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Introduction to Neuroradiologic Techniques

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Neuroradiology: Introduction

This chapter is not intended to be a comprehensive review of neuroradiology. The aim is to present the concept and content of neuroradiology in a very generalized manner. Some of the concepts have been oversimplified for easier understanding and thus may not be scientifically rigorous, but the author hopes to have avoided incorporating any scientific inaccuracies.

Neuroradiology is a subspecialized branch of radiology which encompasses evaluation of not just the brain and spine but also the face, the neck, and the brachial plexus. Therefore, neuroradiology is the study of not only the central and peripheral nervous system, but also soft tissues including muscles, blood vessels, and bones.

It is a rapidly growing field of medicine, which has diagnostic and interventional applications.

Divisions of Neuroradiology

Neuroradiology can be broadly classified into diagnostic and interventional (see Table 1.1). Diagnostic neuroradiology predominantly deals with interpreting images whereas interventional radiology consists of procedures. Interventional neuroradiology can be further classified broadly into vascular and non-vascular. Vascular neuroradiology consists of diagnostic and therapeutic procedures and deals with conditions like stroke, aneurysms, vascular malformations, tumor embolizations, and stenosis. Non-vascular interventional neuroradiology consists of procedures such as vertebroplasty, kyphoplasty, biopsies, rhizotomies, epidural injections, and lumbar punctures. There is a large degree of overlap between the diagnostic and interventional components.

Basic Techniques/Modalities

The basic techniques/modalities used in neuroradiology are the following (see Table 1.1):

- 1. plain radiographs/X-rays,
- 2. CT,
- 3. MRI,
- 4. fluoroscopy,
- 5. ultrasonography, and
- 6. nuclear medicine.

Terminology

Depending on which modality is being used there is a difference in the basic terminology (Table 1.2). In radiology, a structure or a lesion is described in relation to some other adjacent



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Table 1.1 Broad divisions of neuroradiology

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Table 1.2 Modality specific terminology in radiology

Modality	Нуро	lso	Hyper
СТ	Hypodense	Isodense	Hyperdense
MRI	Hypointense	lsointense	Hyperintense
Ultrasonography	Hypoechoic	Isoechoic	Hyperechoic
X-rays	Radiolucent		Radiopaque
PET	Hypometabolic		Hypermetabolic

structure: if the lesion is similar in density to the structure to which it is compared, the prefix "iso-" is used; for lesser density, "hypo-"; for greater density, "hyper-." The suffix varies according to the modality being used.

- 1. In CT, the suffix is dense or density, leading to the terms hypodense, isodense, or hyperdense.
- 2. In MRI, the suffix is intense or intensity, leading to the terms hypointense, isointense, or hyperintense.
- 3. In ultrasonography, the suffix is echoic, leading to the terms hypoechoic, isoechoic, or hyperechoic.
- 4. In plain films and fluoroscopy, the terms radiopaque and radiolucent are used, corresponding to more bright/denser or less bright/less dense, respectively.
- 5. In nuclear medicine, the terms broadly used are hypometabolic and hypermetabolic.

Plain Radiographs

An X-ray or radiograph is the oldest and simplest modality of imaging, which has been in common use since 1895, when Willhelm Konrad Roentgen discovered X-rays [1]. It uses a simple principle of passing X-rays, produced by a generator, through the body part of interest. Depending on the composition and density of the body part, different amounts of attenuation take place and differing amounts of X-rays pass through [2]. The X-rays which pass through the body part are collected on a detector/cassette and, like the old camera film, the cassette is developed and we get an image. For example, X-rays passing through bone undergo a lot of attenuation and very few X-rays pass through, compared to air, which has minimal attenuation, and almost all X-rays pass through. The cassette itself has a radiation-sensitive emulsion, which undergoes chemical reaction upon interaction with the X-rays. The change in chemical composition is developed as varying degrees of gray density on the final radiograph.

The hardware consists of an X-ray generator, which is the source of X-rays, a table on which the patient lies, and a receptacle for the cassette or detector below/part of the table.

There are six basic densities, which are seen in radiography, and these include air at one end of the spectrum, which is darkest, to metallic density at the other end of the spectrum, which is brightest/most dense (Figure 1.1). Fat is less dark compared to air, but darker than soft tissues or water density. The basic densities are shown in Table 1.3.



Figure 1.1 Plain radiography. Radiograph of the chest demonstrates various densities. Straight arrow – bone density in clavicle, star – soft-tissue density in liver, curved arrow – air density in trachea.

Applications in Neuroradiology

The applications of plain radiographs in neuroradiology have markedly decreased over the years. At the present time, some of the applications include:

- 1. initial evaluation of trauma, especially in primary-care facilities;
- 2. evaluation of shunts like ventriculo-peritoneal and ventriculo-pleural shunts;
- 3. evaluation of foreign bodies, especially metallic foreign bodies in the region of the orbits and face; and
- 4. evaluation of sinusitis.

Advantages

- 1. **Cheap**: Radiographs are inexpensive compared to CT scans and MRI scans.
- 2. **Quick**: They can be performed relatively quickly, and the images are available for interpretation in a short time.
- 3. Easy to perform: They are relatively easy to perform, and there is some flexibility in terms of patient positioning, depending on the body part being examined.

Table 1.3	Spectrum	of densities se	en in ra	diographs
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Least dense/ darkest					Most dense/ brightest
Air	Fat	Water/soft tissue	Blood	Calcium/ bone	Metal

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Disadvantages

- 1. **Poor soft-tissue resolution**: Radiographs have extremely poor resolution as far as evaluation of soft tissues is concerned. Gross, large, soft-tissue swelling and hematoma may be identified, but no information about the brain and the spinal-cord parenchyma can be obtained. The ligamentous structures and their integrity cannot be evaluated.
- 2. Limited evaluation of the bony structures: Gross fractures and dislocations can be visualized on radiographs, but undisplaced fractures, subtle dislocations, and early neoplastic changes cannot be seen on plain radiographs.
- 3. **Radiation:** X-rays are a source of radiation. Though the amount of radiation from plain radiographs is not lethal, radiation by its nature is cumulative and harmful.

Computed Tomography

Computed tomography (CT) scanning is one of the most widely used techniques in radiology. It has markedly evolved over the last 30 years, when Hounsfield and colleagues first discovered it [3]. The basic technique consists of passing X-rays through the body part being imaged through multiple projections. Thousands of image data sets are obtained and these are sent to highly specialized computers, which have algorithms to compute, resulting in radiologic images [4, 5].

The basic hardware consists of a very specialized and high-capacity, sophisticated, X-ray tube, which moves in concert with an arc/array of detectors. The X-ray tube and the detectors function as one unit, and move around the patient in a wide arc. The patient lies in a table, which itself moves into an opening in the X-ray machine that houses the X-ray tube and detectors. This motion of a circle formed by the movement of the tube and detectors, plus the linear motion formed by the table movement, creates a helical pattern of data acquisition, hence the name helical CT scanning [6]. The data acquired are close to three-dimensional volumetric data, and they can be constructed in any number of planes, with some limitations.

CT scanning is one of the main workhorses of neuroradiology. It is widely used in trauma and for evaluation of many structures. Images can be viewed in various settings, also known as windowing and centering, helping in the evaluation of various structures.

Structures are defined in terms of their densities. Similar to radiographic densities, the CT densities have a spectrum from the most hypodense structure, air, to the most hyperdense



Figure 1.2 Computed tomography. Axial CT section of the head in softtissue windows, demonstrates normal anatomy. Straight arrow – white matter, curved arrow – gray matter, and double arrows – cerebrospinal fluid in the ventricle.

structure, metal (Figure 1.2). The densities are objectively stated in terms of Hounsfield units (HU), which typically range between -1,000 and +4,000 (Table 1.4). The density of any structure can be measured on a CT scan by placing a region of interest over it. For example, hemorrhage has a CT density of typically 60 to 100 HU, and fat has CT density of approximately -100 HU.

CT is especially useful in the evaluation of bony structures and calcifications, and in the evaluation of air density, where it is more sensitive than MRI.

Special Techniques

1. **CT perfusion imaging**: Post-contrast dynamic images are obtained through the region of interest and then perfusion maps are generated (Figure 1.3). Various parameters like cerebral blood flow (CBF), cerebral blood volume (CBV), time to peak (TTP), and mean transit time (MTT) are calculated [7]. The main use of this technique is in

 Table 1.4
 Spectrum of CT densities in terms of Hounsfield numbers

	Least dense/darkest					Most dense/brightest
	Air	Fat	Water/soft tissue	Blood	Calcium/bone	Metal
CT Hounsfield units	-1,000	-100	0–30	60-100	400-1,500	2,000-4,000

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(c)

(d)

Figure 1.3 Computed tomography. CT perfusion images in a patient with right middle cerebral artery (MCA) acute infarct (star): (a) MTT, (b) CBV, (c) CBF, and (d) TTP perfusion maps.

the evaluation of stroke. Areas of core infarction and especially the penumbra can be evaluated and measured. The penumbra is the part of the brain that is at risk of infarction, but is potentially viable and can be saved either by neurointervention or by non-interventional measures [8]. 2. **Post-contrast dynamic imaging**: After administration of intravenous contrast, dynamic images can be obtained, and this is helpful for evaluating vascular malformations, sinus thrombosis, and markedly vascular and early enhancing tumors like glomus tumors and parathyroid adenomas [9].

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Figure 1.4 Computed tomography. 3D reconstruction of thoracolumbar spine with posterior surgical fixation in the lumbar spine and transpedicular screws and surgical rods.

- 3. **CT angiogram studies**: Angiographic evaluation of the arteries of the head and neck, and evaluation of the venous structures, can be performed after administration of intravenous contrast. This is relatively less invasive than catheter angiogram, is easier to perform, and takes less time. Three-dimensional (3D) volumetric reconstructions are performed for better visualization.
- 4. **3D volumetric reconstructions**: These are helpful in presurgical planning, and for post-surgical follow-up. A 3D reconstruction of the spine or the facial bones, especially after trauma, provides a better perspective (Figure 1.4). The normal anatomical structures and post-surgical hardware can be color-coded and shaded differently and their relationship to each other is better evaluated.
- 5. Maximum intensity projection (MIP) and minimum intensity projection (MinIP) reconstructions: For better evaluation of contrast-enhancing structures like arteries and veins, MIP can be used to slab and add contrast (Figure 1.5). Similarly, for structures with low densities, such as airways, the contrast can be negatively added together using the MinIP technique [10].

Applications in Neuroradiology

1. **Trauma**: CT scanning is the most widely used modality for patients with trauma [11]. It is commonly used in

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Figure 1.5 Computed tomography. Axial reconstructed MIP image CT angiogram of the head. Right MCA (straight arrow); right posterior cerebral artery (curved arrow).

the evaluation of the head (Figure 1.6) and spine in neuroradiology.

- 2. Stroke: CT scanning is the first investigation performed in evaluation of a patient with stroke [12]. The first step in managing a stroke patient is to differentiate between hemorrhagic and non-hemorrhagic stroke, and CT scanning is the investigation of choice (Figure 1.7). Furthermore, in follow-up studies, especially after administration of a tissue plasminogen activator (t-PA), a CT scan is the preferred modality.
- 3. **Pre-operative planning**: In brain, spine, and head and face surgeries, including the paranasal sinuses and orbits. Pre-operative knowledge of the anatomy is essential before surgical intervention, and a CT scan provides detailed information about the bony anatomy.
- 4. **Reconstruction procedures:** In the spine and face, including dental implants. CT scanning provides accurate anatomic information and pre-planning measurements can be obtained (Figure 1.8).
- 5. To rule out a metallic foreign body: In the orbits (Figure 1.9), close to the brain or spinal cord, before a patient is sent for an MRI examination. Metallicdensity foreign bodies like bullets, cochlear implants, and stimulators may be contraindications for an MRI examination. If the patient has had history of metallicdensity foreign bodies, which are not documented/imaged, then a CT scan is performed for their documentation.

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Figure 1.6 Computed tomography. (a) Axial CT section of the head in soft-tissue window demonstrates left temporal subdural hemorrhage (curved arrow), with underlying fracture (double arrows), bilateral subarachnoid hemorrhage (straight arrows), and right frontal scalp swelling (star). (b) Axial CT section of the head in bone window demonstrates the fracture (double arrow) better than the soft-tissue window image.



Figure 1.7 Computed tomography. Non-contrast CT study of the head, axial section, demonstrates a non-hemorrhagic, acute infarct in the right MCA territory (star).



Figure 1.8 Computed tomography. 3D reconstruction of the face.

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Figure 1.9 Computed tomography. Axial CT study demonstrates a metallic foreign body in the right lateral globe (arrow).

6. In patients with contraindications to MRI study: In patients with history of metallic foreign bodies close to a vital structure, non-MRI compatible pacemakers, cochlear implants, other surgical hardware, patients with claustrophobia, or in uncooperative patients, CT scan may be performed as an alternative to an MRI study.

Disadvantages

- 1. **Suboptimal evaluation of the posterior fossa structures**: Evaluation is limited secondary to significant beam hardening artifacts from the dense bones in the posterior fossa [13, 14]. Evaluation of the brainstem is generally limited for CT.
- 2. **Radiation**: CT scanning uses X-rays and is therefore a potential source of radiation.
- 3. Limited evaluation of soft-tissue structures, especially within the spinal canal.

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) is a technique based on evaluation of the magnetic properties of the body tissues. Lauterbur first described MRI in 1973 [15]. In neuroradiology, magnetic properties of the hydrogen atom are used for imaging [16]. Every element has its own resonant frequency and, when placed in an external magnetic field, the net magnetic vector aligns to the external magnetic field. A radio frequency is used for excitation of the hydrogen atom, with change in the net magnetic vector in the region of interest, for a short period of time, and then the radio frequency is shut off. The free hydrogen atoms within the tissue of interest move back along

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Figure 1.10 Magnetic resonance imaging. Non-contrast T1 axial image of the brain demonstrates normal anatomy. Straight arrows – gray matter, curved arrows – white matter.

the direction of the net magnetic field, and this movement is measured mathematically in terms of free induction decay, which is converted into electrical signals. This moving back is also known as relaxation and is measured in terms of T1 and T2 sequences. These electrical signals are then computed using highly sophisticated algorithms to form an image.

The basic hardware consists of a long tunnel-like table in which the patient lies. The tunnel houses the hardware consisting of the magnet and the various gradient coils. Since the patient lies within an enclosed space, claustrophobic patients may have difficulty in undergoing the examination. Also, MRI takes a relatively longer period of time, varying from 20 minutes to more than an hour, depending on the examination. The technique is very sensitive to motion and therefore patients who cannot stay still for half an hour or more or are claustrophobic may not be able to undergo the examination.

There are different techniques of acquiring images using MRI, known as sequences. There are two basic sequences, T1 and T2; and multiple modifications of these sequences such as fluid attenuated inversion recovery (FLAIR), short T1 inversion recovery (STIR), diffusion, and perfusion, etc. In general, fluid and fluid-containing structures like cerebrospinal fluid (CSF), vitreous in the globe, and urine in the urinary bladder are dark or hypointense on the T1-weighted sequence (Figure 1.10), and bright or hyperintense on the T2 sequence (Figure 1.11).

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Figure 1.11 Magnetic resonance imaging. T2 axial image of the brain demonstrates normal anatomy. Straight arrows – gray matter, curved arrows – white matter.

MRI has excellent contrast resolution and spatial resolution. It gives much more information compared to any other modality, especially for soft-tissue structures, like the brain and spinal cord. MRI is the modality of choice for the evaluation of the central and peripheral nervous system.

Special Techniques

- 1. Diffusion imaging: Diffusion imaging is based on the principle of normal movement of water across the cell membrane, between the extracellular and intracellular compartments [17]. Inhibition of this normal movement is evaluated by diffusion images. Any restriction in this normal diffusion results in diffusion hyperintensity on the b1000 or b800 images, with corresponding hypointensities on the apparent diffusion coefficient (ADC) maps. This is most often seen in acute infarcts. Other conditions which may result in restricted diffusion include: hypercellular neoplasms like lymphoma, medulloblastoma, and rapidly proliferating areas in glioblastoma multiforme; acutely demyelinating conditions like multiple sclerosis or exposure to toxins; and sometimes atypical presentations of posterior reversible encephalopathy syndrome (PRES).
- Perfusion imaging: Perfusion imaging measures the vascularity/perfusion in the arterial distribution of the brain. Various parameters such as CBV, CBF, transit time, permeability, and leakage properties are calculated [18, 19]. Applications of perfusion imaging include: evaluation



Figure 1.12 Magnetic resonance spectroscopy. (a) Normal MRS of the brain. (b) Abnormal MRS of a brain lesion, with marked elevation of the choline peak (straight arrow) and decrease in the NAA peak (curved arrow).

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Figure 1.13 Magnetic resonance tractography. Images demonstrate cortico-spinal tracts (arrows).

of stroke, especially to estimate the core infarct and the viable but at-risk-of-infarction area (penumbra) [20]; evaluation of neoplasms and differentiation between radiation necrosis and recurrent tumor [21, 22]; and in the assessment of the vascularity and aggressiveness of tumors.

- 3. Magnetic resonance spectroscopy (MRS): MRS measures the concentration of various metabolites within the brain, such as N-acetyl aspartate (NAA) - a neuronal marker; choline - a metabolite within the cell membranes; creatine - a marker of energy; and lactate - which is found in anaerobic metabolism [23, 24]. Some other metabolites include glutamate, aspartate, myo-inositol, and lipids. The levels of these various metabolites are altered in various pathologic conditions, including neoplasms, demyelination, and infarction. In malignant neoplasms, the concentration of choline is markedly increased and the concentration of NAA is markedly decreased, with reversal of the normal choline-NAA ratio (Figure 1.12). In infarction, the concentration of all metabolites is decreased, with an increase in the concentration of lactate.
- 4. **Tractography/diffusion tensor imaging (DTI):** In DTI, various tracts are imaged/mapped out, using diffusion

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Figure 1.14 Magnetic resonance angiography. Study of the neck with a reconstructed image in the coronal plane. Internal carotid arteries (straight arrows); vertebral arteries (curved arrows).

imaging in multiple planes (Figure 1.13). The axons forming the tracts have anisotropic properties and these are utilized in tractography [25]. Anatomic delineation of various white-matter tracts is performed. Mass effect or destruction secondary to lesions close to various tracts can be performed and this helps in pre-operative planning, and in deciding the surgical approach.

5. Magnetic resonance angiography (MRA): Angiographic studies of the head, neck, and spine can be performed using MRI (Figure 1.14). Various techniques like time-of-flight, phase-contrast, or postcontrast examinations are utilized for angiographic studies [26]. Post-contrast dynamic images can be

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Figure 1.15 Magnetic resonance CSF: flow study in a Chiari patient. (a) Sagittal image demonstrates the levels of CSF flow measurements at the anterior cervicomedullary CSF space (1), anterior (2) and posterior (3) to the thecal sac in the cervical spine. (b) Temporal variation of CSF flow at these levels, with cardiac cycle. Dampening of flow is seen posterior to the thecal sac (arrow).

performed. Non-contrast MRA images help in the evaluation of vessels in patients with deranged renal parameters, and in other conditions where contrast administration is contraindicated. Evaluation of aneurysms, vascular malformations, and post-surgical/ post-neuro interventional follow-up can be performed with MRI techniques.

- 6. **CSF flow studies**: CSF flow studies (Figure 1.15) can be performed using the phase-contrast technique, with velocity encoding [27, 28]. These are helpful in conditions like Chiari malformations, normal-pressure hydrocephalus, and other lesions causing obstruction in the CSF flow pathway.
- 7. Functional MRI: Functional MRI is a special application of MRI, in which the areas of the brain responsible for particular function of the body are activated and mapped [29]. The properties of oxyhemoglobin and deoxyhemoglobin are utilized, with the active part of the brain having more deoxyhemoglobin. The eloquent areas of the brain, for example the centers for language, motor function, and visual activity, can be mapped using this technique. This is important in pre-surgical planning and in understanding the effects that a mass lesion involving brain have on the neurologic functions of the patient.

Applications in Neuroradiology

- 1. In evaluation of stroke, especially in the first 3 to 24 hours: MRI may be the only modality that will demonstrate findings of infarction in the first few hours of stroke [30]. Diffusion-weighted imaging (Figure 1.16b, c) is very sensitive and may show changes of infarction as soon as within the first half an hour. Early hemorrhagic transformation with an infarct may also be demonstrated more sensitively on MRI examination.
- 2. **Pre-operative planning and post-operative follow-up in neoplasms**: MRI has excellent contrast and spatial resolution and this helps in the evaluation of neoplasms, their extent, morphology, and enhancement pattern, margins, associated mass effect, local and distant spread, and their multiplicity. The surgical approach can be decided upon for both resection and biopsy. Techniques such as magnetic resonance perfusion, MRS, and magnetic resonance tractography help in pre-surgical planning. In post-operative follow-up studies, MRI can provide evidence of early recurrence, or residual lesion.
- 3. In evaluation of non-neoplastic conditions: These include demyelinating conditions like multiple sclerosis (Figure 1.17) and progressive multifocal leukoencephalopathy; infective conditions like abscesses and meningitis; atrophic conditions like Alzheimer dementia, normal-pressure hydrocephalus, and Pick disease; and post-traumatic evaluation of the bony