Introduction to medical imaging

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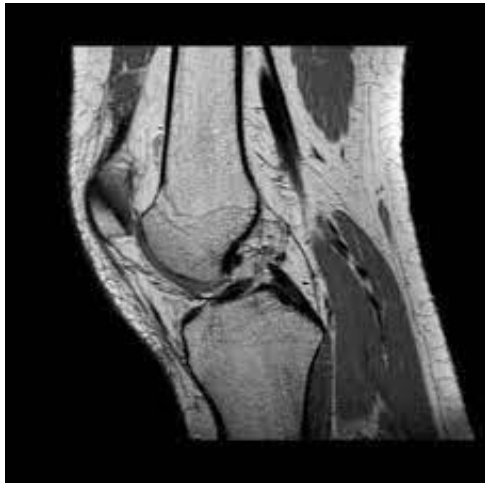
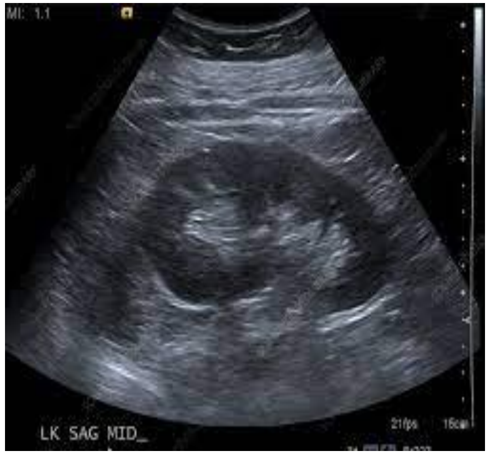
Medical Images





Medical Imaging

- The overall objective of medical imaging is to acquire useful information about physiological processes or organs of the body by using external or internal sources of energy.

Medical imaging

- The quality of the medical image depends
  - better x-ray image can be made when the radiation dose to the patient is high
  - Better magnetic resonance images can be made when the image acquisition time is long
  - When ultrasound power levels are large it provides better ultrasound image.

Medical imaging

- Low dose to high dose image conversion (CT)
- Reconstruction image from few data (MRI)
- Denoise/Enhance X-Ray/Ultrasound Image
- Classification/Recognition/Detection of MRI bone/Tissue

Medical imaging modalities

- **Radiography**
- Fluoroscopy
- Mammography
- **Computed Tomography (CT)**

X-RAY

- **Nuclear Medicine Imaging**
- **Single Photon Emission Computed Tomography (SPECT)**
- **Positron Emission Tomography (PET)**
- **Magnetic Resonance Imaging (MRI)**
- **Ultrasound Imaging**
- **Doppler Ultrasound Imaging**

Image properties

- Contrast
- Spatial resolution

Contrast

- X-ray contrast is produced by differences in tissue composition, which affect the local x-ray absorption coefficient.
- Contrast in MRI is related primarily to the proton density and to relaxation phenomena (i.e., how fast a group of protons gives up its absorbed energy).
- Contrast in ultrasound imaging is largely determined by the acoustic properties of the tissues being imaged.

Contrast

Spatial resolution

- resolve fine detail in the patient.
- RESOLVE= separate into constituent parts
- the ability to see small detail, and an imaging system has higher spatial resolution if it can demonstrate the presence of smaller objects in the image.
- The limiting spatial resolution is the size of the smallest object that an imaging system can resolve.
- In ultrasound imaging, the wavelength of sound is the fundamental limit of spatial resolution. At 3.5 MHz, the wavelength of sound in soft tissue is about 0.50 mm. At 10 MHz, the wavelength is 0.15 mm.

Spatial resolution

TABLE 1-1. THE LIMITING SPATIAL RESOLUTIONS OF VARIOUS MEDICAL IMAGING MODALITIES: THE RESOLUTION LEVELS ACHIEVED IN *TYPICAL* CLINICAL USAGE OF THE MODALITY

Modality	Δ (mm)	Comments
Screen film radiography	0.08	Limited by focal spot and detector resolution
Digital radiography	0.17	Limited by size of detector elements
Fluoroscopy	0.125	Limited by detector and focal spot
Screen film mammography	0.03	Highest resolution modality in radiology
Digital mammography	0.05–0.10	Limited by size of detector elements
Computed tomography	0.4	About ½-mm pixels
Nuclear medicine planar imaging	7	Spatial resolution degrades substantially with distance from detector
Single photon emission computed tomography	7	Spatial resolution worst toward the center of cross-sectional image slice
Positron emission tomography	5	Better spatial resolution than with the other nuclear imaging modalities
Magnetic resonance imaging	1.0	Resolution can improve at higher magnetic fields
Ultrasound imaging (5 MHz)	0.3	Limited by wavelength of sound

Medical imaging: from physiology to information

- Understanding Image medium
- Physics of Imaging
- Imaging instrumentation
- Data Acquisition Methods for Image formation
- Image Processing and Analysis

Medical imaging: from physiology to information

- ***Understanding Image medium:***
  - tissue density is a static property that causes attenuation of an external radiation beam in X-ray imaging modality.
  - Blood flow, perfusion and cardiac motion are examples of dynamic physiological properties that may alter the image of a biological entity.

Medical imaging: from physiology to information

Physics of Imaging: The next important consideration is the principle of imaging to be used for obtaining the data.

- For example, X-ray/CT imaging modality uses transmission of X-rays through the body as the basis of imaging.
- On the other hand, in the nuclear medicine modality, Single Photon Emission Computed Tomography (SPECT) uses emission of gamma rays resulting from the interaction of radiopharmaceutical substance with the target tissue.

Medical imaging: from physiology to information

Imaging instrumentation:

- The instrumentation used in collecting the data is one of the most important factors defining the image quality in terms of signal-to-noise ratio, resolution and ability to show diagnostic information.
- Source specifications of the instrumentation directly affect imaging capabilities. In addition, detector responses such as non-linearity, low efficiency and long decay time may cause artifacts in the image.

Medical imaging: from physiology to information

Data Acquisition Methods for Image formation:

- The data acquisition methods used in imaging play an important role in image formation.
- Optimized with the imaging instrumentation, the data collection methods become a decisive factor in determining the best temporal and spatial resolution.

Medical imaging: from physiology to information

***Image Processing and Analysis*:**

- Image processing and analysis methods are aimed at the enhancement of diagnostic information to improve manual or computer-assisted interpretation of medical images.

What you want to know about each modalities?

- a short history of the imaging modality,
- the theory of the physics of the signal and its interaction with tissue,
- the image formation or reconstruction process,
- a discussion of the image quality,
- the different types of equipment in use today {block diagram + implementation},
- examples of the clinical use of the modality,
- a brief description of the biologic effects and safety issues, and
- some future expectations.

Safety

- MR and ultrasound, which do not produce any ionising radiation, could perform diagnostic roles that were traditionally the preserve of X-ray radiology.

Safety

- How does the referring doctor decide to request an MRI rather than an X-ray, CT or ultrasound image?
- In general, the investigation chosen is the simplest, cheapest and safest able to answer the specific question posed.

X-ray

- Because of the high contrast between bone and soft tissue, the X-ray is particularly useful in the investigation of the skeletal system.
- An X-ray image of the chest, for example, reveals a remarkable amount of information about the state of health of the lungs, heart and the soft tissues in the mediastinum (the area behind the breast bone).

X-ray

- In contrast, soft tissue organs such as the spinal cord, kidneys, bladder, gut and blood vessels are very poorly resolved by X-ray. Imaging of these areas necessitates the administration of an artificial contrast medium to help delineate the organ in question.

CT

- In general, CT images are only obtained after a problem has been identified with a single projection X-ray or ultrasound image; however, there are clinical situations (a head injury, for example) in which the clinician will request a CT image as the first investigation.
- CT is particularly useful when imaging soft tissue organs such as the brain, lungs, mediastinum, abdomen and, with newer ultra-fast acquisitions, the heart.

Gamma imaging: SPECT

Single Photon Emission Computed Tomography

- Like X-ray images, gamma investigations are limited by the dose-related effects of ionising radiation and their spatial resolution, even with tomographic enhancement, means that they are poorly suited for the imaging of anatomical structure.
- However, the technique has found an important niche in the imaging of function, that is to say, how well a particular organ is working.

Gamma imaging

- In practice, function equates to the amount of labelled tracer taken up by a particular organ or the amount of labelled blood-flow to a particular region.
- The radionuclide is usually injected into a vein and activity measured after a variable delay depending on the investigation being performed.
- A quantitative difference in 'function' provides the contrast between neighbouring tissues, allowing a crude image to be obtained.

PET
Positron Emission Tomography

- In contrast, PET, first proposed in the 1950's, has taken much longer to be accepted as a clinical tool.
- The problem is related in part to the cost of the scanner and its ancillary services the cyclotron and radio pharmacy — and in part to the absence of a defined clinical niche.
- Thus, while PET has a number of theoretical advantages over SPECT such as its higher spatial resolution and its use of a number of biologically interesting radio nuclides,
- in practice, it remains a research tool, found in a handful of national specialist centres, used in the investigation of tumours or heart and brain function.

MRI

- it has already found a particular place in the imaging of the brain and spinal cord.
- One reason is its ability to detect subtle changes in cerebral and spinal cord anatomy that were not resolvable with CT (a slipped disc pressing on a spinal nerve or a small brain tumour, for example).

MRI

- This advantage of MRI over CT is due in part to the superior spatial resolution of the technique and in part to the fact that MR images are insensitive to bone — in CT, the proximity of bony vertebrae to the spinal cord make this region difficult to image as a result of partial volume effects.
- Furthermore, patients with pacemakers, artificial joints or surgical clips cannot be scanned and there are technical problems in scanning unconscious patients that require monitoring or artificial ventilation.

Ultrasound

- Ultrasound is an effective and safe investigative tool. It offers only limited spatial resolution but can answer a number of clinical questions without the use of ionising radiation and, unlike MRI, the equipment required is portable, compact and relatively inexpensive.
- It has found a particular place in the imaging of pregnancy, but it is also used to image the liver, spleen,
- kidneys, pancreas, thyroid and prostate glands, and is also used as a screening tool in interventional radiology
- Ultrasound plays an important role in the investigation of the heart and blood vessels

Ultrasound

- However, there are a number of specific clinical situations in which ultrasound cannot be used.
- Structures surrounded by bone, such as the brain and spinal cord, do not give clinically useful images, and
- the attenuation of the ultrasound signal at air/tissue boundaries means that the technique is not suitable for imaging structures in the lung or abdominal organs obscured by gas in the overlying bowel.