INTRODUCTION TO ANATOMICAL IMAGING TECHNIQUES

PBM 218
Fall 2017
INTRODUCTION TO ANATOMIC IMAGING METHODS

Survey of different methods of imaging human anatomy
- Radiography
- Fluoroscopy
- Computed Tomography (CT)
- Ultrasound (US)
- Magnetic Resonance Imaging (MRI)
- Positron Emission Tomography (PET)

Provide background to enable students to identify and understand images presented in later lectures

(Not a presentation of imaging physics - This comes from other PBM courses & labs)
RADIOGRAPHY

• Discovery of x-rays
  • Wilhelm Röentgen in 1895
  • Almost immediate applications exploring medical use

• First Nobel Prize in Physics awarded to Roentgen in 1901
Wilhelm Röntgen

Wilhelm Conrad Röntgen (ˈrøntɡən, -dʒən, -nt-) [1] German: [ˈvɪlhelm ˈʁoŋtɡen], 27 March 1845 – 10 February 1923) was a German physicist, who, on 8 November 1896, produced and detected electromagnetic radiation in a wavelength range known as X-rays or Röntgen rays, an achievement that earned him the first Nobel Prize in Physics in 1901 [2] in honour of his accomplishments, in 2004 the International Union of Pure and Applied Chemistry (IUPAC) named element 111, roentgenium, a radioactive element with multiple unstable isotopes, after him.

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1 Biography
   1.1 Career
   1.2 Personal life
2 Honors and awards
3 Legacy
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5 References
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Biography [edit]

In 1865, he tried to attend the University of Utrecht without having the necessary credentials required for a regular student. Upon hearing that he could enter the Federal Polytechnic Institute in Zurich (today known as the ETH Zurich), he passed its examinations, and began studies there as a student of mechanical engineering. In 1869, he graduated with a Ph.D. from the University of Zurich; once there, he became a favorite student of Professor August Kundt, whom he followed to the University of Strassburg (then recently annexed by Germany) in 1873.[3]
X-RAYS

• Short wavelength electromagnetic radiation

• Many objects that are opaque to ordinary light are penetrated by x-rays

• Causes fluorescence in certain “detector” materials

• Visible light is emitted from the detector material when x-rays strike it
X-RAYS

- Radiopaque
  - X-rays are absorbed by denser materials - metals & minerals

- Radiolucent
  - X-rays pass through less dense materials
**RADIOGRAMS**

- Call them “Radiographs” not “x-rays”
- Fluoroscopic imaging
  - radiopaque areas appear dark
  - weak light intensity
- Photographic film radiography
  - film optimized for visible light
- Radiopaque areas appear bright
  - “negative” photography
- Radiographs are “shadowgrams”
  - Thickness and composition are important
- Objects far from the detector are “magnified”
- Anatomy of interest should be as close to the detector as possible
Fluoroscopic Imaging  
(detection of fluorescence)

Radiographic Imaging  
(use fluorescence to expose photographic film)
RADIOGRAPHS

Thickness is important
Composition is important
SAMPLE RADIOGRAPHS
RADIOGRAPHS
Routine Posteroanterior (PA) Film
• X-rays pass from back to front (organs of interest closest to film)
• Viewed as if you face the subject (subject’s left on your right)
WHAT IS THE DIFFERENCE BETWEEN THE TWO SUBJECTS?
MAMMOGRAPHY
BREAST CANCER

Fibroadenoma
- Benign tumor

Ductal Carcinoma
- Malignant cancer

Breast cancer mammogram
A mammogram is an X-ray of the breast. It shows any tumors or other lumps as dense, white areas in the breast tissue. Screening for breast cancer is done by a mammogram.
FLUOROSCOPY/ANGIOGRAPHY

• Real time visualization using x-rays

• Continuous beam of x-rays with electronic fluoroscopic detection

• Placement of catheters for administration of contrast material

• Iodinated contrast material -- a dense radiopaque material)
ANGIOGRAPHY

- Imaging of the arteries and veins using fluoroscopic techniques
  - Arteriograms
  - Venograms

- Pulmonary Arteriogram
- Renal Venogram
DIGITAL SUBTRACTION ANGIOGRAPHY

Brain, lateral view

Posterior

Aneurysm

Anterior

Inferior
RADIOGRAPHY CONFOUNDING
RADIOGRAPHY CONFOUNDERS
TOMOGRAPHY

- Thin sections provide improved radiographic visualization
- Permit 3D reconstruction
COMPUTED TOMOGRAPHY

• Unique (transaxial) cross-sectional images
• Pencil thin beam of x-rays passes at all angles through one section of the patient
• Ultra-sensitive electronic detection
• Computer used to reconstruct tomographic images (Hounsfield - Nobel Prize for medicine)
Godfrey Hounsfield

From Wikipedia, the free encyclopedia

Sir Godfrey Newbold Hounsfield, CBE, FRS,[1] (28 August 1919 – 12 August 2004) was an English electrical engineer who shared the 1979 Nobel Prize for Physiology or Medicine with Allan McLeod Cormack for his part in developing the diagnostic technique of X-ray computed tomography (CT).[2][3]

His name is immortalised in the Hounsfield scale, a quantitative measure of radiodensity used in evaluating CT scans. The scale is defined in Hounsfield units (symbol HU), running from air at −1000 HU, through water at 0 HU, and up to dense cortical bone at +1000 HU[4] and more.

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<th>Sir Godfrey Hounsfield</th>
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<tr>
<td>Born</td>
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<tr>
<td>Godfrey Newbold Hounsfield</td>
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<tr>
<td>28 August 1919</td>
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<td>Nottinghamshire, England</td>
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<tr>
<td>Died</td>
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<td>12 August 2004 (aged 84)</td>
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<td>Kingston upon Thames, Surrey, England</td>
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<td>Nationality</td>
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<td>Electrical engineer</td>
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<td>X-ray computed tomography (CT)</td>
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Allan McLeod Cormack

From Wikipedia, the free encyclopedia

Allan MacLeod Cormack (February 23, 1924 – May 7, 1996) was a South African American physicist who won the 1979 Nobel Prize in Physiology or Medicine (along with Godfrey Hounsfield) for his work on X-ray computed tomography (CT).

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Early life and education [edit]

Cormack was born in Johannesburg, South Africa. He attended Rondebosch Boys’ High School in Cape Town, where he was active in the debating and tennis teams. He received his B.Sc. in physics in 1944 from the University of Cape Town and his M.Sc. in crystallography in 1945 from the same institution. He was a research student at Cambridge University from 1947–49, and while at Cambridge he met his future wife, Barbara Seavey, an American physics student.
COMPUTED TOMOGRAPHY

• Images presented as if you were viewing the patient from the “foot of the bed”
  • Patient’s right on your left

• Tomograms
  • Typical thickness is 5 -10 mm
  • Not projections
  • Clarity obvious
COMPUTED TOMOGRAPHY

- Multiplanar views accomplished by moving the subject through the scanner
- Permits 3-dimensional reconstructions
BREAST TOMOSYNTHESIS
ULTRASOUND

Imaging with high frequency sound waves
ULTRASOUND

- Sound reflected from tissue interfaces
  - Solid organs are echogenic
  - Can’t look “behind” bone
  - Cysts (fluid-filled cavities) are anechnotic (echolucent)
ULTRASOUND

- US images are not as clear as CT or MRI, but
  - Safe (no radiation)
  - Interactive imaging in any plane
  - Cheap
  - Bedside procedure
  - Permits visualization of movement
MAGNETIC RESONANCE IMAGING (MRI)

- Complicated signal detection procedure
- Spectroscopic detection of spin resonance detects hydrogen nuclei (mostly from water and fat)
- Makes use of magnetic fields
- Tomographic technique
  - Tissue sections
  - Arbitrary imaging planes
- Excellent depiction of soft tissues
MRI

- Can penetrate bone
- Good contrast
- T1W - lipids are bright, fluid is dark
MRI 3D RECONSTRUCTION

- Visualizing 3D anatomy is hard
- Since MRI is tomographic we can create 3D reconstructions of imaged tissues
MRI CLINICALLY

- Patient with traumatic brain injury (TBI)
- Hyperintensities are clotted blood (iron)
- These hyperintensities allow us to identify hemorages
WHOLE BODY MRI

Table moves patient through the scanner
MRI IS INTRINSICALLY MULTIPARAMETRIC

• MRI “Flavors”
  • Proton density weighted
    • Signal intensity depends (mostly) on water (or fat) content
  • T1 weighted (T1w)
    • Signal intensity depends (mostly) on water relaxation time T1
  • T2 weighted (T2w)
    • Signal intensity depends (mostly) on water relaxation time T2

• Relaxation times T1 and T2 are nuclear magnetic properties that depend on the surrounding physical structure (biological tissues)
ANATOMIC MRI READING

• T1w
  • Cell-free fluid is dark
  • Grayscale level for cellular tissues depends on cell density and other features
  • Fat is bright

• T1w + contrast agent
  • T1w rules apply plus
  • Vascular space is bright
  • Tumors are often bright (contrast agent leaks into tumors)

• T2w
  • Cell-free fluid is bright
  • Grayscale level for cellular tissues depends on cell density and other features
  • Fat is dark
TI-WEIGHTED MRI
(STRUCTURAL)

- Without contrast
  - $T_I$ is dependent on tissue's microscopic structure

- With contrast
  - Intravenously administered material that alters the nuclear spin $T_I$
WARNING

• Text uses many falsely colored MRI
• This is highly non-standard
• Routine MRIs are always displayed as grayscale images
POSITRON EMISSION TOMOGRAPHY (PET)

• Based on the existence of a subatomic particle called a positron (a positive electron)

• Certain unstable nuclear isotopes emit positrons
  • Requires an onsite cyclotron

• Emitted positrons move a small distance before encountering a negative electron causing decay to two gamma rays
PET

- Patient is injected with radioactive tracer
- Decaying isotope emits a positron
- Positron annihilates with nearby electron
- 511 keV photon is detected
PET IMAGING
PET TRACERS

- $^{18}$Fluorodeoxyglucose (FDG) is a tracer of glucose metabolism
  - Injected into vascular system
  - Transported into cells by glucose transporters
  - FDG metabolism reaches a ‘dead end’ after phosphorylation
  - Tracer of glucose metabolism
- $^{15}$O$_2$
  - Delivered by inhalation
  - Tracer converted to CO$_2$ by respiration and washed out by blood flow
  - Analysis of time course can be used to determine the rate of oxygen metabolism if a CBF measurement is also done
- Many other PET tracers are in development
  - The basis of ‘molecular imaging’
PET TRACERS

2-[F-18]Fluoro-2-Deoxy-D-Glucose (FDG)

E = mc^2

511 keV photon

180°