Introduction to Medical Imagery

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M2 MIA / GICAO (P+R)

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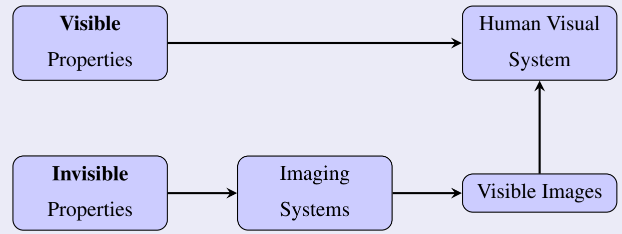
Imaging Science: Bringing the Invisible to Light

Medical images allow us to see

- Anatomy (bones, soft tissues, ...)
- Anatomical Movement (hart, lung, ...)
- Physiological measures (blood flow, ...)
- Metabolism processes (biochemistry: use of radioactive markers)

Principle of Medical Image Acquisition



Imaging Science: Bringing the Invisible to Light

Element	Imaging Systems	Abbreviations
Light	Endoscopy	–
Ultra-sound	Ultra-sound imaging Doppler Effect	US Dupplex US
X-Ray	X-Ray imaging Digital Angiography Computed Tomography Computed Tomography Angiography	XR DSA CT-Scan CTA
Gamma Ray	Scintigraphy Single Photon Emission Computed Tomography Positron Emission Tomography	 SPECT PET
Electromagnetic Field	Magnetic Resonance Imagery Magnetic Resonance Angiography	MRI MRA

Purpose of Medical Images

- Diagnosis
- Pre-operative planning (surgery, radiotherapy)
- Follow-up care for patients
- Guided surgery: real time imagery
- Teaching / Formation

Principle

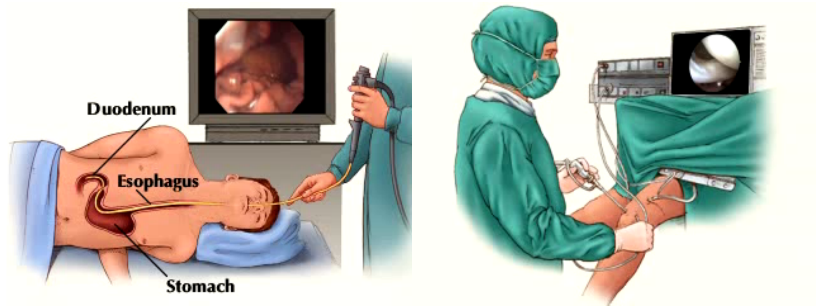
Medical Terminology

- *endo*: within
- *scopy*: examination of
- *scopy* = visualization of a body part by means of a scope.

Endoscopy = looking inside

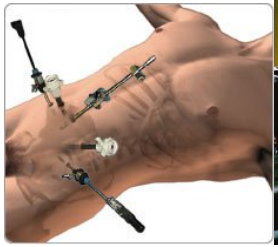
A minimally invasive way to *look inside*

Endoscopy with fibrescope / Arthroscopy



http://www.mayoclinic.com

Laparoscopy



- C Assistant
- A Surgeon
- 1 Endoscope
- 2 Endoscopic Video Camera
- 3 Endoscopic Image
- 4 Surgical Instruments

Endoscopy

Advantages

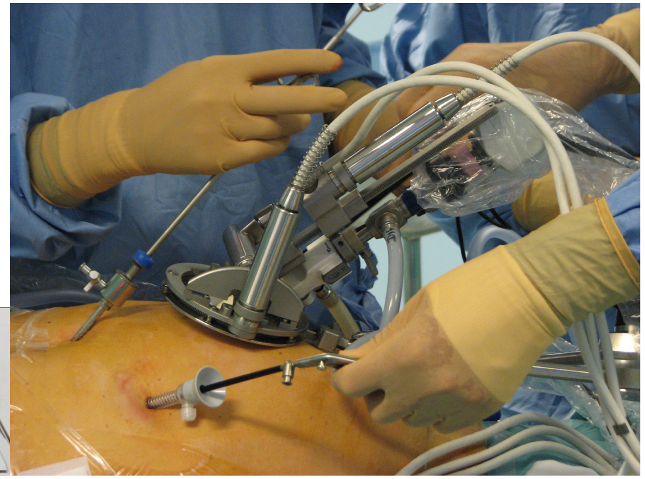
- Minimally invasive
- Allows local anesthesia
- quick healing / less reinfection.

Drawbacks

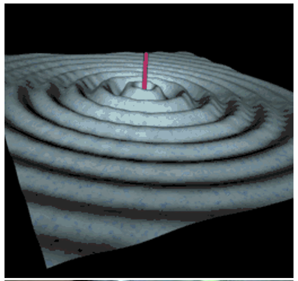
- Very partial view
- Need of an assistant to manipulate the endoscope
- Loss of touch sensitivity
- 2D Views

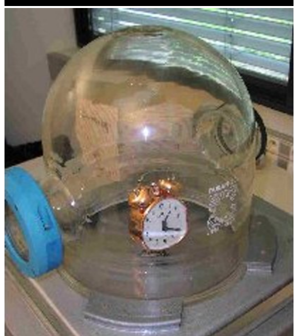
Da Vinci

Viky



Acoustic waves

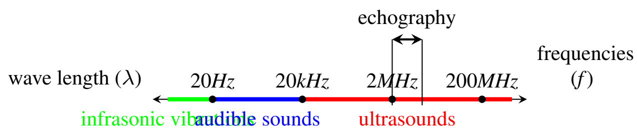




Mechanical waves

- Propagate through the matter using
  - compressions
  - relaxations
- No propagation in vacuum

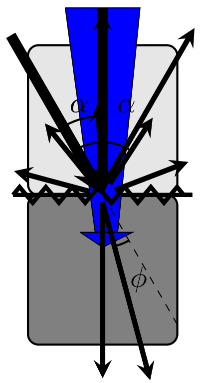
Propagation through matter



Sound propagation speed

Environment	Propagation speed (m/s)
Air	333
Watter	1480
Fat matter	1446
Muscle	1542–1626
Blood	1566
Bones	2070–5350

Interaction with matter



- Absorption
- Reflection (echo)
- Refraction
- Dispersion / Scattering

Attenuation

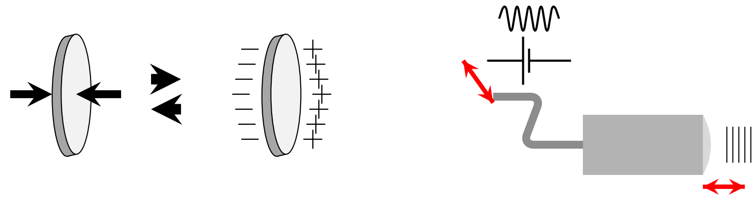
probe frequency	max depth
2,5–3,5 MHz	> 15cm
5 MHz	10cm
7,5 MHz	5-6cm
10 MHz	2-3 cm

Piezoelectric Effect

Piezoelectric Effect

Capacity to

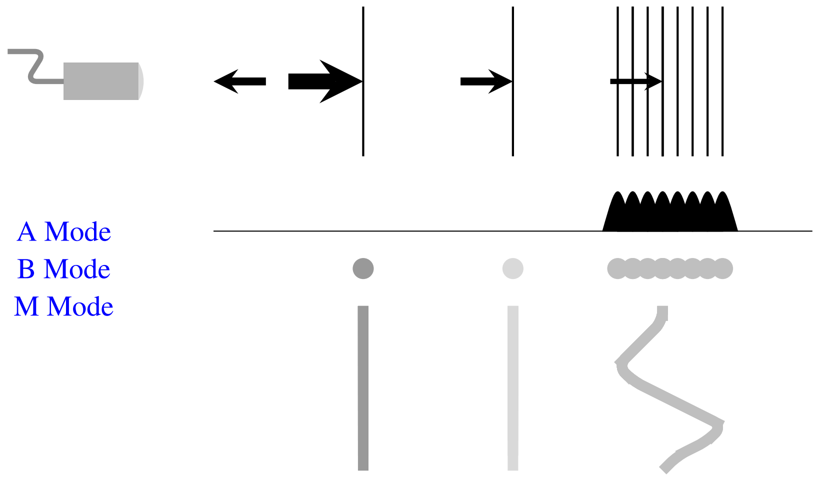
- Charge during a compression
- Bend under electricity



Hypotheses for Ultrasound Images Reconstruction

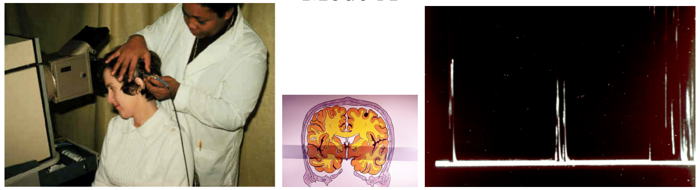
- The ultrasound beam is unique
- Only reflections happens
- The distance between the probe and the location of the reflection is calculated using the mean sound speed in soft tissues (1540 m/s)

Ultrasound Imaging in 1D



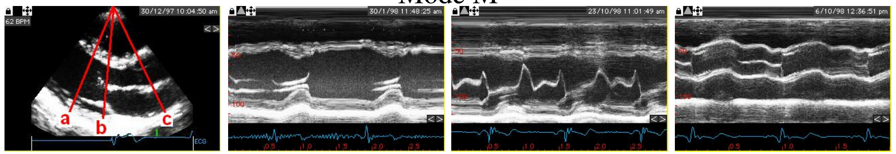
Ultrasound Imaging in 1D

Mode A



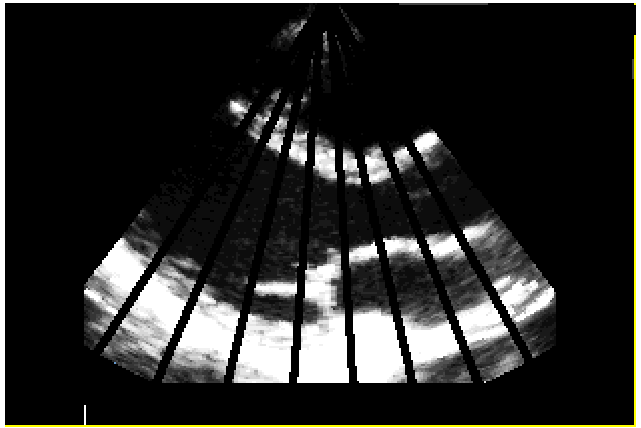
http://www.obgyn.net/ultrasound/

Mode M



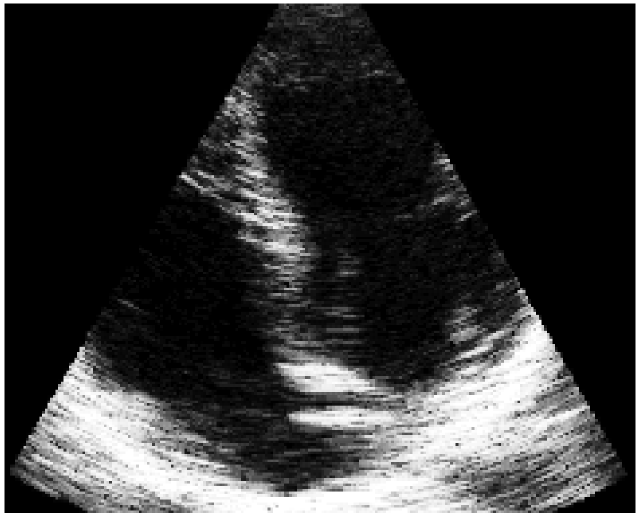
http://folk.ntnu.no/stoylen/strainrate/Ultrasound

Ultrasound Imaging in 2D



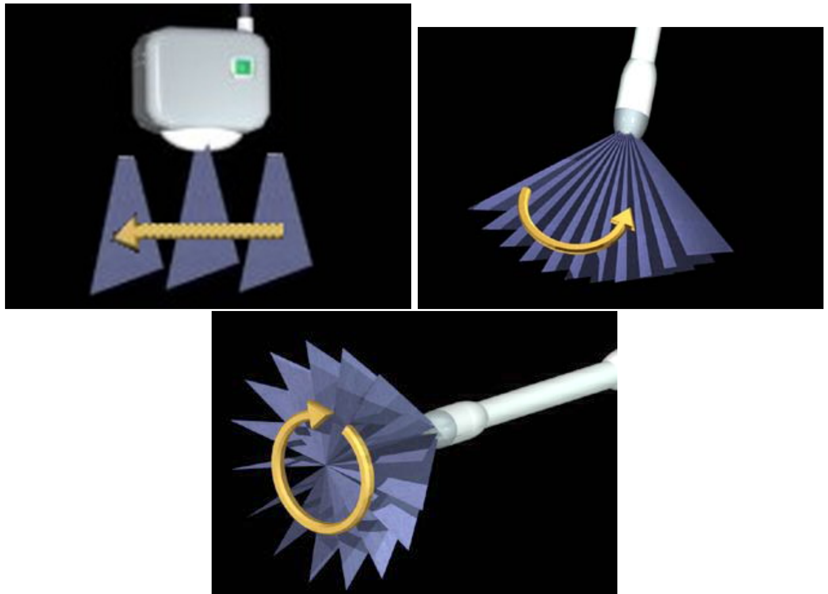
http://folk.ntnu.no/stoylen/strainrate/Ultrasound

2D + Time Imaging

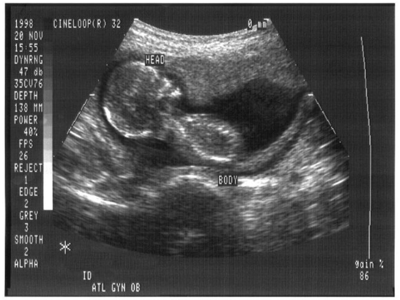


http://www-sante.ujf-grenoble.fr/sante/CardioCD/cardio/video.htm

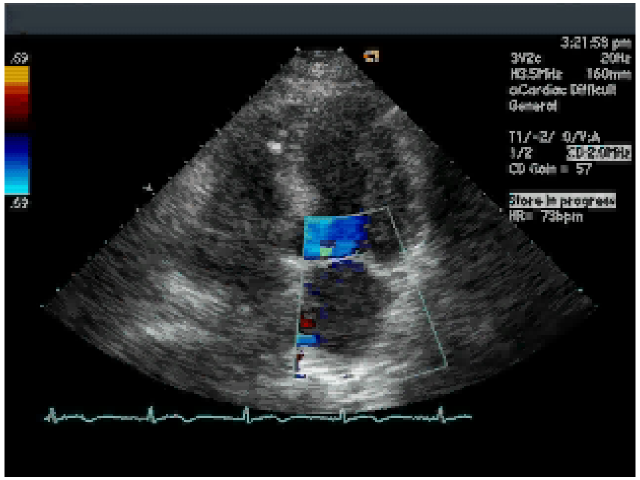
3D Ultrasound Imaging



3D Ultrasound Imaging



Doppler: Example



http://www-sante.ujf-grenoble.fr/sante/CardioCD/cardio/video.htm

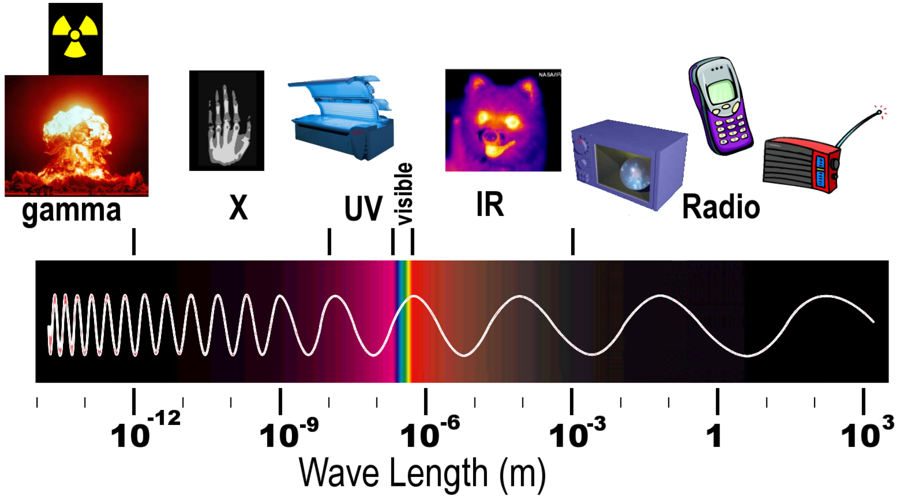
Conclusion

- Interface Imagery
- Anatomical information
- Functional information (Doppler effect)
- Good Space resolution (about 1mm)
- Good time resolution
- Less expensive than other methods
- Noisy images

Questions

- Why is a water-based gel is usually placed between the patient's skin and the probe ?
  ultrasounds move very slowly in the air.
- Why do physicians avoid rib bones to image the heat ?
  ultrasounds are absorbed by bones
- Why is *speckle* noise a multiplicative noise ?
  It is ultrasound interferences.
- Why does a smooth surface slanted with respect to the probe makes the signal disappear ?

X-Rays

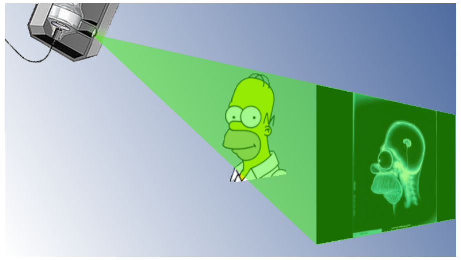


corpuscular theory

waves theory

X-Ray photography

Principle : Attenuation of X-Rays differs according to tissues (thickness, density, Z, X-Ray energy)

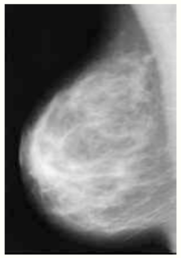


X-Rays may be

- Not affected
  - Darkest parts of the radiography
- Stopped (Photoelectric effect)
  - Gray levels on the image depend on this effect
- Deviated (Compton scattering)
  - Scattered rays
  - Produces a uniform shadow on the radiography

Exemples of application

Fracture

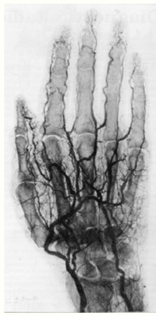


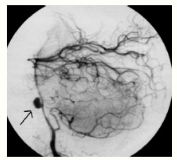
Mammographie

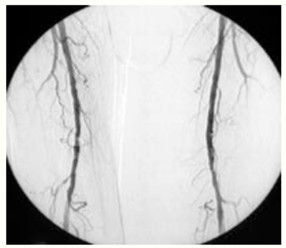
Tube digestif

Angiography

Injection of a contrast media opaque to X-rays in blood vessels
► visualization of blood network.







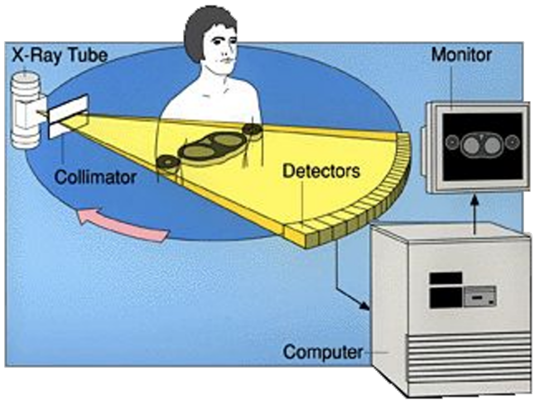
Conclusion

- Anatomical information
- Good contrast bone / soft tissures (high resolution)
- 70% of medical images
- Dangerous
  - precausions must be taken for patients (definition of doeses and areas exposed to x-rays) an for radiologist
- Loss of information 3D ▶ projection in 2D

Questions

- Why do radiologists use lead aprons when they perform X-Ray radiology ?
- Why do we baryum or iodine are injected in the patient's blood for angiography ?

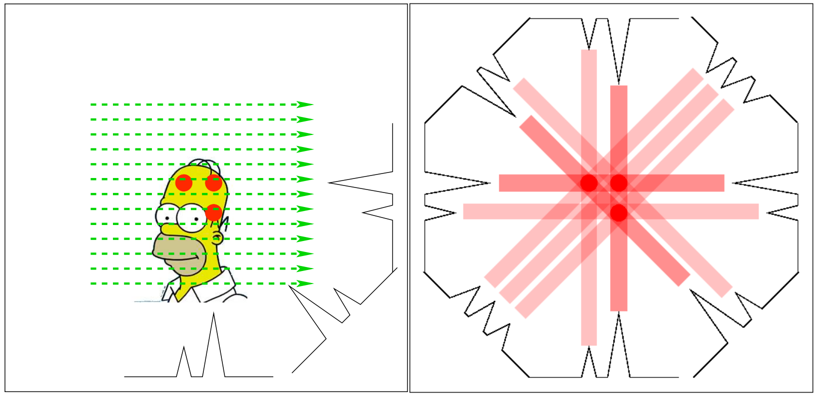
X-Ray Computed Tomography (CT)



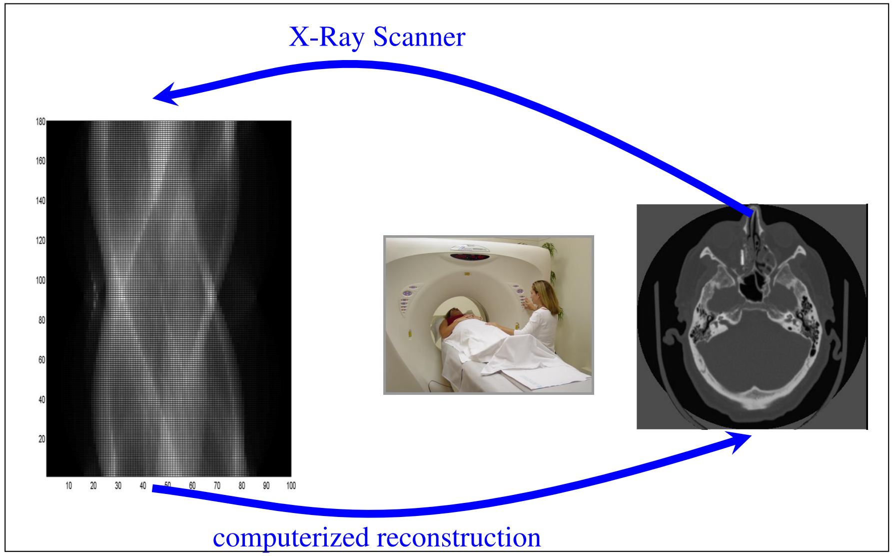
Physical information acquisition | Mathematical / computerized processing | screen / reconstruction visualization

Computed Tomography: Principle

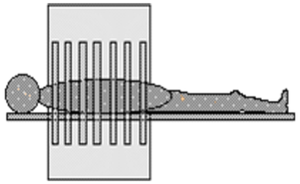
Mac Cormac' idea : 2D reconstruction from 1D projections



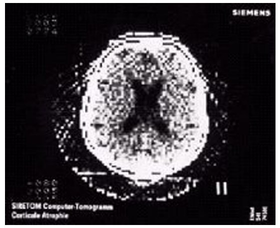
CT and Radon transform

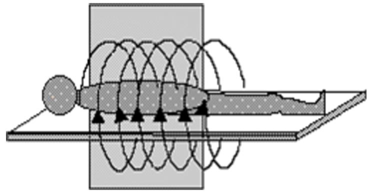


X-Ray Computed Tomography (CT)



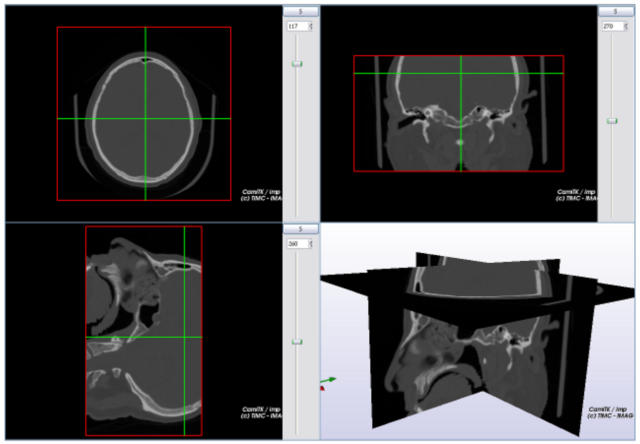
- 1971: Low acquisition (5 minutes) and low reconstruction (15minutes)
- Planar, sequential acquisition



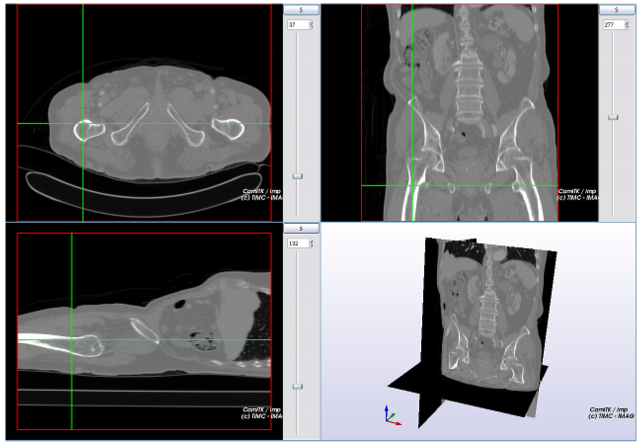


- 80': helicoid scan
- Fast volume acquisition

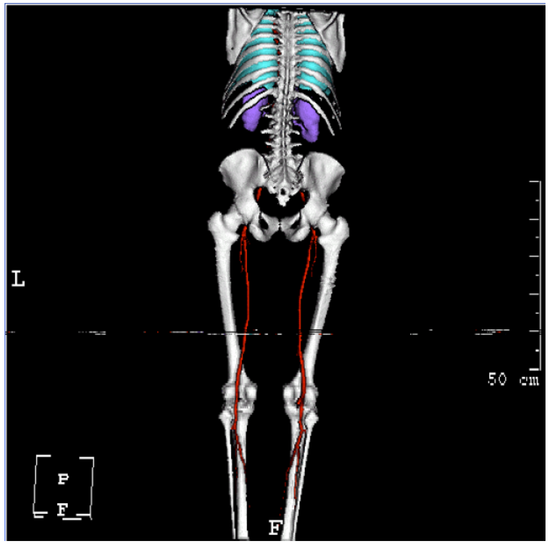
Examples



Examples



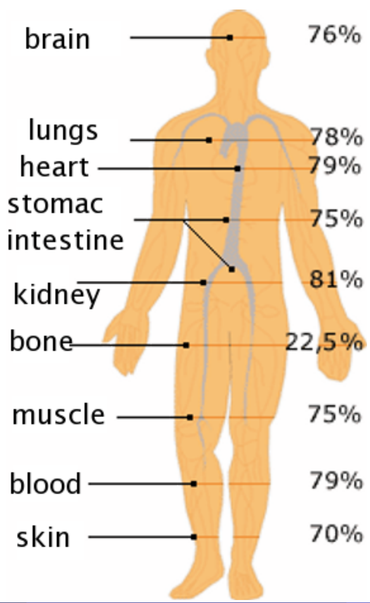
Examples



Conclusion

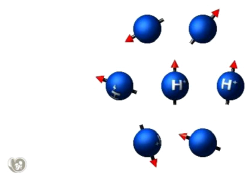
- Good contrast bones / air
- Good spatial resolution ($\approx 0.5mm$)
- Fast image acquisition
- No gray level superposition (contrary to radiography)
- Irradiation of the patient
- Risks with contrast media
- Several reconstruction methods

Hydrogen in human body



Nuclear Spin

Outside magnetic field



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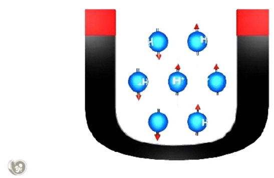
Proton H^+

- Nuclear Magnetic Dipole
- Rotating around its axis

▶ No Global magnetization

Under a macroscopic magnetization field $\overrightarrow{B_0}$



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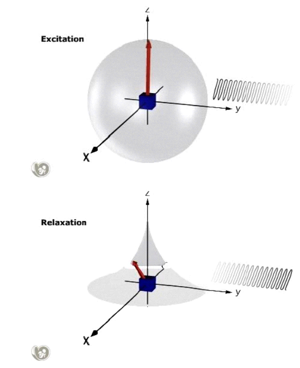
Orientation of the spins in $\overrightarrow{B_0}$ direction

- parallel direction
  low energy
- antiparallel direction
  higher energy

Nuclear Magnetic Resonance

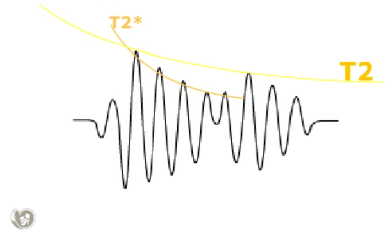
Interaction with Radio Frequency Wave



- Radio Frequency = ω_0
- Brings energy to the system
  - ▶ *excitation*
- End of the RF wave
  - ▶ *relaxation*

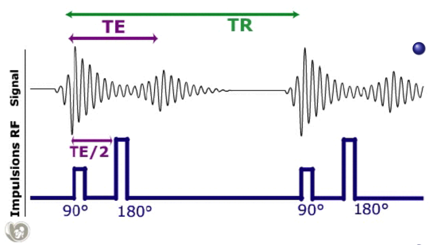
  energy emission

180° RF Pulse



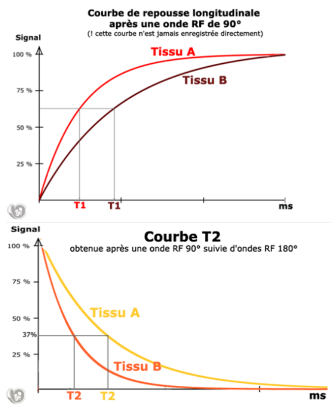
- After a 90° RF pulse
  - spins dephase and transverse magnetization decreases.
- If we apply a 180° RF pulse
  - ▶ spins rephase
- ▶ transverse magnetization reappears

Spin Echo



- Repetition of 90° - 180° RF pulses
- Echo Time (TE)
  - time between the 90° RF pulse and MR signal sampling, corresponding to maximum of echo.
  - The 180° RF pulse is applied at time TE/2.
- Repetition Time (TR)
  - time between 2 excitations pulses (time between two 90° RF pulses).

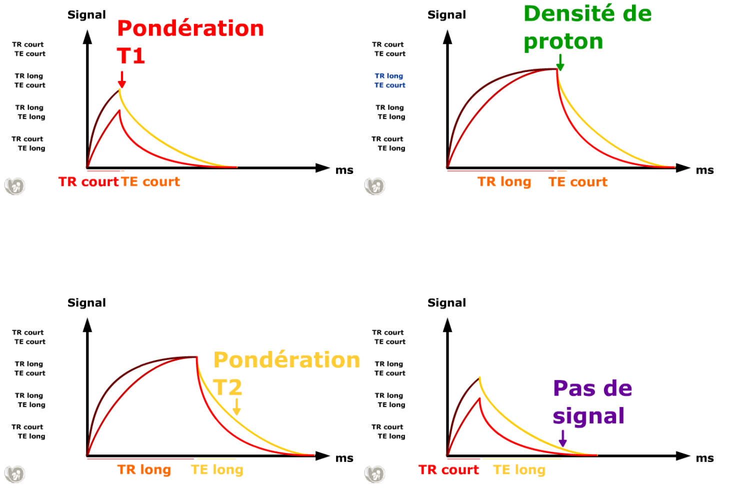
Signal Weighting (T1, T2, PD)



Each tissue has a specific proton density, T1 and T2 time. The NMR signal depends on these 3 factors.

- T1 : time for the longitudinal magnetization has returned to 63 % of its final value.
- T2 : time for the transverse magnetization has returned to 37 % of its initial value.

Signal Weighting (T1, T2, PD)

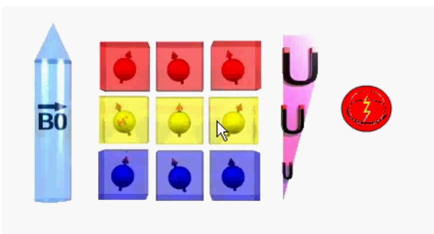


Spatial Encoding

Spatial localization is based on magnetic field gradients, applied successively along different axes. Magnetic gradient causes the field strength to vary linearly with the distance from the center of the magnet. These gradients are employed for slice selection, phase encoding and frequency encoding.

- Slice selection is performed thanks to a slice selection gradient *SSG*
- Selection of the vertical position and horizontal position of a point within a slice are performed thanks to phase encoding graidient (*PEG*) and frequency encoding gradient (*FEG*).

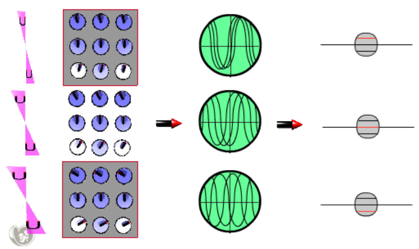
Slice Selection Gradient



- A magnetic field gradient is applied perpendicular to the desired slice plane (Slice-selection gradient).
- *SSG* adds to $\overrightarrow{B_0}$
- As the magnetic field varies in the direction of the gradient, all the planes perpendicular to the direction of the gradient have different precessional frequencies.
- A RF pulse is applied at the resonance frequency of the spins on the desired slice plane:

  $\Longrightarrow$ only the protons of the desired slice will be excited.

Phase encoding



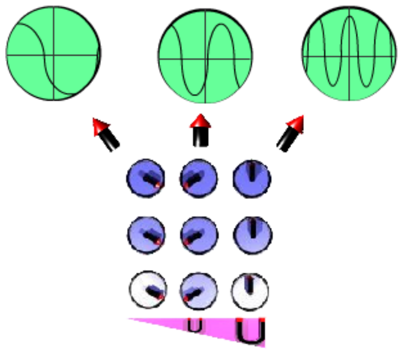
For one of the plane direction

- A magnetic gradient field is applied briefly in the direction of the columns (Oy).
- As the change in frequency is very brief, when the gradient is switched off

  $\Longrightarrow$ It causes a change in phase that is proportional to the distance.
- The protons in the same column have different phases.
- N lines $\Longrightarrow$ N acquisitions with a different phase encoding.

NB: In the following animation, the signals of each row are drawn separately to show the phase shift. The actual recorded signal is a mix of all these signals.

Frequency encoding

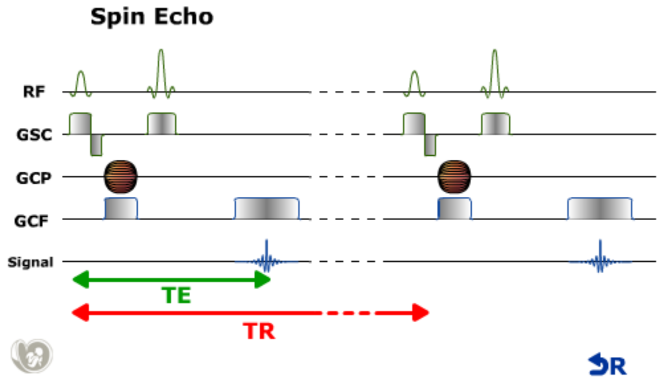


During data acquisition

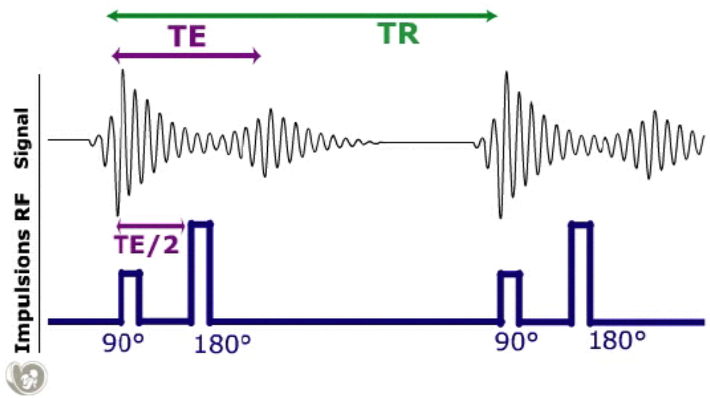
- Frequency Encoding Gradient *FEG*
- Modifies Larmor frequency of spins

$\Longrightarrow$ The MR signal is a mix of all these frequencies (encoding in the frequency-encoding direction) and phase shifts (encoding in the phase-encoding direction).

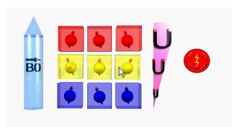
Spatial Encoding



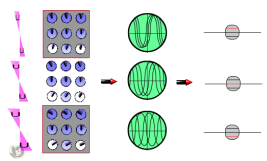
MRI Acquisition Sequence



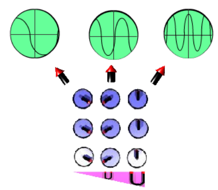
Spatial Encoding



Slice Selection Gradient
(*we get one plane*)



Phase Encoding Gradients
phase encoding in 1 direction

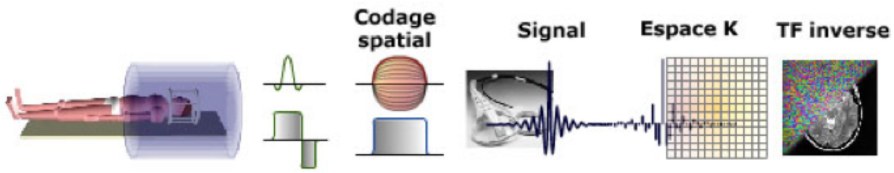


Frequency Encoding Gradients
frequency encoding in 1 direction

MR Image Formation

- Application of the different steps of MRI acquisition (FR pulses at 90° and 180°)
- Application of the spatial encoding steps
- Signal numerization and signal processing to obtain the numerical image
- Signal RNM stored in a talbe name K Space or Fourier plane or Frequency space
- Inverse Fourier Transform

MR Image Formation



Questions

- Why is it difficult to see bones on MRI ?