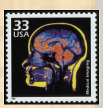
Medical Equipment II Info

- Meetings: Lecture + Sections (2+1)
- Total Grade: 75 points
  - Midterm and activity: 25 points
  - Term Exam: 50 points (2 hour exam)
- Textbook: Hobbie and Roth
- Contents: basics of ultrasound, x-rays and magnetic resonance imaging



OVERVIEW OF MEDICAL IMAGING

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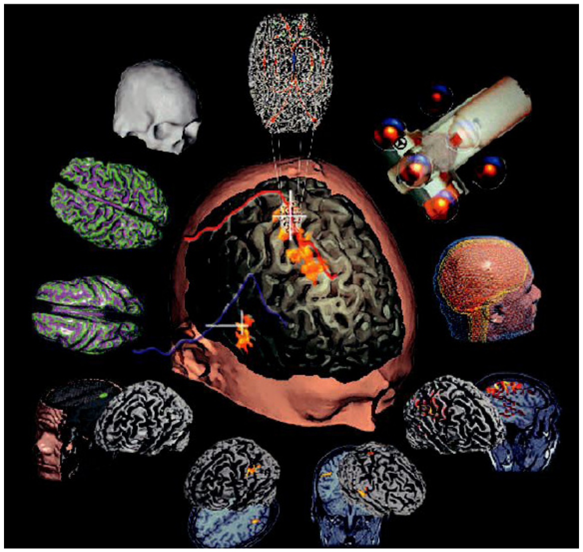
Associate Professor, Cairo University

Objective

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

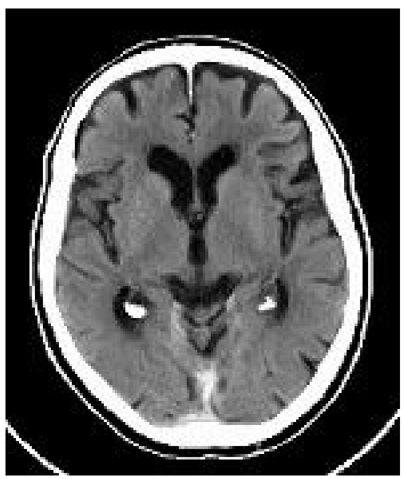


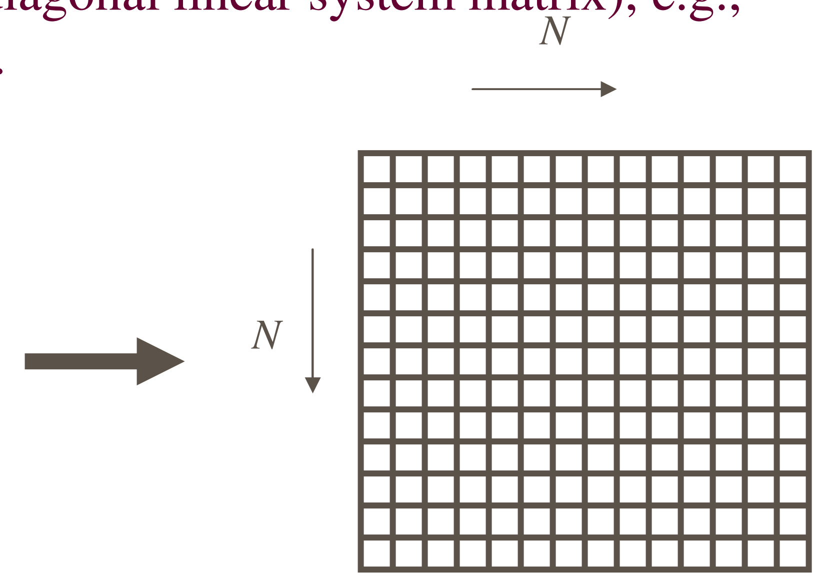
Contents

- 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
  - Image of connectivity
- Safety of Medical Imaging
- Challenges for biomedical imaging

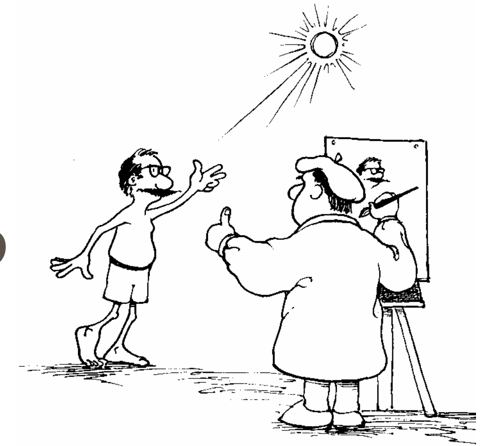
Mathematical Problem

- For an $N \times N$ image, we have N^2 unknowns to estimate
  - Sufficient equations must be available
  - In most cases the problem can be formulated as a linear system
  - Simplest case when the acquired data correspond directly to the image points (i.e., diagonal linear system matrix), e.g., ultrasound imaging.

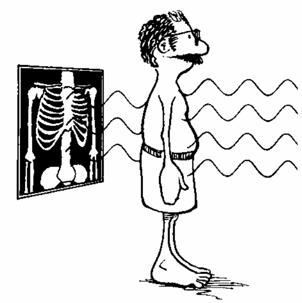


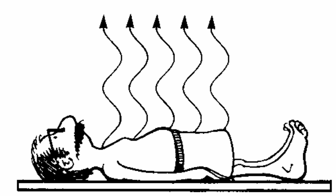


Basic Ideas of Imaging



- 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





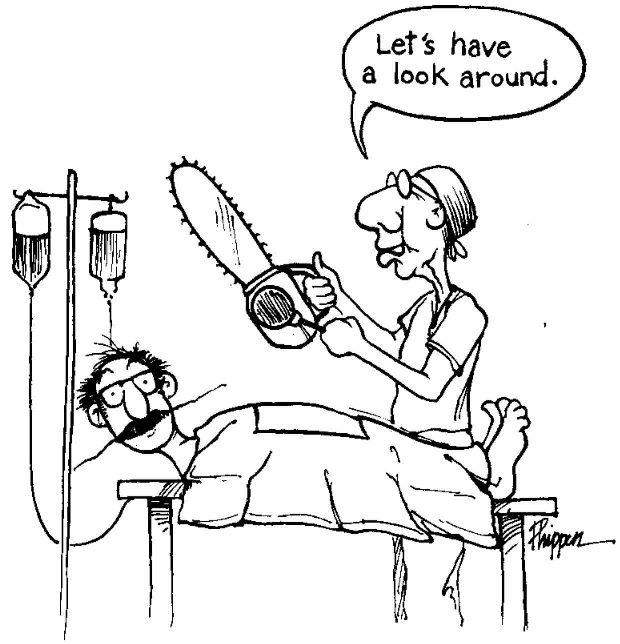
Imaging Methods

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

Energy Sources	*Tissue Properties*	*Image Properties*
X rays	Mass density	Transmissivity
γ rays	Electron density	Opacity
Visible light	Proton density	Emissivity
Ultraviolet light	Atomic number	Reflectivity
Annihilation Radiation	Velocity	Conductivity
Electric fields	Pharmaceutical Location	Magnetizability
Magnetic fields	Current flow	Resonance
Infrared	Relaxation	Absorption
Ultrasound	Blood volume/flow	
Applied voltage	Oxygenation level of blood	
	Temperature	
	Chemical state	

History of Medical Imaging

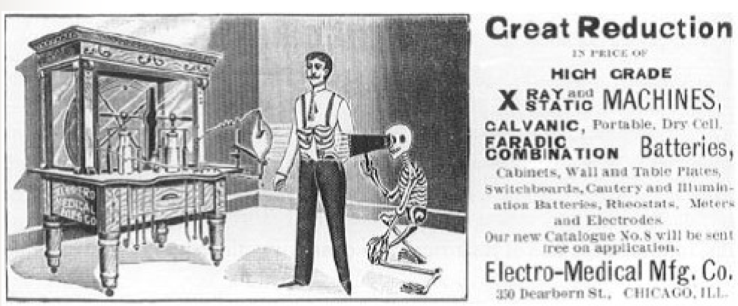
- In the 1800s and before, physicians were extremely limited in their ability to obtain information about the illnesses and injuries of patients.
  - They relied essentially on the five human senses

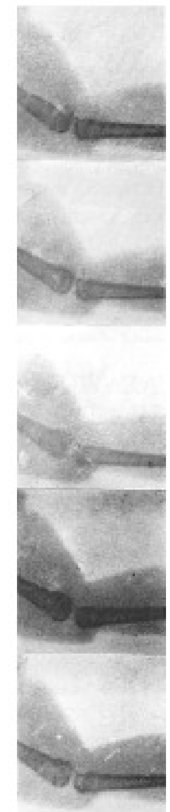


History of Biomedical Imaging

- 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

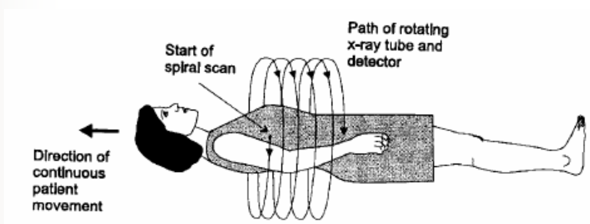


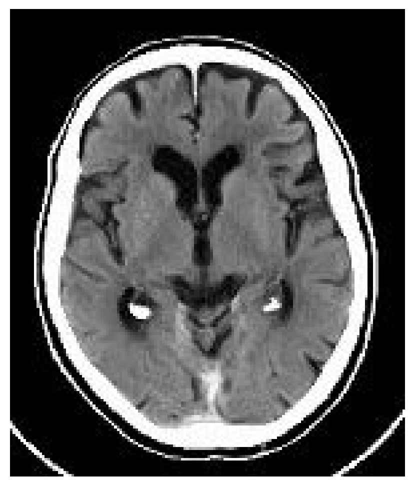


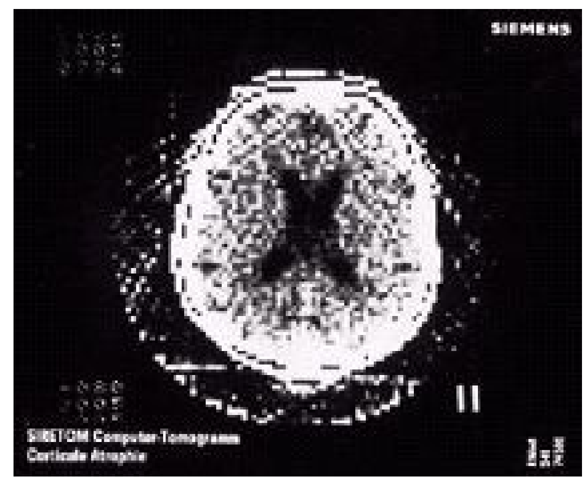
First x-ray "movie" showing 5 views of a frog's leg

History of Biomedical Imaging

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

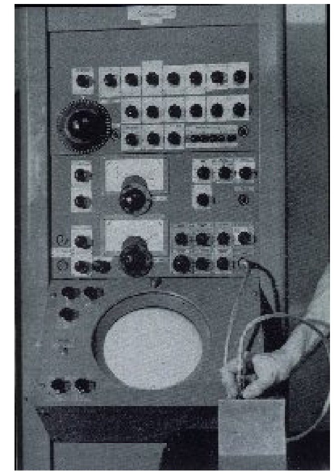


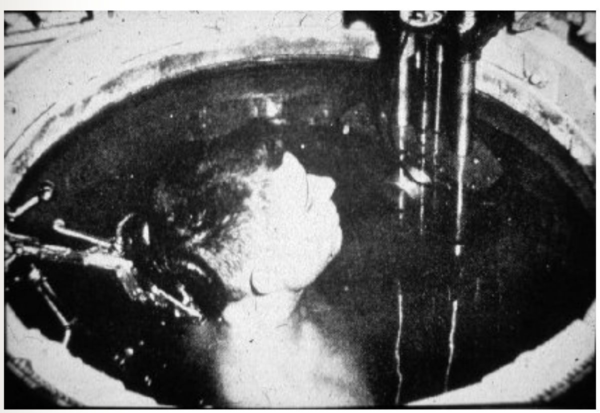


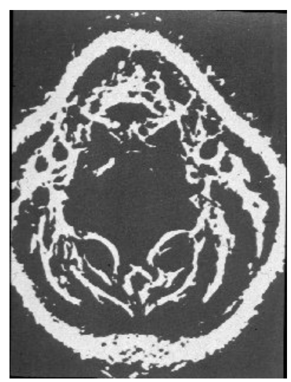


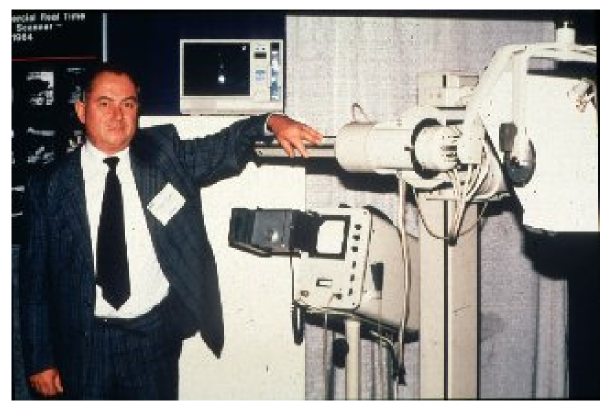
History of Biomedical Imaging

- WW-I: Sonar
- 1942: ultrasound in medicine
- 1963: Real-time ultrasound



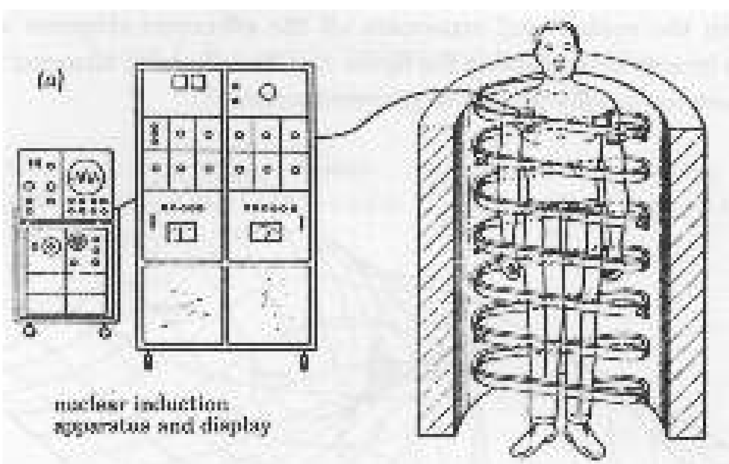






History of Biomedical Imaging

- 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.



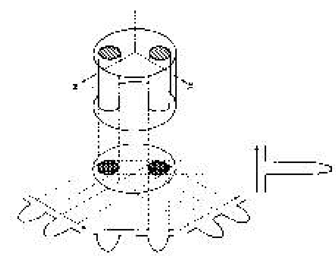
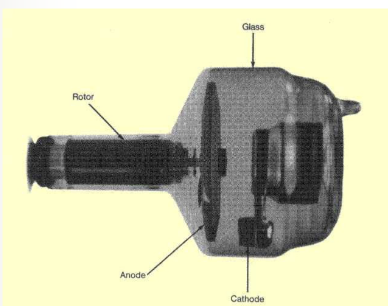


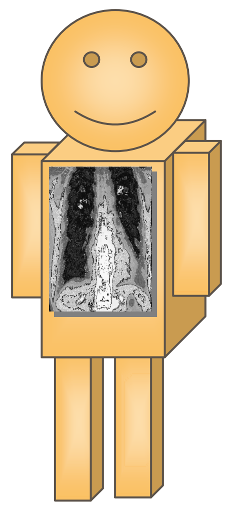
Fig. 1 Relationship between a three-dimensional object, its two-dimensional projection along the Y-axis, and four one-dimensional projections at 45° intervals in the XZ-plane. The arrows indicate the gradient directions.

Fig. 2 Proton nuclear magnetic resonance zeugmatogram of the object described in the text, using four relative orientations of object and gradients as diagrammed in Fig. 1.

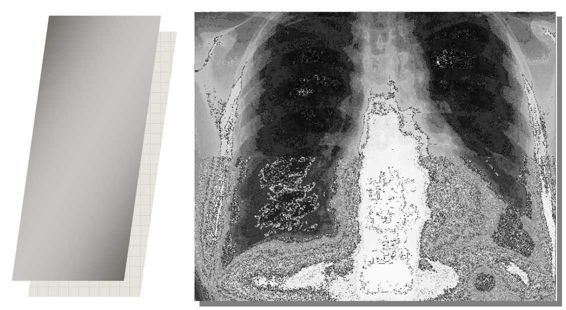
Plain X-Ray Imaging



X-Ray Tube

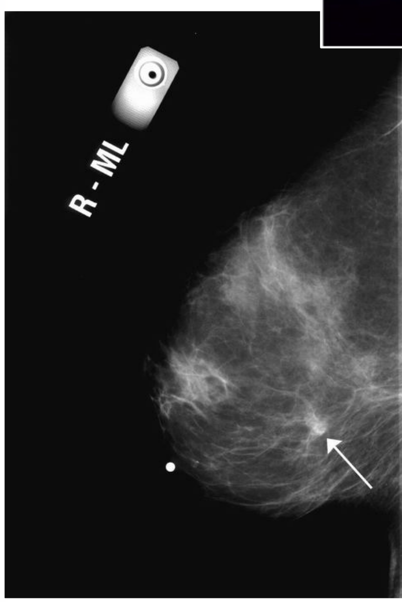


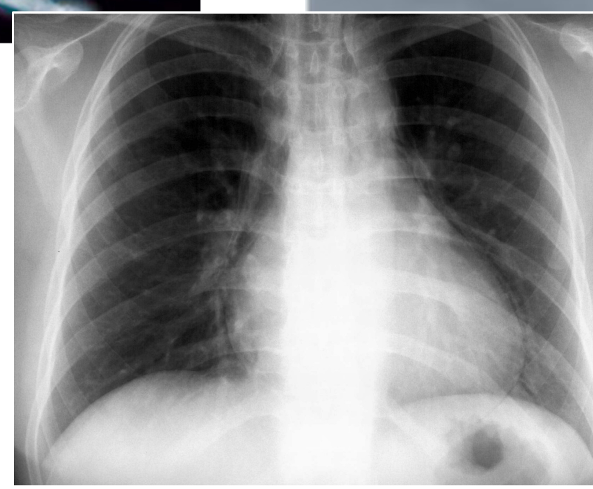
Patient



Film

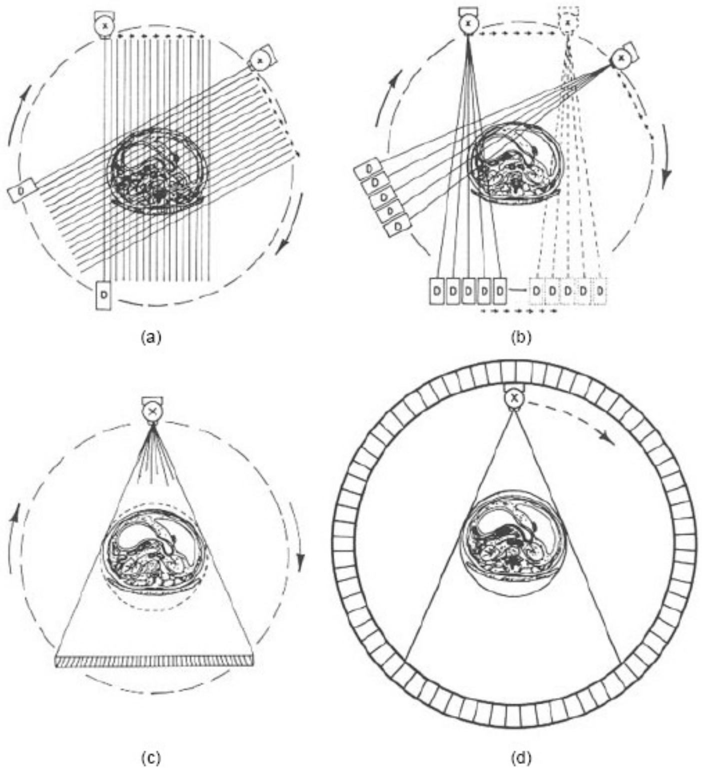
X-Ray Imaging
Applications and Limitations





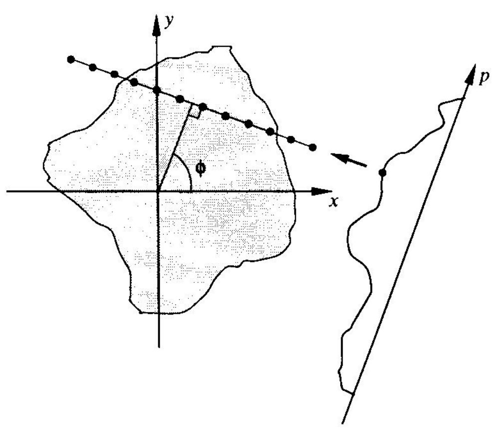
Computerized Tomography (CT)

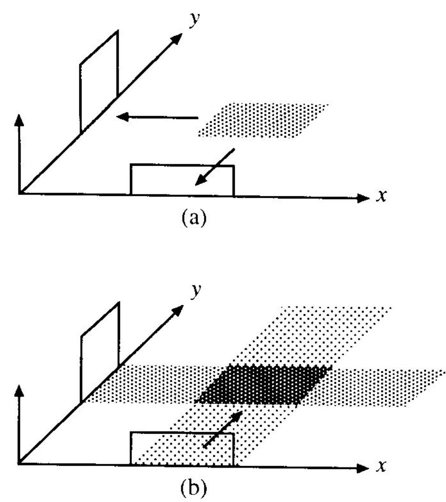
- Collect enough information to estimate and map x-ray attenuation



CT: Back-Projection Method

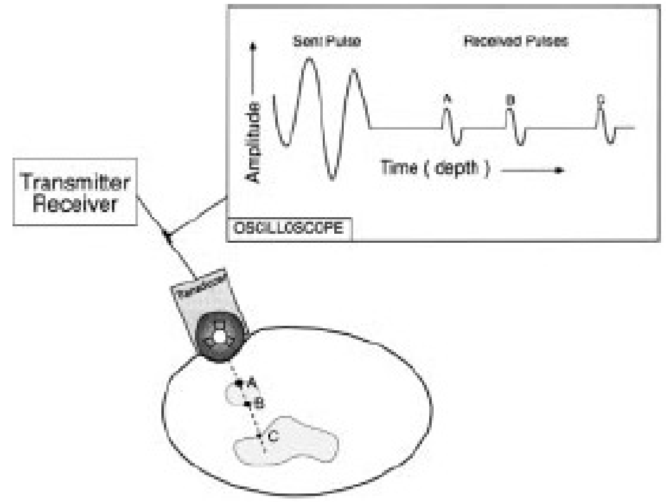
- Start from a projection value and back-project a ray of equal pixel values that would sum to the same value
- Back-projected ray is added to the estimated image and the process is repeated for all projection points at all angles
- With sufficient projection angles, structures can be somewhat restored

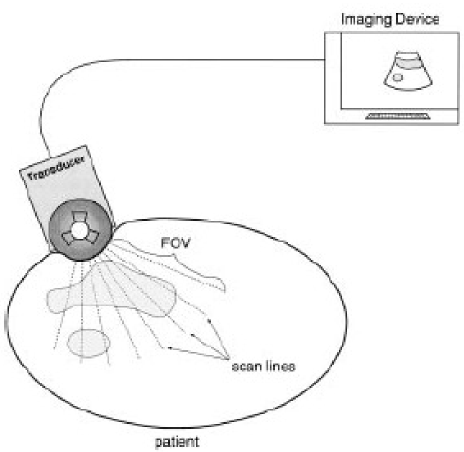


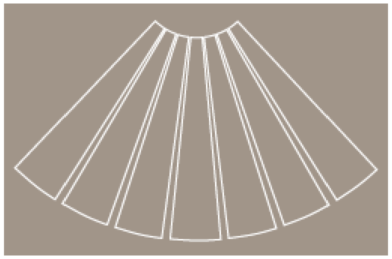


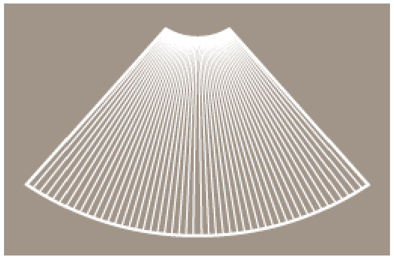
Ultrasound Imaging

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



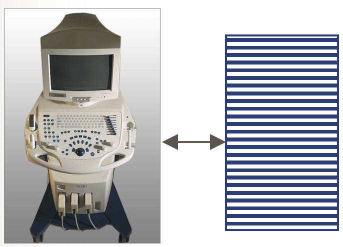


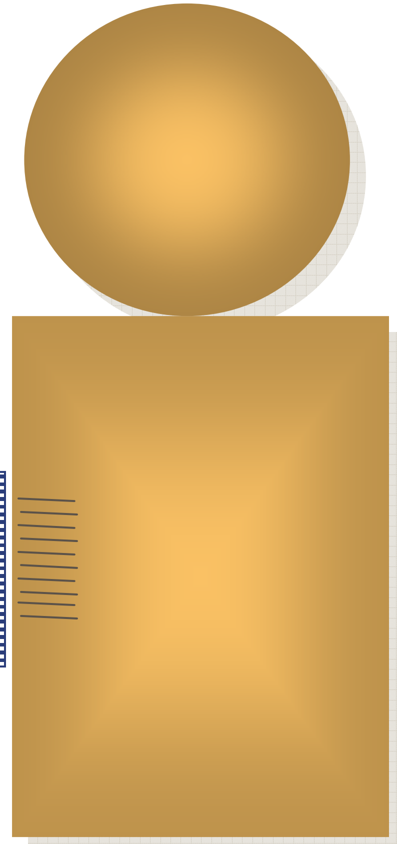




Ultrasound Imaging

Probe

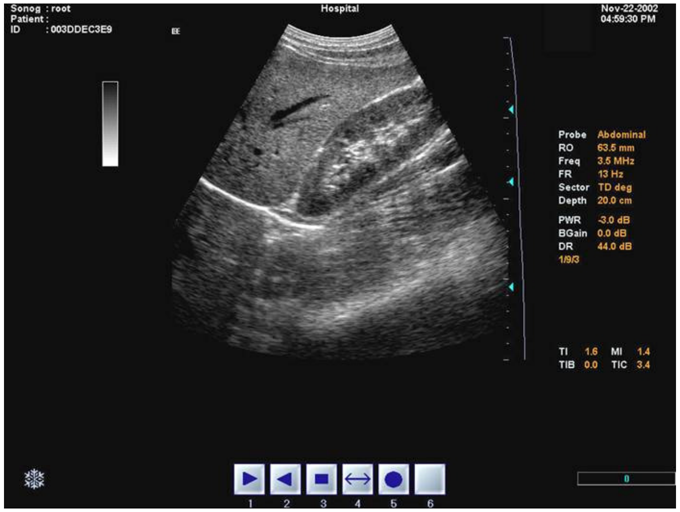


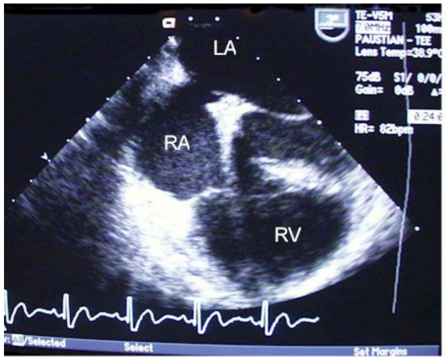


Patient

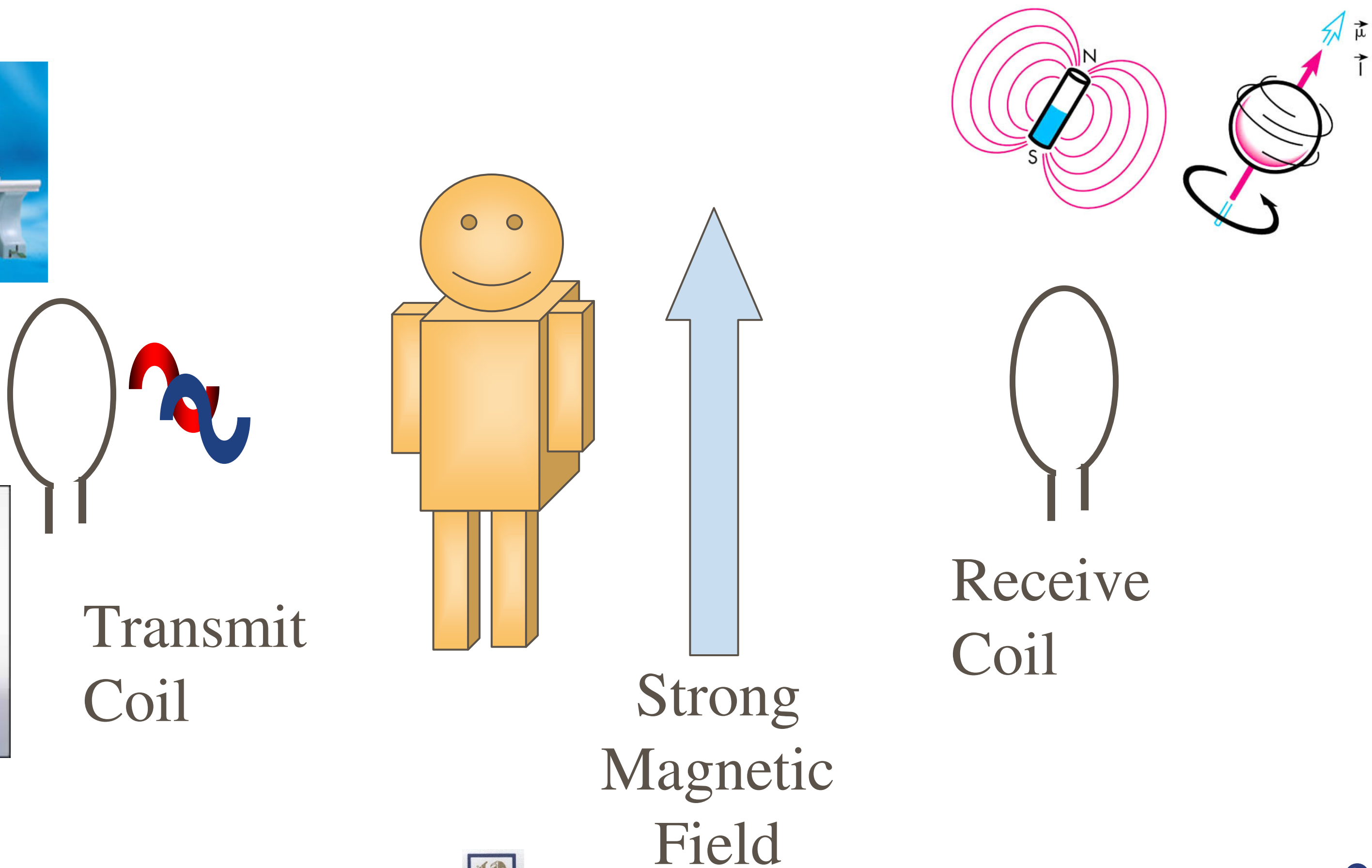
Image on Monitor

Ultrasound Imaging Applications and Limitations





Magnetic Resonance Imaging (MRI)



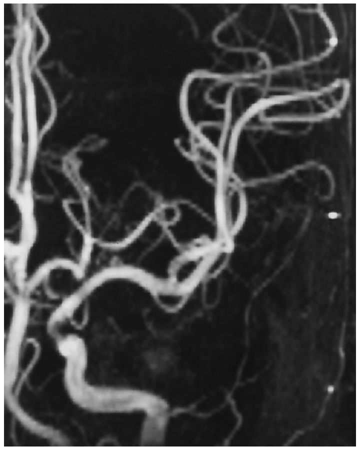
Applications of Medical Imaging

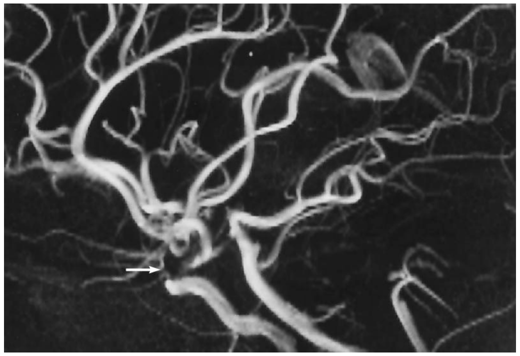
- Imaging of Anatomy
- Imaging of Flow
- Imaging of Function
- Imaging of Chemical Composition
- Image Guided Interventions
- Imaging of Connectivity

Imaging of Anatomy

Imaging of Blood Flow: MRA

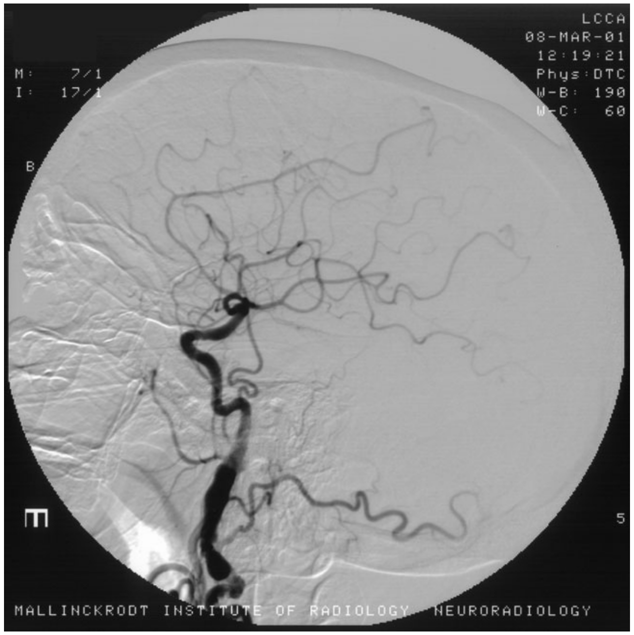
- Time-of-flight or phase contrast
- Velocity encoding for quantitative results
- Can be done with or without contrast agents
- MIP visualization





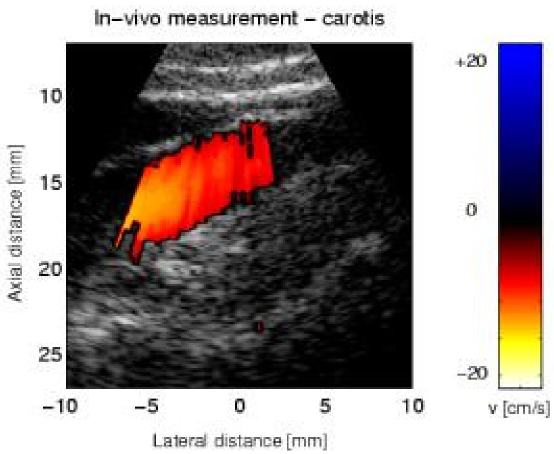
Imaging of Blood Flow: X-ray

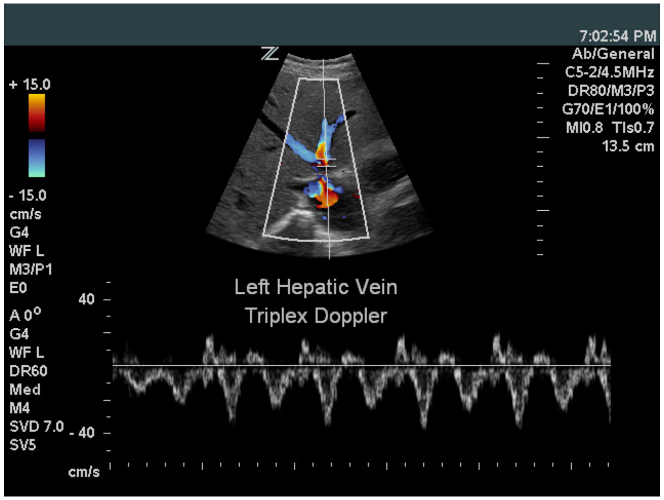
- Contrast agent must be injected
- Digital subtraction angiography



Imaging of Blood Flow: Ultrasound

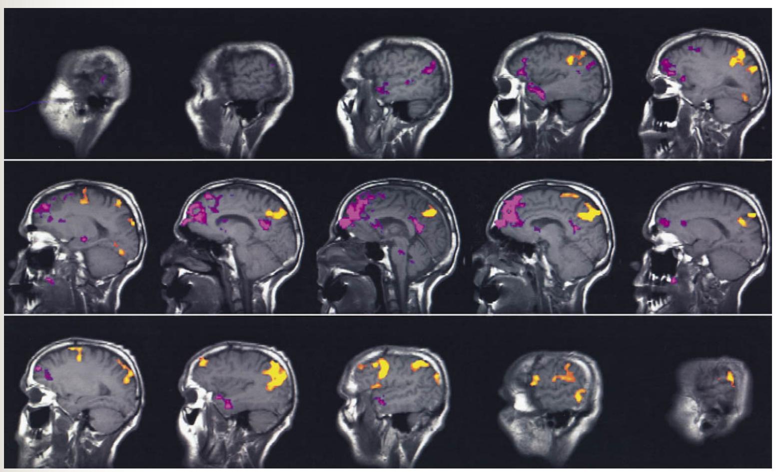
- Doppler effect
- Spectrogram display
- Color flow mapping
  - Spatial resolution vs. velocity accuracy

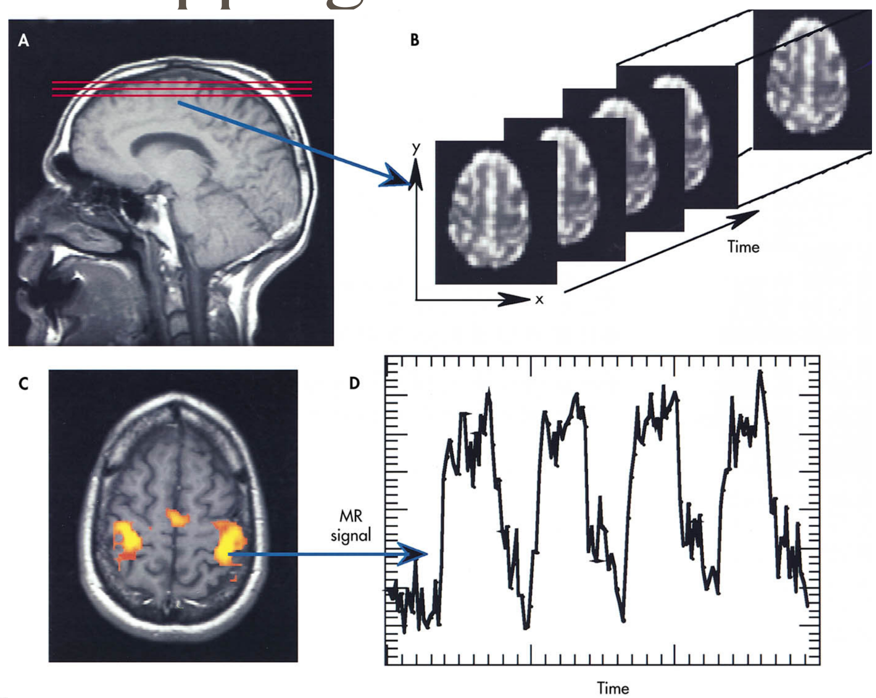




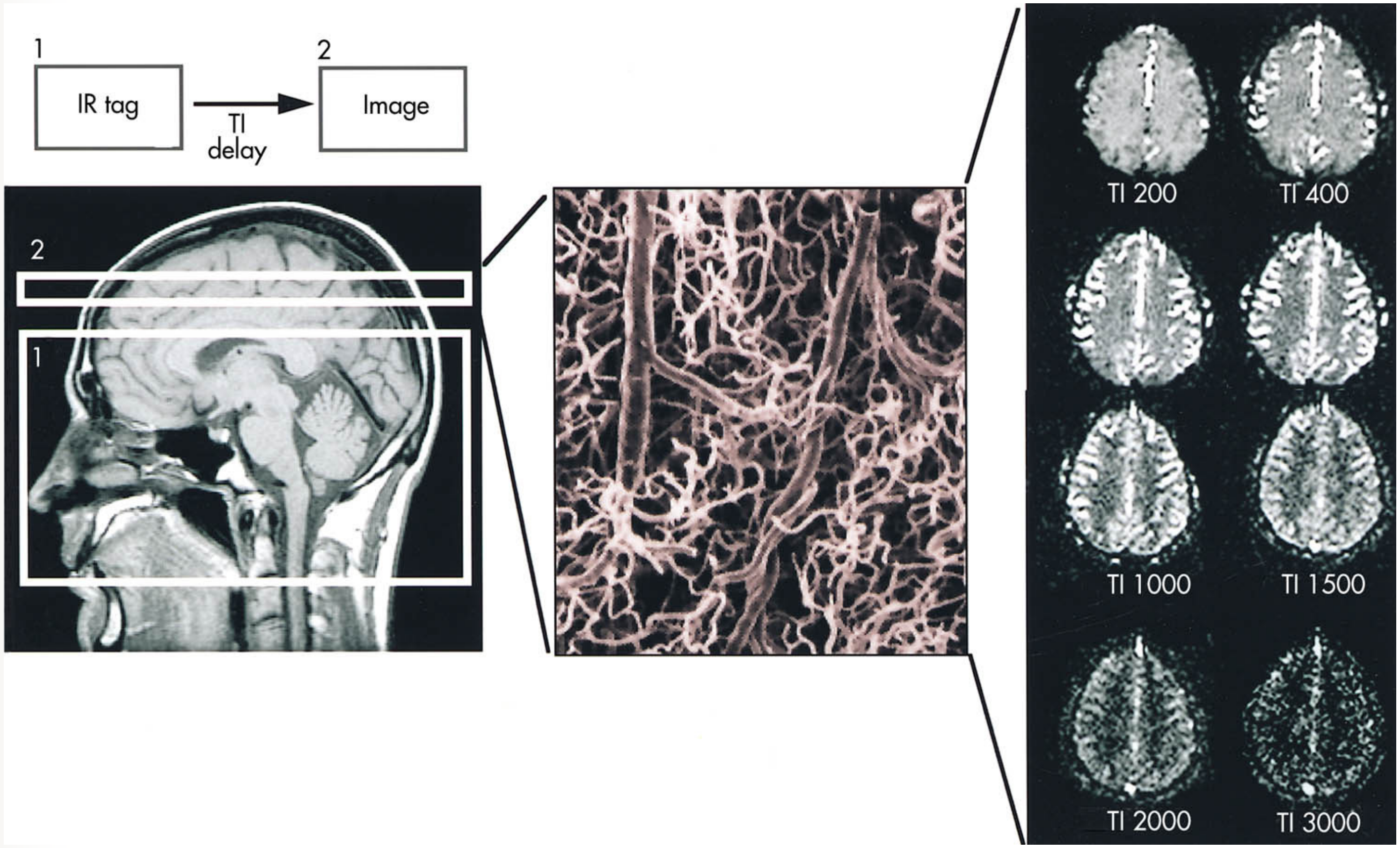
Imaging of Function: BOLD

- Map changes with a physiological function
- Neuronal activation mapping



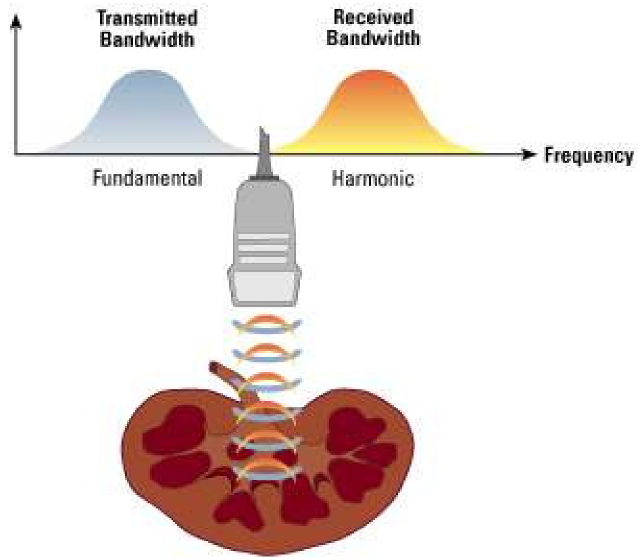


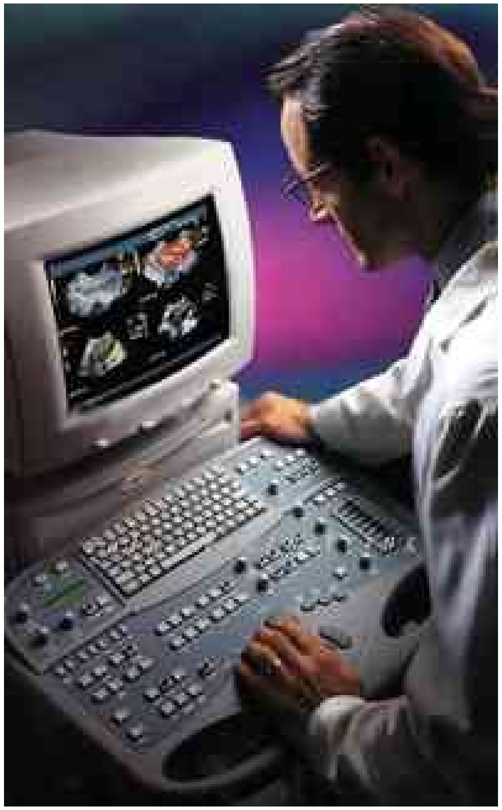
Imaging of Function: Perfusion



Imaging of Function: Tissue Harmonic Perfusion Imaging

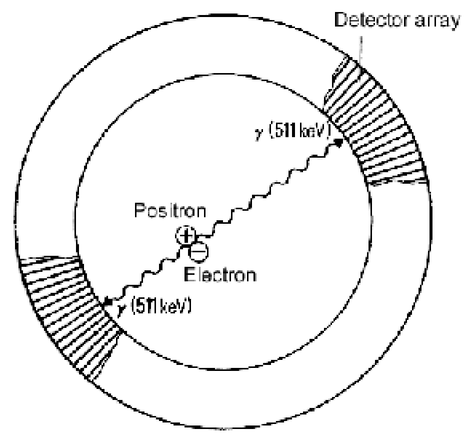
- Contrast agent with microbubbles
- Processing the harmonic signals of microbubbles
  - enhances sensitivity of perfusion analysis

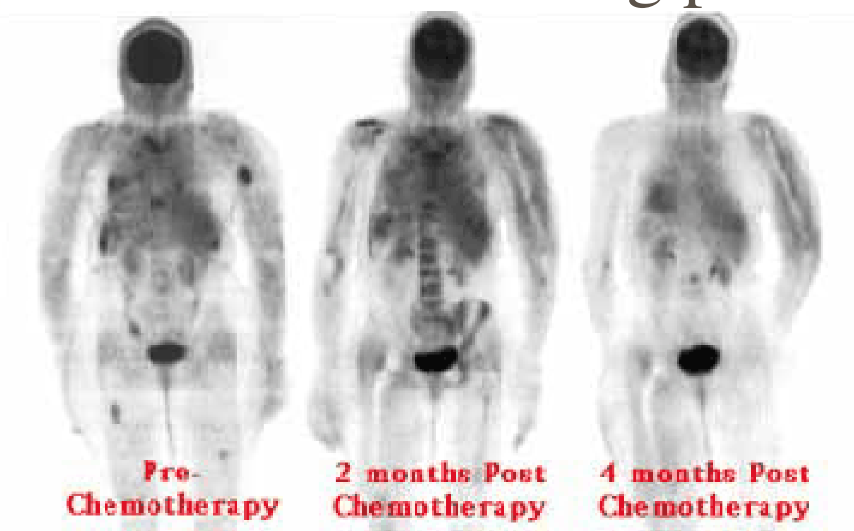


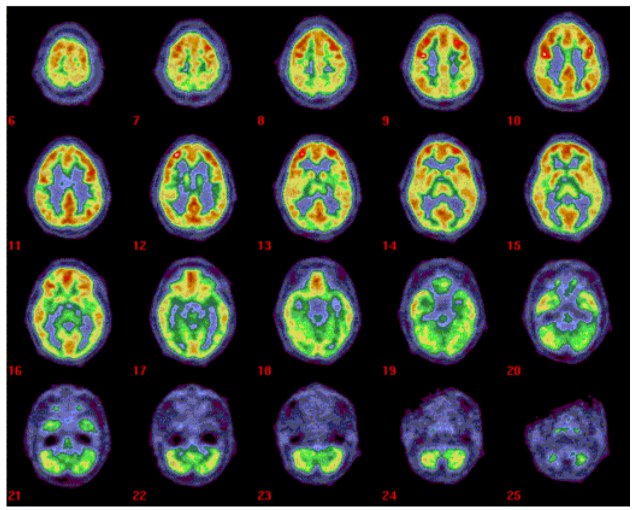


Imaging of Function: PET

- Radioactive decay with positron generation
  - Annihilation
- Detection of resulting photons

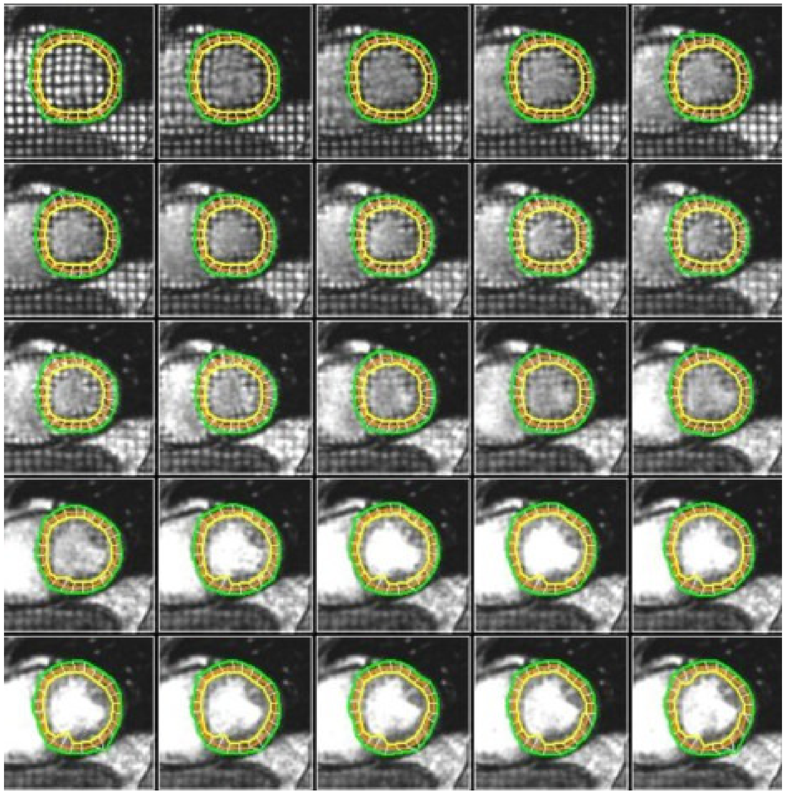






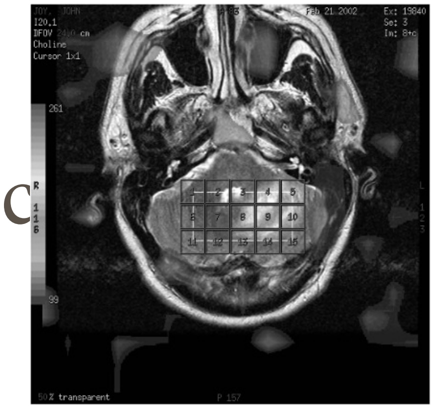
Imaging of Function: Cardiac MRI

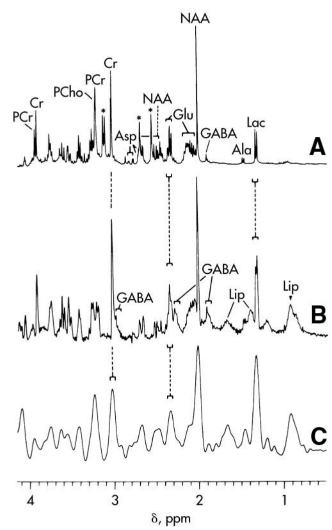
- SPAMM tagging
- Tag tracking
- Quantitative wall viability assessment
- Fast and accurate analysis is a challenge

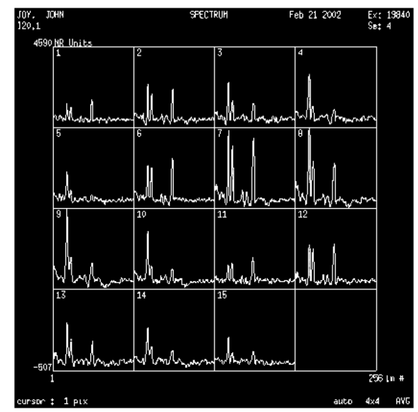


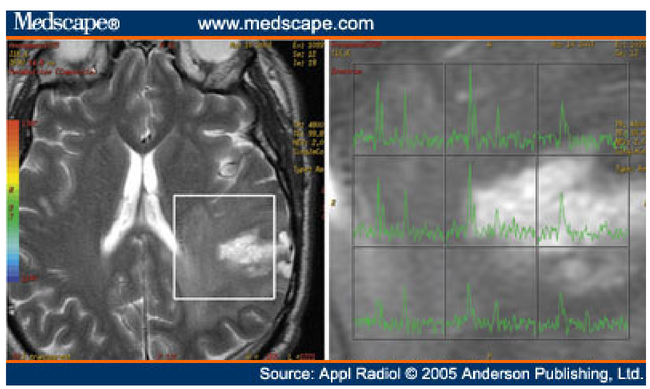
Imaging of Chemical Composition: Spectroscopy

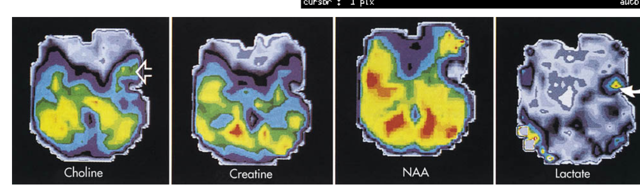
- Quantitative measurement of different metabolites in a specific area in the image
- Multiple nuclei











Imaging of Chemical Composition: Limitations

- Acquisition takes a long time
  - Patient discomfort
  - Motion must be restricted
- High SNR is necessary
  - 1.5 T and Higher only
  - Special coils
- Detection of small signals within large clutter

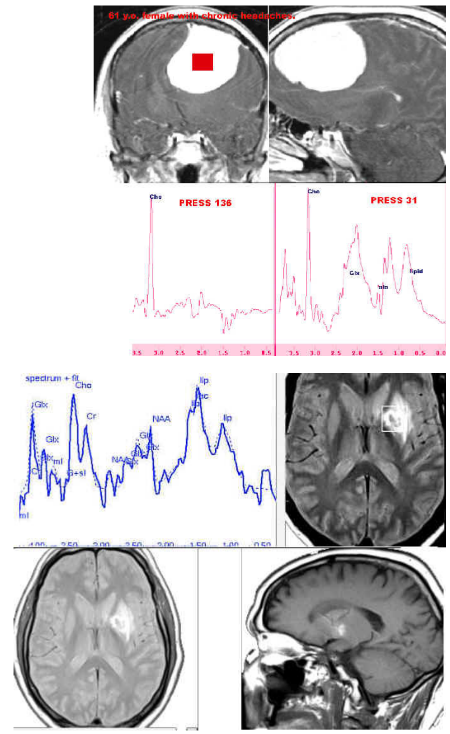
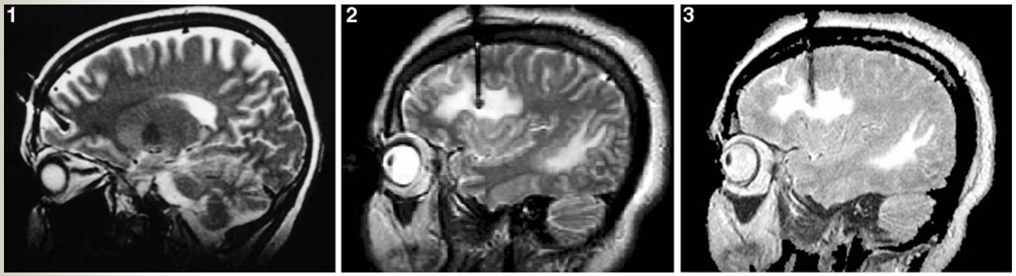


Image-Guided Interventions

- Image-guided surgical planning
  - Minimally invasive brain surgeries
- Image-guided surgical procedures
  - Cathlab
  - Needle-Biopsy



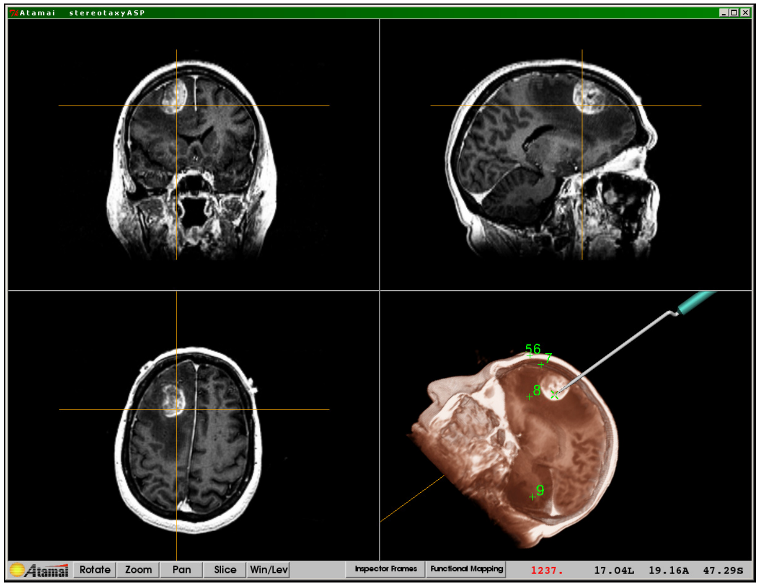


Image-Guided Interventions: Hardware Limitations

- Special surgical tools
- Custom suite designs
- Custom imaging equipment

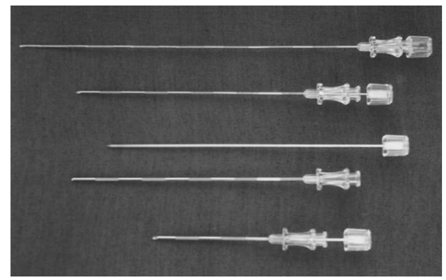
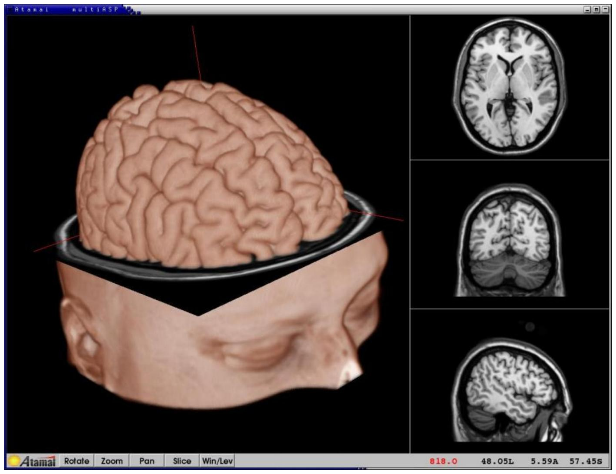


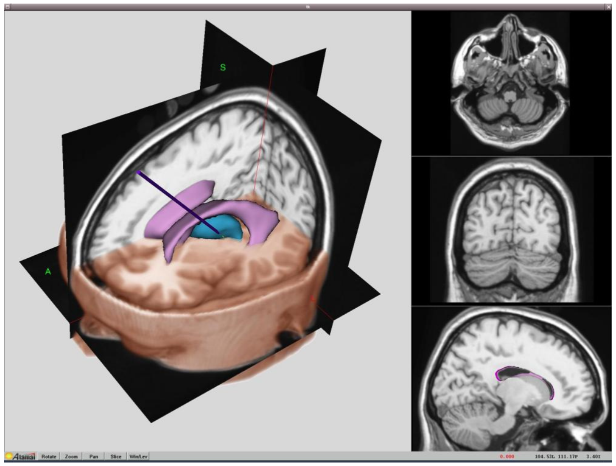





Image-Guided Interventions: Software Limitations

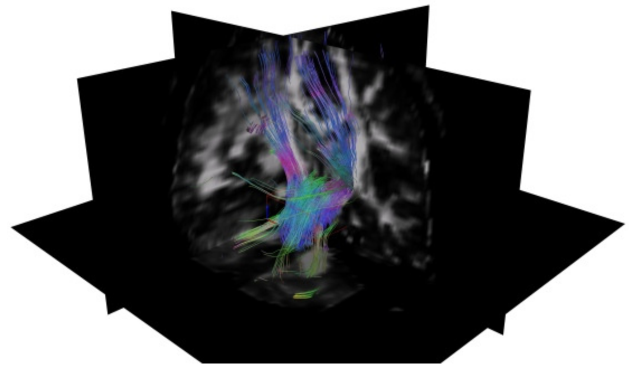
- Discrepancy between planning data and reality
- Visualization/image manipulation during procedure
- Automatic segmentation of relevant structures

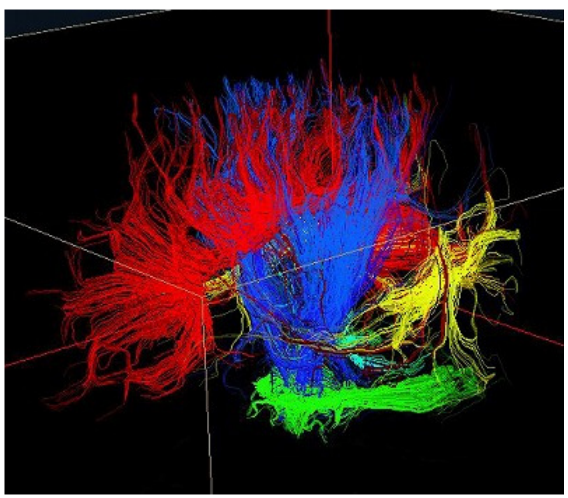


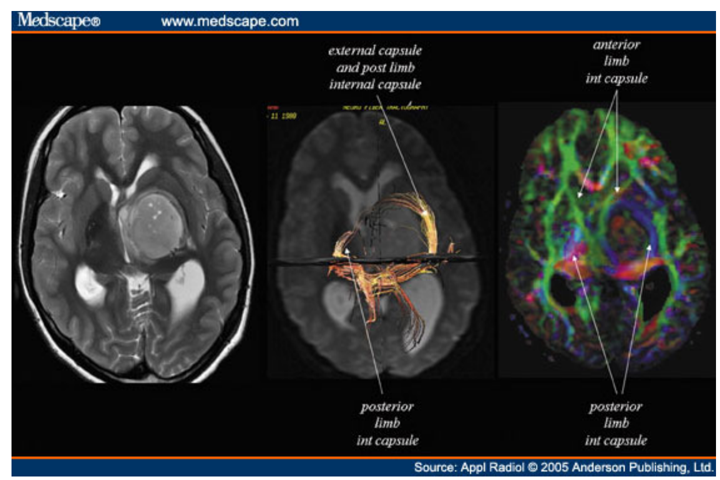


Imaging of Connectivity: Anatomical Connecitivity

- Detection of nerve fiber orientations
- Tracking of fibers – "Tractography"







Imaging of Connectivity: Functional Connecitivity

- Detection of functional activations that happen to always coincide
- Limited by spatial and temporal resolutions

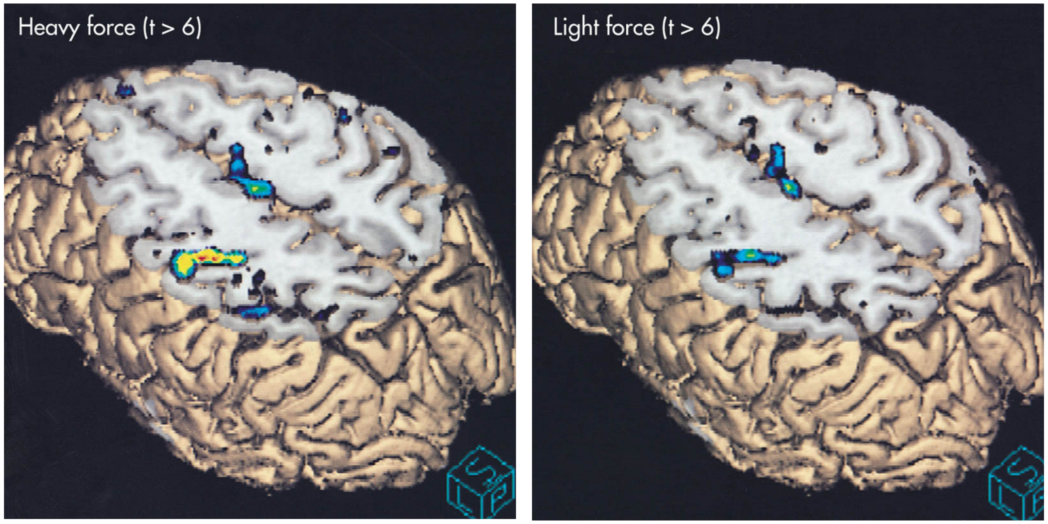
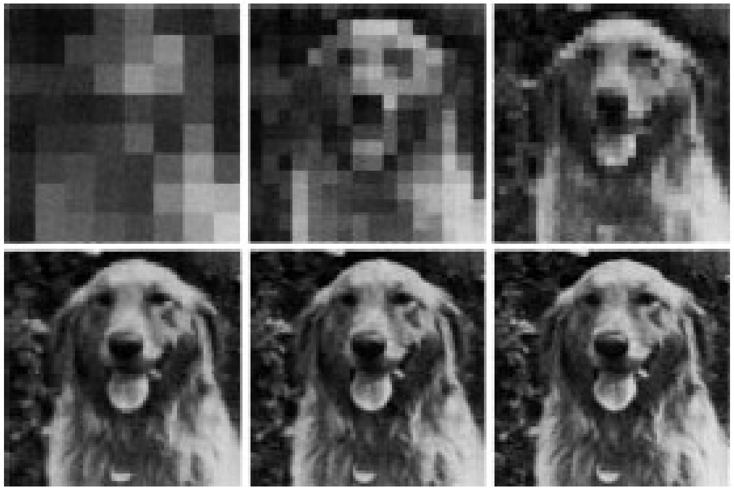


Image Interpretation: Factors

- Matrix size
  - resolution



- Dynamic range
  - Grayscale

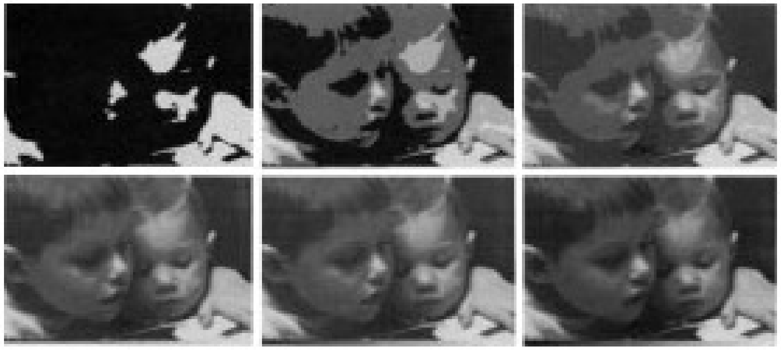
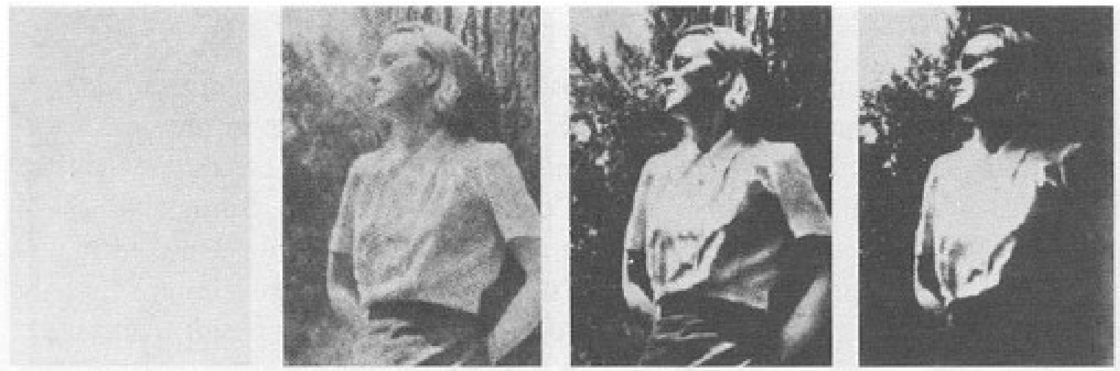


Image Interpretation: Factors

- Contrast

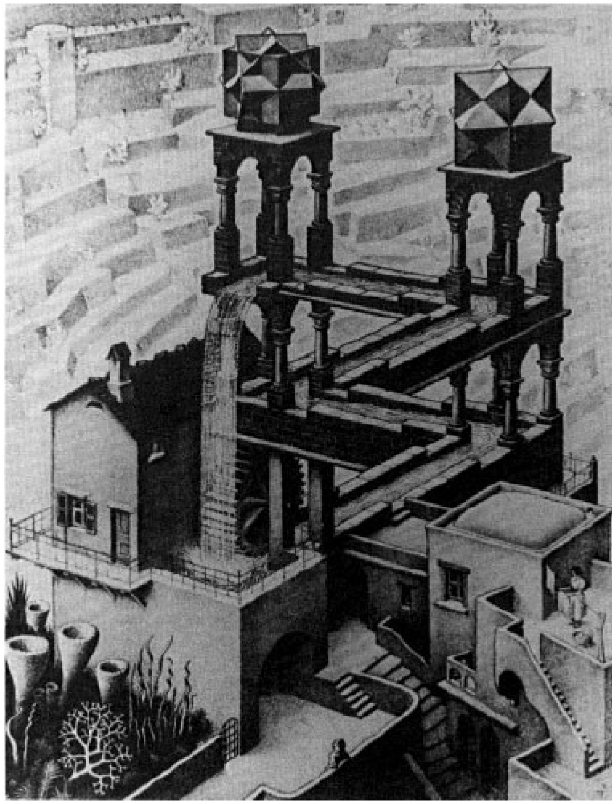


Radiography	*Nuclear Medicine*	*Ultrasound*	*Computed Tomography*	*Magnetic Resonance*
Atomic number Physical density Thickness	Activity Distribution Thickness	Velocity Physical density Thickness	Physical density Electron density Flow	Proton density Relaxation times Flow

Interpretation: Human Factors

Detection challenge

Recognition challenge



Interpretation challenge:
Moving water without origin

Safety of Medical Imaging

- Ultrasound is known to be the safest
- MRI used with clinical systems is safe
- X-ray with small doses per year is safe
- Factors:
  - Difference between ionizing and non-ionizing radiations
  - Heat generated

Biomedical Imaging Trends

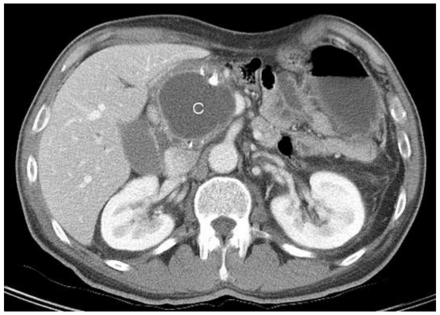
From		To
Anatomic	→	Physiobiochemical
Static		Dynamic
Qualitative		Quantitative
Analog		Digital
Nonspecific agents		Tissue-Targeted agents
Diagnosis		Diagnosis/Therapy

Resistance to New Technologies: CT Example

- In the early years of CT, an often-heard remark was "why would anyone want a new x-ray technique that when compared with traditional x-ray imaging:
  - yields 10 times more coarse spatial resolution
  - is 1/100 as fast in collecting image data
  - costs 10 times more

Resistance to New Technologies: CT Example

- EMI Ltd., the commercial developer of CT, was the first company to enter CT into the market.
  - They did so as a last resort, only after offering the rights to sell, distribute, and service CT to the major vendors of imaging equipment.
- The vendors rejected EMI's offer because they believed the market for CT was too small!



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.

Thank You!