Introduction to Medical Imaging

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Neuroimaging, A clinical specialty concerned with producing images of the brain by noninvasive techniques such as computed tomography, magnetic resonance imaging, and positron-emission tomography (www.med.nyu.edu/cbh/glossary/).

Imaging Informatics, also known as Radiology Informatics or Medical Imaging Informatics, is a subspecialty of Biomedical Informatics that aims to improve the efficiency, accuracy, usability and reliability of medical imaging services within the healthcare enterprise*

In Vivo Neuroimaging Methods

- Projection Radiography (x-ray)
- Computed Tomography (CT, ultra-sound)
- Electroencephalography (EEG: EP, ERP etc.)
- Magnetoencephalography (MEG)
- Magnetic Resonance Imaging (MRI)
  - sMRI (neuroanatomy)
  - DTI (white matter structure, structural connectivity)
  - MR Spectroscopy (MRS; neurochemistry)
  - fMRI (brain physiology, functional connectivity)
- Positron Emission Tomography (PET)
  - Glucose/Oxygen metabolism & blood flow
  - Receptor density (radioactive ligands)
Projection Radiography

- Also known as computed radiography (CR) or digital radiography
- Uses X-ray ionizing radiation and a film detector
- Image values represent absorption patterns of x-rays due to tissue attenuation

Advantages:
- Fast and relatively inexpensive
- Widely available
- Good spatial resolution

Disadvantages:
- Poor differentiation of low contrast objects
- Superposition of structures
- Uses ionizing radiation
Pneumoencephalography (PEG)

- Drain cerebral spinal fluid (lumbar puncture)
- Replace with air, oxygen, or helium
- X-ray
Computed Tomography

- Computed Tomography (CT) or Computed Axial Tomography (CAT)
- X-ray tubes and detectors rotated around object
- Image values represent absorption patterns of x-rays due to tissue attenuation

Advantages:
- Good contrast resolution
- Good for tumor staging

Disadvantages:
- High equipment cost
- High doses of ionizing radiation
- High-attenuation area artifacts
CT Scanner
Sinus CT
EEG and MEG

- MEG – Magnetoencephalography
  - Measures magnetic field generated by neural cells

- EEG – Electroencephalography
  - Measures electrical potentials generated by neural cells across electrodes
Combined EEG + MEG

http://ese.wustl.edu
What is MRI?

- Magnetic Resonance Imaging (MRI)
- Also called Nuclear Magnetic Resonance (NMR)
- Certain nuclei when placed in magnetic field, absorb energy from an electromagnetic field oscillating at a particular frequency.
- After being excited the nuclei can transfer energy back to a detector coil at the same frequency.

**Advantages:**
- Non-ionizing radiation
- Excellent soft tissue contrast
- No bone artifact

**Disadvantages:**
- High equipment cost
- Difficult for patients to tolerate
- Poor images of lung fields and inability to show calcification
Certain atomic nuclei including $^1\text{H}$ exhibit nuclear magnetic resonance.

Nuclear “spins” are like magnetic dipoles.
Polarization

- Spins are normally oriented randomly.
- In an applied magnetic field, the spins align with the applied field in their equilibrium state.
- Excess along $B_0$ results in net magnetization.
Static Magnetic Field

From: Brian Hargreaves, Stanford University
Precession

- Spins precess about applied magnetic field, $B_0$, that is along $z$ axis.
- The frequency of this precession is proportional to the applied field:

$$\omega = \gamma B$$

From: Brian Hargreaves, Stanford University
Relaxation

- Magnetization returns exponentially to equilibrium:
  - Longitudinal *recovery* time constant is $T_1$
  - Transverse *decay* time constant is $T_2$
- Relaxation and precession are independent.

From: Brian Hargreaves, Stanford University
Precessing spins cause a change in flux ($\Phi$) in a transverse receive coil.

Flux change induces a voltage across the coil.
MR Image Formation

- Gradient coils provide a linear variation in $B_z$ with position.
- Result is a resonant frequency variation with position.
Selective Excitation

\[ \text{Slope} = \frac{1}{\gamma G} \]

From: Brian Hargreaves, Stanford University
- Gradient causes resonant frequency to vary with position.
- Receive sum of signals from each spin.

From: Brian Hargreaves, Stanford University
- Received signal is a sum of “tones.”
- The “tones” of the signal are the image.
- This also applies to 2D and 3D images.
What can Structural MRI show us?
What can DTI MRI show us?

**Fractional Anisotropy**
- (FA) (the more narrow the ellipse, the brighter the signal)
- might mean tract is more myelinated, more organized, or both
- CSF = isotropic
- gray matter = isotropic (smaller radius)
- white matter = anisotropic

Less Organized

More Organized
DTI: Tractography
DTI Tractography Results
Head Injury – DTI Tractography

www.brainimage.net
MR Spectroscopy


Chemical Shift (ppm)
What is FMRI?

- Functional Magnetic Resonance Imaging (MRI)
- Decay time of MR signal is slightly lengthened in response to brain activity
- Changes in local blood oxygenation that accompany neural activation
- BOLD – blood oxygenation level dependent effect is measured in fMRI.

Advantages:
- High temporal resolution
- Non-ionizing radiation

Disadvantages:
- No quantification of BOLD signal
- Low spatial resolution
Function MRI

- Statistical Map superimposed on anatomical MRI image
- fMRI Signal (% change) over Time
- ROI Time Course
- Condition
- Time
- Region of interest (ROI)
- ~ 2s
- ~ 5 min

Condition 1
Condition 2
Quantitative Determination of the location of positron emitting isotopes (hence *Positron Emission*).
- static isotope location (at a particular time)
- time course of isotope distribution (time series)

Primary use is in functional imaging (hence *Tomography*) because of what is labeled with these isotopes.
### Positron-Emitting Isotopes-PET

<table>
<thead>
<tr>
<th></th>
<th>O-15</th>
<th>N-13</th>
<th>C-11</th>
<th>F-18</th>
<th>Rb-82</th>
<th>Ga-68</th>
<th>Cu-62</th>
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<tbody>
<tr>
<td>Half-life</td>
<td>2 min</td>
<td>11 min</td>
<td>20 min</td>
<td>110 min</td>
<td>75 s</td>
<td>68 min</td>
<td>9.7 min</td>
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<tr>
<td>Availability</td>
<td>On-site cyclotron</td>
<td>On-site cyclotron</td>
<td>On-site cyclotron</td>
<td>Cyclotron, regional distribution</td>
<td>Generator Sr-82/Rb-82</td>
<td>Generator Ge-68/Ga-68</td>
<td>Generator Zn-62/Cu-62</td>
</tr>
</tbody>
</table>

- **Oxygen-15** – blood flow
- **Nitrogen-13** – myocardial perfusion (Ammonia)
- **Carbon-11** – beta-amyloid plaques (PiB)
- **Flourine-18** – glucose use (FDG)
- **Rubidium-82** – myocardial perfusion/stress
- **Gallium-68** – neuroendocrine tumors/somatostatin receptors
- **Copper-62** – perfusion tracer for blood flow to heart, brain, and kidney.
Physics of PET; PET Overview

- positron emitting isotope production (cyclotron)
- tracer labeling (radiochemistry)
- tracer injection
- data acquisition
- image acquisition/reconstruction
- statistically significant differences
Scandatronix MC-17 Cyclotron
PET Scanner
Detector System

16 Cassettes

2 Ring Packages

13 14 15 16 1
2

1
2

1 2 3 4
5 6 7 8
9 10 11 12

301x189 2 Ring Packages
308x375 16 Cassettes
Detector Cassette

4 Detector Modules per Each Cassette

4 Rings per Each Package
Detector Module

One Detector Module
Detector Module

16 Crystal Detectors

R1
R2
R3
R4

C1  C2  C3  C4

2 Dual Photo-Multiplier Tubes (PMT)
Basic PET Physics – Positron Anihilation

- Positron Emission
- Photon
- Detector
- 511 keV
- Positron Range
- 180°
- Photon
- Detector
Basic PET Physics - Coincidence

\[ e^+ + e^- \rightarrow \text{MAX} = 9\text{ns} \]
Image Acquisition
FDG (glucose) PET for AD

Alzheimer's Disease

- Decreased Temporoparietal
- Occipital Lobe

Normal Control

- Frontal Lobe

Cerebellum

0.00

19.36

mg/100g/min
Fallypride PET - D2/D3 Receptors
PIB Beta-Amyloid PET

Alzheimer’s Disease

Elderly Control
PIB Beta-Amyloid PET
Gene Chip

Computer analysis

Neuroarray

Analyze Image

Neuroimaging + Genetics

Probabilities of medication response and development of side-effects

<table>
<thead>
<tr>
<th>Efficacy</th>
<th>Negative</th>
<th>Cognitive</th>
<th>DM</th>
<th>Weight</th>
<th>Suicide</th>
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<tr>
<td>Clozapine</td>
<td>90</td>
<td>80</td>
<td>25</td>
<td>50</td>
<td>85</td>
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<tr>
<td>Olanzapine</td>
<td>80</td>
<td>70</td>
<td>20</td>
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<td>90</td>
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<tr>
<td>Ziprasidone</td>
<td>85</td>
<td>75</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Blood sample in physician’s office

Gene Chip

Neuroimaging

Analyze Image

WWW: Analyze Image
• Two new genes detected.
• Peaks point to the location of the gene that affects the brain areas with abnormal function in schizophrenia.

From: D. Keator, F. Macciardi, J. Fallon, J. Turner
Image Fusion

PET

MRI/fMRI

DTI
Functional Imaging Federation Workflow
Human Imaging Database (HID)
- Distributed/federated database model
- Extensible data model, fixed schema
- Advanced support for clinical assessment data entry/ form building

Extensible Neuroimaging Archive Toolkit (XNAT)
- Workflow model is most closely related to a central site data warehouse
- Provides a number of built in data types and catalogs to help laboratories model their own data in XML
- Once a data model is created in XML, XNAT uses the data model to build database schema tables, setup relationships, triggers, and all the behind the scenes functionality contained in data management systems

Picture Archiving and Communication Systems (PACS)
- Storage, retrieval, distribution and presentation of images in DICOM format
- Handles limited image metadata
- Usually proprietary

(for overview: Keator. (2009) Management of Information in Distributed Biomedical Collaboratories. )
Neuroimaging Metadata Interchange Formats

- **XML-Based Clinical and Experimental Data Exchange (XCEDE)**
  - Gadde et al. 2012, Keator et al. 2006
  - XML schema provides an extensive metadata hierarchy for describing and documenting research and clinical human imaging studies.

- **Annotation and Image Markup Project (AIM)**
  - focused on semantic integration and annotation of medical imaging information
  - includes: (1) An ontology for describing the contents of medical images and an information model for semantic annotations; (2) An image annotation tool for collecting user annotations as instances of the ontology; (3) Methods for transforming the annotations into common medical and Web accessible formats

- **Digital Imaging Communications in Medicine (DICOM)**
  - DICOM provides services and information objects for transmission and persistence of objects such as images and documents, query and retrieval support, workflow management, and quality and consistency of image appearance.

(For overview: Keator. (2009) Management of Information in Distributed Biomedical Collaboratories.)
Thank You!