TRENDS IN MEDICAL IMAGING

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Medical Equipment I
Part II (2009)
Objective

- Provide an overview of medical imaging to promote student interest and knowledge of its basic ideas and clinical applications
Contents

- Basic Ideas of Medical Imaging
- Brief history
- How it works: Examples for ultrasound, x-ray and MRI
- Applications
  - Imaging of anatomy
  - Imaging of flow
  - Imaging of function
  - Imaging of chemical composition
  - Image-guided interventions
- Challenges for biomedical imaging
Basic Ideas of Imaging

- To use a means to measure and map a useful property of the human tissues
- Non-invasive or minimally-invasive
- Examples:
  - Reflection – photography, ultrasound
  - Transmission – x-rays
  - Radiation – MRI, PET/SPECT
Imaging Methods

- A variety of energy sources can be used to measure one or many tissue properties

<table>
<thead>
<tr>
<th>Energy Sources</th>
<th>Tissue Properties</th>
<th>Image Properties</th>
</tr>
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<tbody>
<tr>
<td>X rays</td>
<td>Mass density</td>
<td>Transmissivity</td>
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<tr>
<td>(\gamma) rays</td>
<td>Electron density</td>
<td>Opacity</td>
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<tr>
<td>Visible light</td>
<td>Proton density</td>
<td>Emissivity</td>
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<td>Ultraviolet light</td>
<td>Atomic number</td>
<td>Reflectivity</td>
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<td>Annihilation Radiation</td>
<td>Velocity</td>
<td>Conductivity</td>
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<tr>
<td>Electric fields</td>
<td>Pharmaceutical</td>
<td>Magnetizability</td>
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<tr>
<td>Magnetic fields</td>
<td>Location</td>
<td>Resonance</td>
</tr>
<tr>
<td>Infrared</td>
<td>Current flow</td>
<td>Absorption</td>
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<td>Ultrasound</td>
<td>Relaxation</td>
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<td>Applied voltage</td>
<td>Blood volume/flow</td>
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<td></td>
<td>Oxygenation level of blood</td>
<td></td>
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<tr>
<td></td>
<td>Temperature</td>
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<td></td>
<td>Chemical state</td>
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History of Medical Imaging

- In the 1800s and before, physicians were extremely limited in their ability to obtain information about the illnesses and injuries of patients.
  - They relied essentially on the five human senses.

Let’s have a look around.
History of Biomedical Imaging

- 1895: physicist Wilhelm Röntgen, discovered x-rays
- A few months later, the use of x-rays in medical application started in several places

Poster for a public demonstration of x rays, 1896, Crystal Place Exhibition, London and an advertisement for x-ray studio

First x-ray “movie” showing 5 views of a frog’s leg
History of Biomedical Imaging

- 1972: CT was invented by Godfrey Hounsfield of EMI Laboratories
- 1989: Spiral CT was introduced
History of Biomedical Imaging

- WW-I: Sonar
- 1942: ultrasound in medicine
- 1963: Real-time ultrasound
History of Biomedical Imaging

- 1946: Felix Bloch and Edward M. Purcell independently described the NMR phenomenon.
- 1973: Magnetic resonance imaging was first demonstrated on small test tube samples by Paul Lauterbur.
Plain X-Ray Imaging

X-Ray Tube

Patient

Film
X-Ray Imaging
Applications and Limitations
Computerized Tomography (CT)

- Collect enough information to estimate and map x-ray attenuation
CT: Back-Projection Method

- Start from a projection value and back-project a ray of equal pixel values that would sum to the same value.
- Back-projected ray is added to the estimated image and the process is repeated for all projection points at all angles.
- With sufficient projection angles, structures can be somewhat restored.
Ultrasound Imaging

- Acoustic energy is sent through the body
- Reflected energy is detected and used to construct an image
Ultrasound Imaging

Probe

Patient

Image on Monitor
Ultrasound Imaging
Applications and Limitations
Magnetic Resonance Imaging (MRI)
Applications of Medical Imaging

- Imaging of Anatomy
  - How internal organs look like

- Imaging of Flow
  - How blood vessels are doing

- Imaging of Function
  - How physiology is doing

- Imaging of Chemical Composition
  - Biochemical analysis of a location noninvasively

- Image Guided Interventions
  - Operation prepared or done using imaging
Imaging of Anatomy
Imaging of Blood Flow: MRA

- Time-of-flight or phase contrast
- Velocity encoding for quantitative results
- Can be done with or without contrast agents
- MIP visualization
Imaging of Blood Flow: X-ray

- Contrast agent must be injected
- Digital subtraction angiography
Imaging of Blood Flow: Ultrasound

- Doppler effect
- Spectrogram display
- Color flow mapping
  - Spatial resolution vs. velocity accuracy
Imaging of Function: Blood Oxygen Level Dependent (BOLD)

- Map changes with a physiological function
- Neuronal activation mapping
Imaging of Function: Perfusion

Perfusion: capillary blood supply to cells
• increases when cells are at work
• measured using MRI or ultrasound
Imaging of Function: PET

- Radioactive isotopes related to a particular function (biomarkers)
  - e.g., Iodine necessary for thyroid
- Radioactive decay with positron generation (measured and mapped)
Imaging of Function: Cardiac MRI

- SPAMM tagging
- Tag tracking
- Quantitative wall viability assessment
- Fast and accurate analysis is a challenge
Imaging of Chemical Composition: MR Spectroscopy

- Quantitative measurement of different metabolites in a specific area in the image
- Multiple nuclei
  - e.g., Hydrogen, Phosphorus, etc
Image-Guided Interventions

- Image-guided surgical planning
  - Minimally invasive brain surgeries
- Image-guided surgical procedures
  - Cathlab
  - Needle-Biopsy
Image-Guided Interventions: Hardware Limitations

- Special surgical tools
- Custom suite designs
- Custom imaging equipment
# Biomedical Imaging Trends

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
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<tbody>
<tr>
<td>- Anatomic</td>
<td>- Physiobiochemical</td>
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<tr>
<td>- Static</td>
<td>- Dynamic</td>
</tr>
<tr>
<td>- Qualitative</td>
<td>- Quantitative</td>
</tr>
<tr>
<td>- Analog</td>
<td>- Digital</td>
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<tr>
<td>- Nonspecific agents</td>
<td>- Tissue-Targeted agents</td>
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<tr>
<td>- Diagnosis</td>
<td>- Diagnosis/Therapy</td>
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Summary

- Medical imaging is both a science and a tool to explore human anatomy and to study physiology and biochemistry.
- Medical imaging employs a variety of energy sources and tissue properties to produce useful images.
- Increasingly, clinical pull is the driving force in the development of imaging methods.
- Pushing the limits of resolution and accuracy is the focus of current research in this area.
- Molecular biology and genetics are new frontiers for imaging technologies.