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
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
X-ray production

X-ray production: cathode ray tube

C=Cathode
A=Anode
X=Xray
Basics of CT
CT projection

Filtered Back Projection

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 a specific angle. In the frequency domain, the spectrum of each view is a one-dimensional “slice” of the two-dimensional image spectrum.
Cross section of a CT Scanner
“Spiral” CT
“Volume” CT imaging
Attenuation differences thru the body
Radiation

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

Bar chart showing mass general doses compared to national benchmarks for different body parts.
Contrast Media

Iodinated Contrast Media
Iodinated Contrast
Non ionic iodinated contrast

Non ionic Iodinated Contrast
CT

Windowing a CT

“Windowing” a CT
MRI

Magnetic Resonance Imaging

Prostate Cancer on MRI and Pathology
MRI Advantages

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

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

MRI Physics 101

Protons in space: no field

Protons in magnetic field
MR physics

MR Physics

Radio receiver
Summary

(a) Schematic representation of a voxel with net magnification vector.
(b) Illustration of a 90-degree RF pulse and net magnetization vector.
(c) Diagram showing pulse sequence with TI, TR, RF, Gz, and signal over time.
Creating a MR Image

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

Vents outside
Safety issues in MRI

- Quench Pipe
- Injector
- Ear protection
The Importance of MR Safety

“Maybe it is time for us to review the magnet safety instructions.”
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>
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<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>
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<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>
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<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>
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<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>
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<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>
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<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>
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Nephrogenic systemic sclerosis

Examples: nephrogenic systemic sclerosis
Nephrogenic Systemic Fibrosis (NSF)

• May 2006 Danish Medicine Agency reported 25 cases of NSF in patients in renal failure who received gadodiamide (~2m)
• Nov 2006 Loma Linda reported 12 (8 on dialysis) NSF patients receiving 0.2mmol/Kg gadodiamide within 2-8 weeks of injection
• Since then over 200 cases have been reported with all of the available contrast agents but mostly Omniscan and Optimark
• By 2013 almost no cases are reported
Case of NSF
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.
Risk Factors

• Renal failure:
  – Dialysis
  – Chronic renal failure (GFR <30cc/min)
• Dose
  – Double, triple (vs. half dose)
• Contrast agent
  – Omniscan>Optimark>Magnevist>Prohance>
• Alternative imaging?
  – Non con MRI
  – CT, US, PET
Imaging of cancer

Imaging of Cancer:
Ultrasound
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.)
Imaging dependent on the speed of sound in tissue
Fate of sound waves in body

- Attenuation
- Absorption
- Reflection
- Scattering
- Refraction
- Diffraction
Liver metastases
Ultrasound probes

US Probes
Ultrasound devices

Evolution of US devices
Ultrasound guided biopsy

US guided biopsy-real time
Ultrasound

US Microbubble contrast
SPECT

Single Photon Emission Computed Tomography-SPECT

- Single Photon Emission

- Computed Tomography
SPECT Advantages/Disadvantages

• Relatively inexpensive
• Broad experience

• Disadvantages
  – Radiation exposure
  – Preparation of imaging agent
  – Nuclear Regulatory
  – Scanning is slow, low resolution
SPECT detectors

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 imaging

SPECT Imaging

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

The bone scan:

$^{99m}$Technetium-methyl diphosphonate

Radioactive decay of Technetium 99m (half life = 6 hours)
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)
Hybrid Imaging
Safety

- Operator
- Patient
Positron Emission Tomography
PET: Advantages and Disadvantages

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

Positron Emission Tomography
Positron travel
Positron travel
Positron travel
Positron travel

$^{18}F \rightarrow e^+ + e^-$
Positron and Electron
Annihilation

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

18\textsuperscript{F}
Gamma ray orientation

Very high sensitivity (pM-nM)
Quantitative
± Spatial resolution 3-4mm
F-18 Deoxyglucose

Otto Warburg

Lou Sokoloff
PET imaging

$^{18}$FDG PET Imaging
PET-CT device

Facilitate Advanced Imaging Technology

- Positron Emission Tomography
  - PET-CT Device
Metastatic Breast Cancer

Mediastinal and spine metastases (breast)
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
Image Correction

Non-attenuation corrected

Attenuation corrected
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

Summary of Cancer Imaging

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<th>Cost (low-hi)</th>
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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: