Chapter 2

Medical Image techniques:

- X-ray Imaging: Uses special waves to see inside the body by noticing how much they're absorbed. It shows differences between tissues.

- Magnetic Resonance Imaging (MRI): Uses magnets to see what things are made of and how they work. It's like taking a detailed picture of the body's insides.

- Ultrasound Imaging: Uses sound waves to make pictures of the body. It's like seeing shapes with sound.

- Nuclear Imaging: Uses a special material to see how organs and tissues are doing. It shows where things are active.

Image Types:

1. Projection Images:
   - Show a projection of the 3D human body onto a 2D plane.
   - Provide an overall view but lack depth information.

2. Slice Images:
   - Show a distribution of measurement values in a 2D slice through the human body.
   - Offer detailed information about a specific plane.

X-rays:

- X-ray Production: X-rays are created when high-energy electrons strike a metal target inside a machine called a cathode ray tube. These X-rays are a type of electromagnetic radiation.

- Interaction with Matter: X-rays interact differently with materials in the body. Dense materials, like bones with high atomic numbers, absorb more X-rays, while softer tissues allow more X-rays to pass through.

- Bone Imaging: X-rays are commonly used to visualize bones because they are good at highlighting dense structures. This helps doctors assess bone health and detect fractures or abnormalities.

- CT Scans: CT scans combine X-ray technology with advanced computer processing. They take X-ray images from many different angles around the body, which a computer then uses to create detailed cross-sectional images.

- Medical Diagnosis: Doctors use X-rays and CT scans to diagnose a wide range of medical conditions, from broken bones to internal injuries, by examining the images produced and identifying any abnormalities.

- Exposure: Exposure refers to the amount of radiation received by a person. X-rays release electrons from atoms and are measured in Roentgen (R). Absorption of radiation by the body is measured in rad or gray (Gy). Bones absorb more than soft tissues.

- Imaging Equipment: X-ray machines emit X-rays through a tube and capture them with receptors like film or digital detectors.

- Image Receptors: Image receptors can be film, image intensifiers, or digital flat panel detectors. They capture X-rays and produce images for diagnosis.

- Resolution and Adjustability: Digital radiography offers adjustable resolution without changing exposure.

Fluoroscopy and Angiography:
- Fluoroscopy: Visualizes moving objects in the body, such as the heartbeat or contrast agent flow, in real-time.

Angiography: Images blood vessels using contrast agents, assisting in surgical interventions.

Digital Fluoroscopy: Enables real-time imaging and 3D reconstruction, enhancing diagnostic capabilities.

Digital Subtraction Angiography (DSA): Removes non-vascular structures from images, improving clarity and aiding in the assessment of blood vessels.

Digital Techniques: Reduce motion artifacts and enhance image quality, providing more accurate diagnostic information.

Mammography:
- Mammography detects breast lesions using specialized X-ray tubes.
- Mammography tubes use low-energy beams to enhance tissue contrast.
- Digital mammography offers advantages like higher dynamic range and easier distribution.

Computed Tomography (CT):
- CT reconstructs 3D images from X-ray projections, improving resolution and reducing artifacts.
- Images are computed from projection measurements, allowing detailed 3D visualization.
- Hounsfield units normalize attenuation coefficients for standardized image interpretation.

Contrast Enhancement in CT:
- Contrast agents enhance structures in CT scans, especially blood vessels.
- CT angiography (CTA) provides 3D images for quantitative analysis.
- CTA requires higher X-ray exposure but provides detailed soft tissue information.

Image Analysis on X-ray Generated Images:
- Radiographs have high spatial resolution for detecting small lesions.
- Assignments between brightness and tissue type are limited.
- Motion and exposure issues can reduce contrast and cause blurring.
- CT images have lower spatial resolution but offer improved 3D visualization.

Magnetic Resonance Imaging (MRI):
- Protons and neutrons in atom nuclei possess spin, forming the basis of MRI.

- MRI aligns nuclei spins in a magnetic field and uses radio signals to create images based on spin properties.
- MRI provides excellent soft tissue contrast due to variation in hydrogen density and molecular binding.
- MRI does not use ionizing radiation, offers versatile slice orientations, and can image various functional attributes.

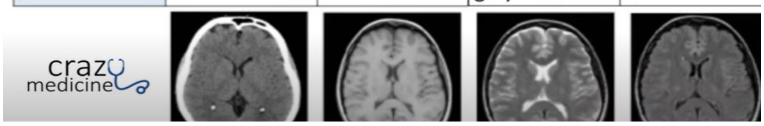
MRI Basics:
- MRI uses static magnetic fields measured in Tesla (T) or Gauss.
- Higher magnetic fields increase signal sensitivity.
- Spin frequency depends on magnetic field strength and gyromagnetic constant.
- Exciting proton spins in specific locations using gradient fields allows for slice selection in MRI.

k-space Imaging:
MRI Technique: MRI (Magnetic Resonance Imaging) utilizes k-space imaging to create images directly in frequency space.
Gradient Usage: Phase encoding and frequency encoding gradients are employed to dephase spins and measure signal frequency, respectively.
Data Collection: k-space is filled with measured data acquired through these gradients.
Image Reconstruction: The collected data in k-space is then transformed back into the spatial domain, generating detailed images for diagnosis.

MRI Imaging Vs CT:
- MRI equipment resembles CT, but MRI gantries are usually smaller.
- MRI can produce images in arbitrary planes and various sequences to enhance tissue contrast.
- Different MRI sequences alter the appearance of tissues based on parameters like spin density and relaxation times (T1, T2).
- MRI does not have a normalized scale like Hounsfield units in CT.

Some MR Sequences:
- T1 and T2 relaxation time constants influence image contrast in MRI.
- Spin echo sequence cancels out T2* effects, producing T2-weighted images.
- Inversion recovery sequence heavily influences T1 time constant for image contrast.
- MRI head images typically have 1-3 mm slice thickness with 256x256 or 512x512 voxels per slice.
- Turbo spin echo sequences (RARE) speed up image acquisition by making multiple measurements at once.
- Fast imaging techniques like Echo Planar Imaging (EPI) acquire complete k-space in a single resonance experiment.

	CT	T1 Weighted MRI	T2 Weighted MRI	FLAIR MRI
Bone	WHITE	Dark	Dark	Dark
CSF	Dark	Dark	WHITE	DARK
White Matter		White	Darkish compared to grey matter.	Dark



Artifacts in MR Imaging:
- Chemical shift causes material-dependent frequency deviations, particularly apparent in ultrafast sequences like EPI.
- Ghosting occurs due to phase encoding inaccuracies or patient movement.
- Shading results from RF signal attenuation and magnetic field inhomogeneity.
- Noise and partial volume effects (PVE) cause image artifacts similar to CT imaging.
- Metal artifacts from paramagnetic materials can cause signal deletion.

MR Angiography:
Contrast Enhancement: MR angiography (MRA) can be enhanced using gadolinium contrast agents, resulting in high-contrast images of blood vessels.
Image Presentation: MRA images are commonly displayed as maximum intensity projection (MIP) images, which highlight the maximum intensity of the contrast-enhanced vessels for better visualization.

BOLD Imaging:
- Blood Oxygen Level Dependency (BOLD) Imaging detects local magnetic field distortions caused by deoxygenated hemoglobin.
- BOLD imaging can be used to measure brain activity by correlating intensity changes with tasks performed by the subject.

Perfusion Imaging:
Perfusion Measurement: Gadolinium-enhanced MRI is utilized to measure perfusion by assessing changes in blood volume and flow.
Diagnostic Applications: Perfusion imaging aids in diagnosing stroke and analyzing blood flow in conditions such as tumors or cardiac studies.
Diffusion Imaging:
Diffusion Coefficient Measurement: Diffusion imaging evaluates the diffusion coefficient of isotropic or anisotropic diffusion, indicating changes in tissue.
Diffusion Tensor Imaging (DTI): DTI specifically tracks fiber direction in the brain, enabling MR tractography to reconstruct brain connections.
Image Analysis on Magnetic Resonance Images:
- MRI provides better soft tissue contrast but lacks standardized image intensity measurements.
- Image appearance can vary based on sequence type, scanner type, and acquisition parameters.
- Artifacts like shading and noise can complicate tissue-to-image brightness mapping and affect image analysis methods.

Ultrasound Imaging:
- Ultrasound waves are reflected at boundaries between materials with different acoustic impedance, allowing for imaging of organ boundaries.
- Reflections can be reconstructed based on the speed of sound in the tissue.
- Ultrasound imaging utilizes a transducer to send and receive ultrasound waves.
- Diagnostic ultrasound frequencies typically range between 1 and 20 MHz.
- High-frequency waves attenuate faster and penetrate the body less effectively than low-frequency waves.

1. **Ultrasound A-Scan:**

- A single ultrasound wave is sent into the body and records the amplitude of reflections over time.
- It provides a one-dimensional probe into the body, showing tissue boundaries and other regions with different acoustic impedance.

2. **Ultrasound B-Scan:**
    - Ultrasound images (B-scans) are created from a planar fan beam of differently rotated A-scans.
    - Amplitudes are mapped to gray values to create the image, which can also be acquired as 3D images with the fan beam rotating around a perpendicular axis.

Ultrasound Imaging Applications:
- Ultrasound imaging, or sonography, can show real-time motion of internal organs.
- Organs commonly imaged include the liver, gallbladder, pancreas, kidneys, spleen, heart, and uterus.
- Techniques like transesophageal ultrasound (placing the device into the esophagus) and transrectal ultrasound (placing the device into the rectum) enable imaging of specific organs.
- Intravascular ultrasound (IVUS) involves inserting the device into arteries to image and quantify calcifications.

Doppler Imaging:
- Utilizes the Doppler effect to estimate the speed and direction of moving objects (e.g., blood) in ultrasound images.
- Helps diagnose vessel blockages or changes in blood flow due to stenosis.
- Color-coded velocity depictions differentiate between flow directions and velocities.

FUS Imaging:
- Focused ultrasound (FUS) can be used in image-guided therapy to increase energy at a specific point, such as thermal ablation of tumors.
- FUS may also induce mechanical effects or stimulate growth in various body regions, but it requires substantial support during intervention.

Artifacts in Ultrasound Imaging:
- Various effects cause artifacts in ultrasound images, including attenuation, absorption, scattering, refraction, interference, and wave divergence.
- Absorption leads to decreased amplitude with depth, while interference, scatter, and refraction cause speckle artifacts.
- Tissue boundaries may produce mirror echoes or multiple echoes, and motion artifacts can distort boundaries.
- Acoustic shadowing may hide tissues, while fluid-induced signal enhancement can lead to position-dependent signal increases.
- Absorption decreases the signal-to-noise ratio with increasing distance from the transducer.

Image Analysis on Ultrasound Images:
- Ultrasound is noninvasive and inexpensive, making it widely used for diagnosis.
- Artifacts and underlying assumptions can affect quantitative analysis, including localization errors due to variations in the speed of sound and displacement errors from refraction.
- Organ boundaries, motion artifacts, and acoustic shadowing can also impact analysis.

- Absorption affects the signal-to-noise ratio based on distance from the transducer.

Nuclear Imaging:
- Measures radioactive tracer distribution in the body for functional imaging.
- Tracer material is injected intravenously, distributing through blood circulation.
- Applications include brain activity, heart perfusion, inflammation diagnosis, and tumor detection.
- Images formed by measuring photons emitted by tracer material.
- Lower spatial resolution due to low tracer concentration.
- High sensitivity allows detection of signals from few photons.

Major Techniques:
- Scintigraphy: Projects tracer distribution similar to X-ray imaging.
- SPECT (Single Photon Emission Computed Tomography): 3D reconstruction from tracer projections.
- PET (Positron Emission Tomography): Utilizes positron-emitting tracer materials for imaging.

1. **Scintigraphy:**
    a. Uses 99Tc tracer molecule detected by a gamma camera.
    b. Camera includes a collimator, scintillator crystal, and photomultipliers.
    c. Collimator provides approximate parallel projection of tracer photons.
    d. Limitations in spatial resolution and contrast due to collimator characteristics.

2. **SPECT:**
    a. Reconstruction from gamma camera projections.
    b. Spatial resolution approximately 3-6 mm.
    c. Acquisition with single or multi-head cameras.
    d. Applications include heart perfusion, tumor detection, and brain studies.

Image Analysis:
- Signal strength depends on tracer amount and metabolism.
- Quantitative measurements usually compare activity between regions.
- Poor image quality due to low photon count and acquisition restrictions.
- Often requires correlation of functional signal with anatomy.

Other Imaging Techniques:
    a. Optical Coherence Tomography: Utilizes light waves for imaging, useful in ophthalmology and dermatology.
    b. Photography: Used for vascular processes in retina and diagnosis of skin tumors.
    c. Optical Microscopy: Analyzes living structures, often used for pathology diagnosis.
    d. Electron Microscopy: Higher resolution imaging using electron detection.
    e. EEG and MEG: Measures brain activity through electrical or magnetic impulses.