superparamagnetic iron oxide (USPIO). These contrast agents consist of suspended colloids of iron oxide nanoparticles and are injectables, they reduce the T2 signals of absorbing tissues. SPIO and USPIO contrast agents have
been used successfully in some liver tumor enhancement. Available iron oxide contrast agents are Cliavist, Combidx, Resovist and Sinerem.

Manganese chelates such as Mn-DPDP enhance the T1 signal and have been used for the detection of liver lesions. It is absorbed intracellularly and excreted in bile.

**Oral Contrast Agents**

In MRI oral contrast can be used for enhancement of the gastrointestinal tract. Gadolinium, manganese chelates and iron salts are used for T1 signal enhancement.

SPIO, barium sulfate, air and clay have been used to lower T2 signal. Blueberry and green tea having high manganese concentration can also be used for T1 increasing contrast enhancement.

Perflubron, a type of perfluorocarbon, has been used as a gastrointestinal MRI contrast agent for pediatric imaging. This contrast agent works by reducing the amount of protons in a body cavity.

Gadolinium initially disperses through the vascular system and then diffuses into the extracellular space, before moving into the intracellular space. Whilst still circulating within the vessels, magnetic resonance angiography (MRA) can be performed.

Gadolinium does not cross the intact blood-brain barrier and helps identifying intracranial lesions with interruption of the barrier, like infection and tumors. It helps to discriminates tumors from edema, low-grade from high-grade tumors, scar tissue from a tumor tissue or prolapsed intervertebral disk.

Oral gadolinium is used to highlight loops of bowel to distinguish from surrounding soft tissue.
Superparamagnetic agents are more specific hepatic lesions and are specially taken up by the Kupffer cells in the liver and help make a distinction between normal liver and malignant tissue.

**MRA**

All pulse sequences are sensitive to flow. There is a complex relationship between the type and rate of flow and the resultant signal intensity. As a general rule, fast or turbulent vascular flow results in a signal dropout, whilst slow vascular flow results in high signal. There are two principal flow-sensitive sequences, time of flight and phase contrast. MRA can also be performed with intravenous gadolinium whilst in the vascular phase of enhancement.
The earliest signs of cerebral ischemia on MRI are those that reflect abnormal blood flow to the affected area. Two signs have been described: the absence of normal arterial flow void and the presence of intravascular enhancement following intravenous gadolinium contrast. The first parenchymal sign of acute stroke on spin echo MRI is anatomic distortion secondary to brain swelling in the form of sulcal effacement. Edema is seen within 2 hours on T1WI images, corresponding to cytotoxic edema. Increased signal on T2WI images occurs within 2 – 4 hours and corresponds with the development of vasogenic edema (Figs 14.1A to C). Both T1WI and T2WI findings become positive on all sequences by 24 hours. Larger infarcts may show gadolinium contrast enhancement by 1 to 3 days, following breakdown of the blood brain barrier. Two types of parenchymal enhancement are seen; when the enhancement is present early within 2 -3 days and the area of enhancement exceeds the area of T2WI high signal the patient suffers a minimal or reversible neurologic deficit. When the enhancement appears late and the area of T2WI high signal equals or exceeds the area of enhancement the patient usually has a fixed or irreversible neurological deficit. The stable chronic stage is reached after a few months with
fluid filled cavities showing signals similar to CSF on all sequences.

Figs 14.1A to C: 45 years old male presented with sudden onset right side weakness. Wedge shaped hyperintensity is seen in the left ACA territory on T2W axial (A) and FLAIR coronal (B) images. It shows restricted diffusion on DW image (C)
PITUITARY MACROADENOMA

Pituitary macroadenoma is the most common intrasellar tumor measuring more than one cm in diameter. It is associated with pituitary insufficiency or visual impairment due to compression of the optic chiasma from suprasellar extension of the mass (Figs 14.2A to D). It may be associated with cranial nerve deficit. Enlarged sella may also be evident. Macroadenomas are usually solid encapsulated

Figs 14.2A to D: Sagittal T1 (A), coronal T2 (B) images reveal a large isointense lesion in the sella, extending into suprasellar region. Post contrast axial T1W (C) and coronal T1W (D) images reveals intense homogenous enhancement in a 55-year-old male patient
tumors that may have necrotic, cystic, hemorrhagic or sometimes calcified areas. On MRI, they appear isointense with brain on both T1W and T2W images and enhance moderately with intravenous contrast. Cystic components within the tumor has a signal intensity intermediate between that of the CSF and the tumor on T1WI and have high signal on T2WI images (Figs 14.2A to D).
EMPTY SELLA SYNDROME

An empty sella may be classified as primary (idiopathic) or secondary to:
- Hypophysectomy or after tumor removal
- Radiation therapy of sellar contents or
- Infarction of pituitary.

Primary empty sella is due to a congenital defect in the diaphragma sellae, permitting suprasellar arachnoid and CSF to herniate into the sella. The pituitary gland is compressed against the back and floor of the sella and most of the sella is occupied by CSF (Fig. 14.3).

The condition is usually entirely symptom free and only discovered at imaging.

Fig. 14.3: Empty sella syndrome a chance finding in a 55-year-old male
Gliomas are the largest single group of all intracranial tumors, they are derived from glial cell or stromal cells of the brain (Figs 14.4A to E) and spinal cord. Major types of gliomas are astrocytomas, ependymomas, oligodendrogliomas and choroid plexus tumors. Astrocytomas are the most common among gliomas, they are subdivided into Grade I pilocytic astrocytomas, Grade II diffuse infiltrating astrocytomas, Grade III anaplastic astrocytomas and Grade IV glioblastoma multiforme the most aggressive subtype. On MRI astrocytomas appear as hypo or isointense cysts on T1WI, and hyperintense on T2W, the solid component is isointense or hyperintense to brain parenchyma. Oligodendroglialomas on MRI appear as heterogenous lesions on all pulse sequences, hyperintensity from a previous hemorrhage may be seen on T1WI, calcification may be hypointense on all spin echo sequences. Choroid plexus tumors on MRI appear as hypo or isointense to the brain on most pulse sequences, they may occasionally be hyperintense on T1WI, hydrostatic edema may show as hyperintense signal on T2W images. Ependymomas on MRI show marked heterogenous signal and variable contrast enhancement.
Figs 14.4A to E: 85 years old male diagnosed as glioma shows a hypointense lesion in the right temporal lobe on T1W image (A). It is heterogeneously hyperintense on T2WI and FLAIR images (B to D) and shows heterogenous enhancement on post contrast T1W image (E). There is mild perilesional edema.
NEUROCYSTICERCOSIS

All over the world cysticercosis is the most common parasitic infection of the human central nervous system caused by pork tapeworm *Taenia solium*. Cerebral infection by the larva is usually asymptomatic resulting in a small edematous lesion. The larvae or cysticerci develop into cysts. They mature in 3 months after the ingestion of ova. This stage is often asymptomatic but may result in seizures. The initial small edematous lesion is hyperintense on T2-weighted images. The protoscolex may be identified as a focal nodule within the cyst and is better demonstrated by MR (Figs 14.5A to D).

Figs 14.5A to D: In a 6-years-old male, T2W coronal image (A) reveals a small cystic lesion with hypointense rim and eccentric hypointense nodule, surrounding white matter hyperintensity is due to perilesional edema. Post contrast images. B to D reveal smooth peripheral enhancement with mild enhancement of the nodule. This lesion represents cysticercus granuloma and the nodule within it represents the scolex.
Tuberous sclerosis is a rare, multi-system, congenital disorder of autosomal dominant variety that causes benign tumors to grow in the brain. Symptoms may include seizures, developmental delay, behavioral problems, skin abnormalities, lung and kidney diseases. Skin findings include ash leaf–shaped macules, angiofibromas of the face (adenoma sebaceum), congenital shagreen patches and depigmented nevi.

**Figs 14.6A to C:** Three year old female diagnosed as tuberous sclerosis was born of nonconsanguineous marriage presented with delayed language development skills, intermittent hematuria with two episodes of seizures in infancy. She was able to speak only few familiar words. (A) Plain axial T2WI MRI brain; (B) Axial FLAIR MRI demonstrates cortical hyperintense tubers; (C) Post contrast axial MRI images demonstrates enhancement of subependymal tubers
NEUROFIBROMATOSIS TYPE 2 (NF2)

Neurofibromatosis is inherited nerve sheath disorder with two distinct types, neurofibromatosis type 1 (NF1) and neurofibromatosis type 2 (NF2). NF1 is von Recklinghausen disease. It is 10 times common than NF2. NF1 has prominent superficial tumors (neurofibromas), macular hyperpigmentation (café-au-lait spots) (Figs 14.7A to C) and CNS abnormalities that include true neoplasms usually optic nerve gliomas (Figs 14.8A to F), dysplastic and hamartomatous lesions. Multifocal increased signal intensity is seen on T2 WI in brainstem, cerebellar white matter, dentate nucleus, basal ganglia, periventricular white matter, optic nerve and optic pathways. These hyperintensities represent either abnormal myelination or hamartomatous change. The presence of bilateral optic nerve gliomas is considered diagnostic for NF1.

NF2 develops bilateral acoustic schwannomas with trigeminal nerve being next in frequency. They are predisposed to intracranial or intraspinal meningiomas.
Figs 14.7A to C: Photograph of patient showing squint (A), B and C show café-au-lait spots
Figs 14.8A to F: Oblique sagittal T1 W images show (A) right and (B) left tortuous and enlarged optic nerves (arrow). T2 WI (C) axial and (D) coronal image shows abnormal hyperintense signal in both gangliocapsular region and along optic tracts. Axial post contrast T1 WI showing (E) enlarged enhancing optic chiasma and (F) bilateral tortuous and enlarged enhancing optic nerves.
GERMINAL MATRIX HEMORRHAGE–GRADE IV

Germinal matrix hemorrhage is a hemorrhage into the subependymal germinal matrix with or without subsequent rupture into the lateral ventricle. It is a highly cellular and highly vascularized region in the brain from which cells migrate out during brain development. The germinal matrix is the source of both neurons and glial cells and is most active between 8 and 28 weeks gestation. It is a fragile portion of the brain that may be damaged leading to an intracranial hemorrhage known as a germinal matrix hemorrhage.

Grade IV refers to intraventricular rupture and hemorrhage into the surrounding white matter.

Figs 14.9A and B: T1W axial (A) and GRE axial (B) images reveal hemorrhage in the right germinal matrix (long arrow) with intraventricular extension (short arrows)
Magnetic Resonance Imaging

PERIVENTRICULAR LEUKOMALACIA—CHRONIC

MRI has not been used widely in diagnosis of acute periventricular leukomalacia (PVL), but is extensively used to study chronic PVL. There is increased T2 signal in the periventricular white matter or gliosis, thinning and loss of volume of periventricular white matter with development of porencephalic cysts and ventriculomegaly and thinning of corpus callosum.

Figs 14.10A to C: T1W (A), T2W (B) axial and T1W sagittal (C) images show that there is paucity of white matter (thin arrow), ventricular dilatation with irregular margins and thinning of the corpus callosum (thick arrow)
Clinical Illustrations

SPINAL LIPOMA—INTRADURAL EXTRAMEDULLARY LESION

Spinal lipomas are generally located in the lumbosacral region and are commonly associated with spinal malformations. Spinal lipoma is often an incidental finding on MR, however patients may present with back pain. These lesions have specific characteristics on MR (Figs 14.11A to E). On MRI definitive diagnosis may be based on

Figs 14.11A to E: A well defined T2 and T1 hyperintense lesion is seen in the intradural extramedullary compartment at D11-D12 level. It gets suppressed on fat sat images. It is causing displacement of the lower cord, conus and the traversing nerve roots anteriorly and to right side. The filum terminale is mildly thickened and appears to be tethered at L5-S1 level. A diffuse bulge of D12-L1, L1-L2, L4-L5 and L5/S1 intervertebral disks is present.
characteristic signal intensity of fat as a result of marked T1 and T2 shortening with hyperintense features. MR distinguishes dermoid from lipoma by virtue of the nonfatty component of the lesion.
LUMBAR DISK LESION

The signal returned from degenerated disks is usually lower than from healthy disks and best appreciated on T2WI (Figs 14.12A and B), this high signal is not uniform throughout the whole disk and the dark band of cortical bone of the vertebral endplates is intact. Sometimes due to calcium precipitation in healthy disks the signal may be paradoxically higher on T2WI. Presence of fluid filled clefts in the disks may also show high signals on T2WI. In infective discitis, there is high signal on T2WI with associated reactive changes in adjacent vertebrae. Tears in the external layers of the annulus fibrosus may be visible as high signal foci on T2WI. Signal from degenerative fibrocartilage within the spinal canal

Figs 14.12A and B: T2W sagittal (A) and T2W axial (B) images of the lumbar spine reveal desiccation of L5-S1 disk with posterocentral disk protrusion (arrow)
is quite variable on T2WI and is common for the migratory fragments to be conspicuously brighter than the nucleus of the disk of origin. Disk protrusions present as indentations on the anterior surface of thecal sac opposite the disk space is better appreciated on T2WI.
A pancoast tumor is a superior sulcus mass that involves the brachial plexus and sympathetic ganglion of the lower neck and upper mediastinum. Lung malignancy or metastatic diseases are the commonest causes of pancoast tumors, other causes are lymphoma, mesothelioma, and multiple myeloma. Pancoast syndrome is a clinical triad of (a) Horner’s syndrome (ptosis, miosis, anhidrosis, and enophthalmos), (b) ipsilateral arm pain and (3) wasting of the hand muscles. The pancoast tumors are best depicted on the coronal and sagittal MR images (Fig. 14.13).

Fig. 14.13: A large heterogenous lesion is seen in the apex of right lung involving the ribs, brachial plexus and adjacent soft tissues. Brachial plexus is normal on left side (arrow)
MR cholangiopancreatography is based on a heavily T2 weighted pulse sequence which shows stationary fluids (Figs 14.14A to C), such as bile, which shows high signal intensity whereas the surrounding liver and flowing blood generates

**Figs 14.14A to C**: MR cholangiography in a 60 years old male. Source image (A) and 3D MIP image (B) reveal a well defined round filling defect in the distal CBD with dilatation of the proximal common bile duct (CBD) and intrahepatic biliary radicles. Axial T2WI (C) reveals a hyperintense rim of bile around the hypointense filling defect (CBD calculus)
little signal. As a result of this MRCP provides optimal contrast between the hyperintense signal of the bile duct and pancreatic duct and the hypointense signal of surrounding tissues.
AVASCULAR NECROSIS OF FEMORAL HEAD

It is a self limiting osteonecrosis of the femoral head epiphysis, typically between 3 to 12 years of age, more common in boys. There is symmetric involvement of both hips leading to limping with pain in the groin areas. Typical MRI appearance is loss of normally bright signal intensity of the femoral epiphysis on T1WI (Figs 14.15A to C). Six different patterns have been identified within the femoral head: isointense signal on all images, complete signal void on all images, hyperintense signal on STIR image with or without contrast enhancement. Prognostic evaluation by MRI indices depends on the extent of necrosis, lateral extrusion, epiphyseal involvement and metaphyseal changes.
**Figs 14.15A to C:** STIR coronal (A), T1W coronal (B) images and T2 sagittal image (C) reveal well defined crescents of altered marrow signal in bilateral femoral heads. The marrow within the crescent is predominantly hypointense on T1, T2 and STIR images suggestive of sclerosis. Normal contour of femoral head is maintained. These findings are suggestive of grade II avascular necrosis (Ficat and Arlett classification) Mitchell class D. Marrow edema is seen in the neck and intertrochanteric region. These findings were seen in 24-year-old female with pain in right hip joint with no history of trauma or fever.
The rotator cuff comprises 4 tendons that stabilize the shoulder joint: the supraspinatus, infraspinatus, teres minor and subscapularis. Tendons are fibrous tissue that connect muscle to bone. Tears in the rotator cuff can be within the muscle or at the site where the tendon attaches to the bone (Fig. 14.16). Rotator cuff tears may be partial tears or full thickness tears. MRI is the investigation of choice for rotator cuff injuries.

Fig. 14.16: STIR coronal image shows complete supraspinatus tendon tear with medial retraction of the tendon (short arrow) and superior displacement of the head of humerus (long arrow). Hyperintense signal due to effusion is seen in the subacromial space and joint cavity.
MR urography is useful in patients where use of ionizing radiation is to be avoided. The procedure is performed using heavily T2 weighted images such as RARE sequence (rapid acquisition with relaxation enhancement) and HASTE (Half fourier Single Shot Turbo spin Echo) sequence. The sequence (Fig. 14.17) is performed in a single breath hold. The urine

**Fig. 14.17:** In a case of carcinoma urinary bladder, HASTE coronal MR urography image reveals a large mass with irregular margins seen as a filling defect in the anterior and left part of the urinary bladder involving the left uretero-vesical junction with resultant moderate hydronephrosis and hydroureter on left side. The bladder wall is irregular. Mild hydronephrosis and hydroureter is also present on right side.
gives a bright signal, this aspect is used to create the urographic images while the fat signals from the background are suppressed. While using RARE and HASTE sequences no information about the renal function is obtained. TIWI gadolinium enhanced 3D image FLASH sequence is used, thin sections obtained and processed with maximum intensity projection, the images obtained provide information on renal anatomy and function similar to conventional urography, low doses of a diuretic agent can be administered before this examination to demonstrate filling of the pelvicalyceal system.
Diagnostic ultrasound is a noninvasive imaging modality utilizing high frequency sound energy in the range of 3 to 15 megahertz (MHz). This is well above the normal human ear response to sound frequency of 20-20,000 Hz.

USG works on piezoelectric effect of crystals made from lead zirconate titanate or polyvinylidene difluoride and is used in forming images by using pulse echo principle. Gray scale (B) mode is used in general imaging. Motion (M) mode is used for echocardiography. Color Doppler ultrasound is used for imaging of vessels, Christian Doppler was first to put forth the principle of Doppler.

High frequency sound waves travel through human tissue; they are reflected on traversing interfaces. A transducer which emits high frequency sound is moved over the patient; the reflected waves are returned to the transducer resulting in an image by the computer.

Echoes or reflections of the ultrasound beam form interfaces between tissues with different acoustic properties, resulting information on the size, shape and structure of organs and masses. Ultrasound is largely reflected by air-soft tissue interface and bone-soft tissue interface, thus being of relatively limited use in the chest and musculoskeletal system.
Ultrasonography does not use X-rays as a result there is no risk of ionizing radiations. It is real time, permits multiplanar imaging, helps positive decision for a lesion to be cystic or solid. It is used to perform interventional procedures. The equipment is portable, inexpensive and easily available. It is low cost being cheaper than other cross-sectional imaging techniques. Doppler evaluation allows analysis of blood flow. There are no known harmful effects of high frequency sound waves on human body.

Disadvantages of USG are few. It is difficult in obese patients and in viewing deep structures, it does not show function of tissues. Air, bone and fat are enemies to good ultrasound imaging.

Doppler ultrasonography employs the frequency shift in the reflected ultrasonic beam to recognize the moving fluid in the body. It demonstrates the presence and direction of blood flow. It gives red color coding for blood flowing towards the transducer and blue coding to blood flowing away from the transducer (Fig. 15.1). Doppler can be used to attain spectral trace that shows velocity of flow.
Fig. 15.1: Liver image, a Doppler interrogation box placed over the portal vein
Ultrasound contrast agents comprise of gas-filled microbubbles measuring less than ten microns. They are administered intravenously. Microbubbles have a high degree of echogenicity, and ability to reflect the ultrasound waves. The echogenicity difference between the gas in the microbubbles and the soft tissue surroundings is immense. Thereby, microbubble contrast agents enhances the ultrasound reflections to produce a high echogenicity difference image. Contrast-enhanced ultrasound can be used to image blood perfusion in organs and measure blood flow rate in the heart and other organs.

Optison or Levovist, are injected intravenously into the systemic circulation in a small bolus. The microbubbles remain in the systemic circulation for a certain period of time. During that time, ultrasound waves are directed on the area of interest. The microbubbles reflect unique echo that stands out in contrast to the surrounding tissue. The ultrasound system converts the strong echogenicity into a contrast-enhanced image of the area of interest. Similarly the bloodstream’s echo is enhanced, thus allow distinguish blood from surrounding tissues (Figs 17.16A to C).

Ultrasound imaging allows real-time evaluation of blood flow. Since microbubbles can generate such strong signals, a lower intravenous dosage is needed in micrograms.
However microbubbles do not last very long in circulation. They have low circulation time.

The gas inside the shell is generally perfluorocarbons, which are liquids at room temperature but gas at body temperature. The large molecules of perfluorocarbons have slow diffusion and solubility which increase the enhancement time of the contrast medium as compared to air. They are less the 5 microns in size. This is important because they must filter out through the smallest capillary particularly small enough to pass through the pulmonary circulation and the cardiac chambers without disruption. They are stable enough to persist during the examination. 100% of the gas is eliminated from the body through the lungs during normal breathing in about 15 minutes. It circulates only in the vascular spaces and does not enter the tissues. These microbubbles enhance the blood in the area of interest and demonstrate the pathology. The component of the shell are absorbed by the blood and later metabolized by the liver. They are no proven side effects; they are safe and non toxic.
DUODENAL ESOPHAGEAL ATRESIA

Esophageal and duodenal atresia have characteristic appearances on ultrasound, babies with duodenal atresia have slight distension of the upper abdomen as the stomach can decompress through the esophagus. When esophageal atresia coexists with duodenal atresia the stomach and duodenum are dilated due to the trapped gastric secretions. The abnormal degree of dilation allows distinction from duodenal atresia.

New born baby presented with distended and palpable masses in upper abdomen with inability to pass a nasogastric tube. The kidigram shows gasless abdomen with coiling of nasogastric tube in upper thoracic region suggesting esophageal atresia. Ultrasound of abdomen shows fluid-filled stomach and duodenum. The ultrasound appearances suggest duodenal atresia associated with esophageal atresia. Laparotomy confirmed the findings and duodenoduodenostomy was carried out followed by esophageal repair at a later date (Figs 17.1A to E).
Figs 17.1A to E: Kidigram (A) and magnified (B) view reveals gasless abdomen and coiling of nasogastric tube in upper thoracic esophagus (arrows). Ultrasonography of abdomen in longitudinal (C) and transverse (D) planes reveals a dilated stomach and duodenum. Abrupt cut off of duodenum is well appreciated (E). Intraoperative photograph reveals (F) distal end of duodenum (arrow) and (G) blind end of esophagus (arrow)
GALLBLADDER IN HEPATITIS

In hepatitis gallbladder frequently shows non specific changes like thickening of gallbladder wall >3 mm, multiple focal noncontiguous hypoechoic pockets of edema, fluid within the thickened wall can be seen (Figs 17.2A and B). Other changes can be a thin rim of fluid representing edema in the wall, a double wall appearance or presence of sludge in the gallbladder cavity.

Figs 17.2A and B: Gallbladder shows gross thickening of the wall (between the arrows in A) due to edema and dilated veins seen within the wall (B) in a four years old child with hepatitis.
EPIGASTRIC HERNIA

Typical locations of epigastric hernia are the points of weakness where no muscle is present, along the linea alba in the midline (Fig. 17.3). On ultrasound, seen in cross section, herniated bowel loops appear as target lesions with strong reflective central echoes representing air in the lumen, when obstructed they appear as tubular fluid filled structures containing valvulae conniventies or fecal material. Omentum may also herniate through the defect in anterior abdominal wall. Congenital epigastric hernias are gastrochisis and omphalocele.

Fig. 17.3: Ultrasound shows a rent in anterior abdominal wall (arrow), forming a neck which is displacing the rectus abdominis muscle. The herniated sac with contents is appreciated.
Obstructive uropathy results in hydronephrosis and hydroureter depending on the site of mechanical obstruction. Hydronephrosis is dilation of the calyces and renal pelvis appearing on ultrasound as anechoic areas and gradually there is reduction in renal cortical thickness (Figs 17.4A and B). Ultrasound is a quick, safe and sensitive tool for detecting hydronephrosis and possibly the cause.

**Figs 17.4A and B:** A 9 mm diameter calculus is seen in proximal ureter (B) with acoustic shadowing and resultant hydronephrosis and hydroureter (A and B) with marked thinning of renal cortex. There is thickening of wall of ureter with internal echos in dilated ureter are suggestive of inflammatory process.
Splunuculus or accessory spleen is congenital nodule, composed of normal splenic tissue. The spleen forms from multiple smaller components during embryogenesis, and failure of this fusion leads to one or more nodules or splenunculi remaining separate (Figs 17.5A and B). They are extraperitoneal, benign and asymptomatic and should not be confused with splenosis which is acquired and intraperitoneal.

**Figs 17.5A and B:** (A) Ultrasound image show a small round structure medial to spleen (arrow), the splenunculus. It has same echo signatures as spleen. (B) Contrast CT images show a small round structure medial to spleen, the splenunculus. It has same density as spleen
MULTICYSTIC DYSPLASTIC KIDNEY DISEASE

High resolution ultrasonography allows demonstration of fetal kidneys and urinary bladder from second trimester and enables to detect major congenital anomalies of the urinary system. Multicystic dysplastic kidney disease (MCDKD) is usually an incidental finding during routine antenatal sonographic examination (Figs 17.6A to C). The incidence of MCDKD is about 1 in 10,000 births.

Figs 17.6A to C: (A) Antenatal ultrasound shows enlarged right fetal kidney with multiple cysts; (B) Ultrasound shows dilated bowel loops; (C) Post abortion ultrasound shows enlarged kidneys with multiple cysts
BLADDER CARCINOMA

Transitional cell carcinoma of bladder is the most common urinary bladder malignant tumor. Around 30% of bladder cancer are of invasive type. Patients frequently present with hematuria. On ultrasound these tumors appear as focal non mobile mass (Fig. 17.7) or of urothelial thickening, some may have focal areas of calcification within them. Some bladder tumors may arise from bladder diverticula.

Fig. 17.7: USG shows a large growth from anterior and right wall of urinary bladder. The inner margin of the growth is irregular. There is layering of debris with few internal echos in the bladder
LYMPH NODES

Most lymph nodes on ultrasound appear ovoid in shape and are variable in size, vary in echogenicity (Figs 17.8A and B) although a few of them are homogenous depending on the degree of central lipomatosis. The center of the node is echogenic and the periphery is hypoechoic. Not all enlarged nodes are malignant and not all malignant nodes are enlarged. Normally 1 to 3 mm central artery is present at the hila of lymph nodes, in carcinomatous involvement this central artery is not seen because it is infiltrated and destroyed.

Figs 17.8A and B: Ultrasound shows neck (A) and mesenteric (B) lymph nodes
UNDESCENDED TESTICLE (CRYPTORCHIDISM)

If the testicle cannot be located within the scrotum, it is undescended. An undescended testicle most commonly lies in the inguinal canal or it may lie higher up along the normal line of descent in the abdomen.

Maldescent of the testis occurs in 0.8% of boys. Orchidopexy is ideally performed before the age of two years. Indications for surgery include likely beneficial effect on fertility, prevent malignant potential and social considerations. Laparoscopy is the method of choice.

In this 3 years old child, clinically the right testes was in normal position, left side of scrotal sac was empty. On ultrasound, undescended left testes was lying at the proximal end of inguinal canal and was smaller in size (Fig. 17.9).

Fig. 17.9: Left inguinal USG in oblique plane shows the undescended testicle in the inguinal canal
Bladder outlet obstruction can lead to prominent bladder trabeculations (Fig. 17.10), vesicoureteric reflux, hydronephrosis and eventually, to renal parenchymal damage. If no treatment is given, leads to end-stage renal failure. The common clinical manifestation of bladder outlet obstruction is urinary tract infection. In conclusion, early detection and prevention of deteriorated renal function are important for children with urinary bladder outlet obstruction.

Fig. 17.10: Ultrasound shows bilateral hydroureters suggesting bladder outlet obstruction. The bladder wall is thickened
Risk factors for retinal detachment are advancing age, previous cataract surgery, myopia and trauma. Patient will present with symptoms of light flashes, floaters, peripheral visual field loss and blurred vision. Ultrasound correctly identifies the anatomic position of the retina (Fig. 17.11). At present ultrasound is the only method to ascertain the anatomic position of the retina when direct examination is not possible due to dense vitreous hemorrhage.

Fig. 17.11: Ultrasound shows funnel-shaped retinal detachment (arrow) with vitreous opacifiers and membranes (long arrow) in posterior part of vitreous chamber.
The look of parotid abscess varies depending on the amount of liquefaction that has occurred. In the early stages the gland is enlarged, hypoechoic area within the parenchyma of the gland may be seen, later a thick wall is formed at the periphery with anechoic central area, septations and internal echoes may be seen. On Doppler (Figs 17.12A and B), no color flow is seen centrally in the abscess, the periphery may show vascularity indicating its inflammatory nature. Intraluminal hyperechoic calculi in the Stensen’s duct may be seen on ultrasound.

Figs 17.12A and B: Parotid USG shows a large well defined hypoechoic area within the parenchyma of the gland with internal echoes. On Doppler, no color flow is seen centrally, the periphery show vascularity indicating its inflammatory nature.
TUBERCULOUS ORCHITIS

High resolution sonography is investigation of choice for imaging the scrotum. The sonographic appearances of tuberculous orchitis include diffusely enlarged heterogeneously hypoechoic lesion or nodular enlarged heterogeneously hypoechoic lesions (Figs 17.13A to C). Tuberculous orchitis must be considered in the differential diagnosis apart from testicular tumor, acute infection and inflammatory orchitis. All attempts must be made for early diagnosis and treatment of this condition to avoid in fertility.

Figs 17.13A to C: Testicle outline is deformed with area of necrosis within, hydrocele is present with internal echos and septae. The histological features were suggestive of tuberculous orchitis
HYDROCELE

It is an abnormal collection of serous fluid between the layers of tunica vaginalis (Fig. 17.14). It is a common cause of painless scrotal swelling. It can be congenital or acquired. On ultrasound hydroceles appear as anechoic collections with good acoustic transmission surrounding the anterolateral aspects of the testes. Low level to medium level echoes from fibrin bodies or cholesterol crystal may be found within the hydroceles. Large hydrocele may impede testicular venous drainage and cause absence of ante grade arterial diastolic flow.

Fig. 17.14: USG shows fluid in right tunica vaginalis with internal echos indicating debris
A normal vein on ultrasound has an anechoic lumen which is fully compressible when pressure is applied over the vessel by the transducer. A vein containing thrombus does not allow full compression and has echogenic clot. In normal vein Doppler color flow should be uniform throughout the lumen and in a vessel containing clot, little or no color flow is seen (Figs 17.15A to C).

Figs 17.15A to C: (A) Normal popliteal veins and artery with color flow. Blue color coding is seen in the vein indicating flow away from the transducer and red color coding is seen in the artery indicating flow towards the transducer. (B) Show the vein is full of echogenic thrombus and has no flow on color Doppler inbox, whereas the artery shows normal color coding. (C) Shows the thrombosis with minimal recanalization.
Clinical Illustrations

HEPATIC HEMANGIOMA

The need for USG contrast arises when the lesions are isoechoic to the background parenchyma or are diffusely isoechoic and are difficult to pick up or be characterized by B mode ultrasound. Therefore the use of USG contrast has

Figs 17.16A to E: (A) On ultrasound, right lobe of liver shows a well defined hypoechoic lesion; (B) Intravenous contrast injected, in arterial phase shows outlining the edges of the lesion seen as increased echogenicity of the margins of the lesion; (C) Gradually the circulating contrast shows early filling up the lesion more in the anterior aspect. As a result of peripheral filling there is some change in shape and outline of the lesion. (D and E) Show excellent filling of the lesion resulting in echogenicity isodense to the hepatic tissue which was hypoechoic in precontrast image (A).
significantly changed the capability of ultrasound imaging. Thirty eight years old male reported with general weakness was subjected to ultrasound followed by contrast enhanced scan (Figs 17.16A to E) with SONOVUE by BRACCO.
SECTION FIVE

Clinical Illustrations Using Multiple Modalities
The advent of CT scan, MRI, and USG over last four decades has revolutionized the field of medicine, providing the clinician with baffling ways to image the patient. As a consequence he often lands up subjecting the patient to most cross sectional imaging modalities though often these various modalities compliment each other. Few clinical illustrations using most modalities have been shown attempting to amalgamate these cross sectional techniques into a palatable arrangement.
Spinal dermoid is a rare, benign, slow-growing tumor arising from more than one of the three primitive germ cell layers. It is commonly intradural in location. Imaging demonstrates areas of fat and calcification within it and helps in giving definite diagnosis. Twenty one years female presented with large intradural mass lesion involving thoracolumbar spinal cord. It was heterogeneously hyperintense on both T1W and T2W sequences, with signal suppression on fat-saturated images (Figs 18.1A to F). Plain CT scan of the spine confirmed the presence of fat and calcification within the lesion, thus leading to the diagnosis of an intraspinal dermoid.

Figs 18.1A to F: CT scan of spine in bone window (A) and soft tissue window (B) show intradural mass lesion. Sagittal reformation (C and D) shows the presence of calcification and fat (black arrow) within the lesion with widening of spinal canal. Sagittal T1WI (D) MRI reveal heterogeneous intraspinal mass lesion extending from D11-12 to L4-5 level with suppression of hyperintense signal (arrow) on fat suppression image (E)
MULLERIAN DUCT CYST

Mullerian duct cyst is an uncommon congenital anomaly. It is usually small, asymptomatic, midline, cystic lesion, located behind the superior half of the prostatic urethra and connected to the verumontanum by a thin stalk. Rarely a mullerian duct cyst may be associated with renal agenesis (Figs 18.2A to E) and hypospadias.

Figs 18.2A to E: Transabdominal USG (A) and contrast CT image (B) show cystic nature lesion posterior to bladder. Agenesis of right kidney and normal left kidney, confirmed on contrast reformatted CT (C) and coronal and axial T2 weighted MR images (D and E)
Figs 18.3A to E: Pear shaped cystic nature mass lesion seen hyperintense on STIR and T2 weighted images (A and B) and hypointense on T1 weighted images (C). Sagittal reformatted CT images (D) and STIR MR images (E) show that there is no communication between cystic lesion and urinary bladder/urethra.
OSTEOID OSTEOMA

Osteoid osteoma is a benign lesion frequently found in the appendicular skeleton. The tumors produce excess bone and secrete pain-causing prostaglandins, resulting in intense pain especially at night. A 22 years old male presented with pain and tenderness in left thigh region since 4 months. Radiograph shows sclerosis and cortical thickening due to subperiosteal bone formation. The radiolucent nidus was questionably visualized on X-ray. The location of the nidus, intranidal calcification, sclerosis, mature periosteal bone formation and location of original cortex are precisely demonstrated by CT. MRI also clearly showed the partially calcified nidus and associated cortical thickening. In addition, MR images revealed mild marrow and soft tissue edema in the vicinity of the nidus, which is not demonstrated by CT (Figs 18.4A to E).
Figs 18.4A to E: Plain radiograph (A) reveals an ill-defined region of increased cortical thickness (arrow) and CT axial (B) and coronal reformatted (C) images reveal the presence of small, well-defined calcified nidus and dense cortical thickening near lesser trochanter. MRI coronal (D) and axial (E) images reveal hypointense cortical thickening along lesser trochanter with well-defined small hypointense lesion adjacent to it (arrow)
SECTION SIX

Archival and Communication System
Picture archiving and communication system (PACS), is based on universal DICOM (Digital Imaging and Communications in Medicine) format. DICOM solution are capable of storing and retrieving multi modality images in a proficient and secure manner in assisting and improving hospital workflow and patient diagnosis.

PACS helps eliminating paper requisition forms and radiology reports. Smooth integration of PACS with existing image acquisition systems and hospital information system (HIS) is important.

The aim of PACS is to replace conventional radiographs and reports with a completely electronic network, these digital images can be viewed on monitors in the radiology department, emergency rooms, inpatient and outpatient departments, thus saving time, improving efficiency of hospital and avoid incurring the cost of hard copy images in any medical institution. The three basic means of rendering plain radiographs images to digital are computed radiography (CR) using photostimulable phosphor plate technology; direct digital radiography (DDR) and digitizing conventional analogue films. Non-image data, such as scanned documents like PDF (portable document format) is also incorporated in DICOM format. Dictation of reports can
be integrated into the system. The recording is automatically
sent to a transcript writer’s workstation for typing, but it
can also be made available for access by physicians, avoiding
typing delays for urgent results.

Among all clinical specialties, radiology has led the way
in developing PACS to its present high standards. PACS
consists of four major components: the imaging modalities
such as radiography, computed radiography, endoscopy,
mammography, ultrasound, CT, PET-CT and MRI, a
secured network for the transmission of patient information,
workstations for interpreting and reviewing images and
archives for the storage and retrieval of images and reports.
Backup copies of patient images are also provisioned in case
of image lost from the PACS. There are several methods for
backup storage of images, but they typically involve
automatically sending copies of the images to a separate
computer for storage, preferably off-site.

In PACS no patient is irradiated simply because a
previous radiograph or CT scan has been lost. The image
once acquired onto the PACS is always available when
needed. Simultaneous multilocation viewing of the same
image is possible on any workstation connected to the PACS.
Numerous post processing soft copy manipulations are
possible on the viewing monitor. Film packets are no longer
an issue in PACS as it provides a film less solution for all
images. PACS can be integrated into the local area network
and images from remote villages sent to the tertiary hospital
for reporting (Fig. 19.1).

PACS an expensive investment initially but the costs can
be recovered over a 3 to 5 years period. It requires a dedicated
maintainence program. It is important to train the doctors,
technicians, nurses and other staff to use PACS effectively.
Once PACS is fully operational and no films are issued to
Fig. 19.1: PACS flow chart
patients, the hospital is no longer equipped to provide a film based service again as it has reached a film less solution for images and most paper work.

PACS breaks the physical and time barriers associated with traditional film-based image retrieval, distribution, and display. PACS can be linked to the internet, leading to teleradiology, the advantages of which are that images can be reviewed from home when on call, can provide linkage between two or more hospitals, outsourcing of imaging examinations in understaffed hospitals. PACS is offered by virtually all the major medical imaging equipment manufacturers, medical IT companies and many independent software companies.
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