Imaging of Cancer

Subtitle: What actually happens in a Radiology Department?

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Imaging of Cancer

• Imaging is a key element of:
  – Screening (e.g. lung cancer, breast cancer)
  – Staging (has it spread locally? Metastasized?)
  – Monitoring of treatment (Better or worse?)
  – Recurrence (Has it come back?)
  – Prognosis (What will happen?)
The Main Imaging Devices

• Computed Tomography (CT)
• Magnetic Resonance Imaging (MRI)
• Ultrasound (US)
• Single Photon Emission Computed Tomography (SPECT)
• Positron Emission Tomography (PET)
• Optical Imaging
The Main Imaging Devices

Quiz: Name that Scanner

CT

MRI

SPECT

PET

US
Computed Tomography
X-ray production

X-ray production: cathode ray tube

C=Cathode
A=Anode
X=X-ray
Basics of CT

Basics of CT
Cross section of a CT Scanner
CT projection

Filtered Back Projection

FIGURE 25-18
The Fourier Slice Theorem. The Fourier Slice Theorem describes the relationship between an image and its views in the Frequency domain. In the spatial domain, each view is found by integrating the image along rays at a particular angle. In the frequency domain, the spectrum of each view is a one-dimensional "slice" of the two-dimensional image spectrum.
“Volume” CT imaging
CT

Windowing a CT

“Windowing” a CT
Advantages of CT

• Widely available
• Minimal prep (NPO, drink contrast)
• Very rapid (2-3 seconds neck to pelvis)
• High resolution
• Relatively inexpensive
Disadvantages

- **Radiation**
- Often requires iv contrast media
  - Allergic reactions (minimal)
  - Kidney damage (only in high risk patients)
- Anatomic information only
Radiation reduction on CT

Radiation

Lower kV (energy) x-rays
More sensitive detectors
Better reconstruction algorithms
“Synthetic” images

Reducing Radiation
Attenuation differences thru the body
Contrast Media

Iodinated Contrast Media
Contrast media

Basic Structures of Contrast Media

Ionic Monomer

Nonionic Monomer

Ionic Dimer

Nonionic Dimer

Non ionic iodinated contrast

Non ionic Iodinated Contrast

![Chemical structure of Non ionic iodinated contrast](image-url)
Iodinated Contrast
MRI
Magnetic Resonance Imaging

Prostate Cancer on MRI and Pathology
MRI physics

MRI Physics 101

Protons in space: no field

Protons in magnetic field
MR physics

MR Physics

Radio receiver
Summary

(a) Voxels

(b) 90 Degree RF Pulse

(c) Signal
Creating a MR Image

Creating an MR Image: No detectors! Just antennas (coils)
Anatomy of an MRI

Vents outside

- Coldhead
- Refrigerator Compressor
- Liquid Helium
- Vacuum, Thermal Insulation
- Gradient Coils
- RF Body Coil
- Superconducting Wire
MRI Advantages

• No radiation
• Multiplanar
• Multiple contrast types:
  – T1 weighting, T2 weighting
  – Diffusion weighting
  – Contrast enhanced MRI
  – Spectroscopy
MRI Disadvantages

• Slower than CT
• More expensive
• Does not depict calcifications
• Safety issues
  – Metallic objects become projectiles
  – Incompatible with metallic implanted devices
    • Pacemakers
    • Cochlear implants
Safety issues in MRI

- Quench Pipe
- Injector
- Ear protection
MRI Safety

MRI SAFETY

- MRI scanners are extremely powerful
- Objects that are attracted by the MRI magnetic field can reach 60 miles per hour.
- A sharp or heavy object can be deadly to anyone standing in its path.
- Metal objects used everyday (scissors, oxygen tanks, infusion pumps, etc) become projectiles
- This can cause potential injury to patients or hospital staff.
- MRI departments are divided into Zones for Safety
MRI Safety

MRI SAFETY
Oxygen tank

**O2 Tank, “Missile”**

An Oxygen tank can become an Airborne torpedo in an MRI
Value of Contrast Media
Gd reagents
## GD Reagents

<table>
<thead>
<tr>
<th>Extracellular Gd-CM</th>
<th>Type</th>
<th>Thermodynamic stability constant</th>
<th>Conditional Stability</th>
<th>Amount of excess chelate (mg ml⁻¹)</th>
<th>Kinetic stability (dissociation half-life at pH 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gadoversetamide, Gd-DTPA-BMFA (OptiMark, Tyco, St. Louis, MO)</td>
<td>Non-ionic linear</td>
<td>16.6</td>
<td>15</td>
<td>28.4</td>
<td>Not available</td>
</tr>
<tr>
<td>Gadodiamide, Gd-DTPA-BMA (Omniscan, GE, Waukesha, WI)</td>
<td>Non-ionic linear</td>
<td>16.9</td>
<td>14.9</td>
<td>12</td>
<td>35 s</td>
</tr>
<tr>
<td>Gadobutrol, Gd-BT-DO3A (Gadovist, Schering, Berlin, Germany)</td>
<td>Non-ionic cyclic</td>
<td>21.8</td>
<td>Not available</td>
<td>Not available</td>
<td>5 min</td>
</tr>
<tr>
<td>Gadoteridol, Gd-HP-DO3A (Prohance, Bracco, Italy)</td>
<td>Non-ionic cyclic</td>
<td>23.8</td>
<td>17.1</td>
<td>0.23</td>
<td>3 h</td>
</tr>
<tr>
<td>Gadopentetate Gd-DTPA (Magnevist, Schering, Berlin, Germany)</td>
<td>Ionic linear</td>
<td>22.1</td>
<td>18.1</td>
<td>0.4</td>
<td>10 min</td>
</tr>
<tr>
<td>Gadobenate, Gd-BOPTA, (Multihance, Bracco, Italy)</td>
<td>Ionic linear</td>
<td>22.6</td>
<td>18.4</td>
<td>None</td>
<td>Not available</td>
</tr>
<tr>
<td>Gadoterate, Gd-DOTA (Dotarem, Guerbet, France)</td>
<td>Ionic cyclic</td>
<td>25.8</td>
<td>18.8</td>
<td>None</td>
<td>&gt;1 month</td>
</tr>
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Nephrogenic systemic sclerosis

Examples: nephrogenic systemic sclerosis
Mechanism

• Gadolinium is highly toxic
• Patients with normal renal function excrete Gd-chelates within 24-48h
• Patients with abnormal renal function may take weeks to excrete the agent
• Dissociation of Gd from the chelate could deposit in soft tissues (documented)
  – Hugh et al. Tissue Gd conc .14-24 ng/mL
• Fibrosis is an inflammatory response to toxic Gd ion.
Residual Gadolinium

Residual Gadolinium!
Ultrasound
Ultrasound basics

US basics

Imaging dependent on the speed of sound in tissue
Fate of sound waves in body
Ultrasound probes

US Probes
Liver metastases
Ultrasound devices

Evolution of US devices
Ultrasound guided biopsy

US guided biopsy-real time
US advantages

• No radiation
• Real time
• Inexpensive
• Quick, little prep
• No injection
US disadvantages

• Operator dependent
• What you see is all there is
• Difficult to quantify
• Limited access (lungs, brain, bone etc.)
Ultrasound

US Microbubble contrast

Contrast agent characteristics

- Size
  - microbubble (mean diameter 1–4 mm)
  - nanoparticle (mean diameter <1 mm)
- Gas composition
  - Air or nitrogen
  - Sulfur hexafluoride
  - Perfluorocarbons (C,F₆,F₉,F₁₆)
- Shell composition
  - lipid or other lipid-like surfactant
  - protein (albumin)
  - biocompatible polymers

Current Opinion in Biotechnology
SPECT

Single Photon Emission Computed Tomography-SPECT

- Single Photon Emission

- Computed Tomography
SPECT imaging

SPECT Imaging

- Requires conjugation of a radioactive isotope to a compound of interest which is injected into the patient:

The bone scan:

\(^{99m}\text{Technetium-methyl diphosphonate}\)
SPECT detectors

Source  Collimator  Scintillation crystal  Detector
Collimation

Collimation cont’d

Collimation reduces the sensitivity and resolution of SPECT by rejecting the majority of events.
SPECT agents for cancer

- $^{99m}$Tc MDP  Bone Scan
- $^{99m}$Tc Pertechnetate  (thyroid, salivary gland)
- $^{201}$Thallium Chloride (parathyroid)
- $^{111}$Indium oxine  (WBC labelling)
- $^{131}$Iodine  (thyroid)
SPECT advantages/disadvantages

SPECT Advantages/Disadvantages

- Relatively inexpensive
- Broad experience

- Disadvantages
  - Radiation exposure
  - Preparation of imaging agent
  - Nuclear Regulatory
  - Scanning is slow, low resolution
Hybrid Imaging
Positron Emission Tomography

- **Positron emission**

Positron (e+) → Electron (e-) → 511 keV photon

180 degrees apart

511 keV photon
PET

Positron Emission Tomography
Positron travel

$^{18}_F$
Positron travel
Positron travel

18\textsuperscript{F}
Positron travel

$^{18}\text{F}$

$e^+$

$e^-$
Positron and Electron
Annihilation

$^{18}\text{F}$
Gamma rays

\[ ^{18}\text{F} \]
Gamma ray orientation

Very high sensitivity (pM-nM)
Quantitative
± Spatial resolution 3-4mm

\(^{18}\text{F} \rightarrow \gamma\)

\(\gamma\)
F-18 Deoxyglucose
18FDG PET Imaging

18FDG PET Imaging

E PET MIP

FDG-6-PO₄

HK

GLUT transporter

Intravascular FDG

Intracellular FDG

Intracellular FDG-6-PO₄

Hexokinase
PET-CT scanners
Metastatic Breast Cancer

Mediastinal and spine metastases (breast)
PET: Advantages and Disadvantages

- Highly sensitive
- Metabolic information
- Better spatial resolution than SPECT
- Combined with CT
- Expense
- Regulatory
- Short half life
Notable PET Agents

• Sodium Fluoride: Bone target
• Fluorothymidine: Cellular Proliferation
• Fluoroestadiol: Estrogen receptor
• Fluorocholine: Membrane Turnover
• Fluoromiso: Hypoxia
• Florbetaben: Amyloid (Alzheimers)
• Zirconium Herceptin: labeled antibody
• Zirconium Oxine: Cell labeling
PET Imaging

• Positron emission tomography (PET) has the advantages of:
  – High energy photon imaging
  – High Sensitivity, Moderate Specificity
  – The ability to correct for attenuation
  – No need for collimation
  – Resolution is still limited
## Summary of Cancer Imaging

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<th>Sensitivity</th>
<th>Cost (low-hi)</th>
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<td>US (microbubble)</td>
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General Guidelines

- Overall “workhorse” for oncology: CT
- Specialty cancers: brain, liver, prostate: MRI
- Problem solving (e.g. cyst vs. solid): US
- Bone mets: SPECT
- Metabolic activity: PET
Imaging of cancer

Imaging of Cancer: