MEDICAL IMAGING TECHNIQUES

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Basic Principles of Medical Imaging Techniques

Macroscopic Medical Imaging

External Source
- Transmission
  - X-ray
  - Computed Tomography
- Reflection/Refraction
  - Ultrasound
  - Projected Radiography

Internal Source
- Internal Tracer
  - SPECT
- External Excitation
  - PET
Medical Imaging Techniques

• Classical radiography
• Mamography
• Bone densitometry
• Fluoroscopy
• Computerized tomography
• Angiography
• Magnetic resonance imaging
• Nuclear imaging
• Positron emission tomography
• Ultrasonography

X-ray based imaging tech.
Classical (Conventional) Radiography
Radiological Terminology

- **Radiolucent:** indicates greater permeability to x-ray photons. Renders the radiographic film dark (black).

- **Radiopaque:** represents obstruction to the x-ray photons. Renders the radiographic film light (white)

- **Contrast:** indicates the difference between the image densities of two areas.
  - A function of the number of x-ray photons transmitted or the strength of the signals emitted by the two regions and the response of the recording medium.
Radiographic Quality

- **Density**
  - Overall blackness or darkness of the radiograph (controlled by tube current (50 – 400 mA))

- **Contrast**
  - Range of shades of black to white (controlled by kVp; 40 – 125 kVp)

- **Image distortion**
  - Object film distance
  - Source film distance (focal film distance (FFD); 40 inches ≈ 1 m)
  - Movement
• **FFD (AKA... Source-Image Distance (SID))**
  
  – Is the distance between the center of the anode of the x-ray tube (the focal spot) and the film (top of cassette).
  
  – Effects magnification, distortion, and x-ray beam intensity.
Optical (Radiographic) Density

- **Optical Density**: the amount of blackening in the film
- Defined as the log of the ratio of the intensities of the incident and transmitted light
  - log is used as the eyes response is logarithmic

Optical Density, \( D = \log(\frac{I_{in}}{I_{out}}) \)
Optical Density Range

- The optical density range is from 0.0 for no density to 4.0 for absolute black.
- Useful range in general radiography is from 0.5 to 2.25.
- Image range is 0.5 to 1.25 OD
X-rays Passing Through Tissue

- Depends on the energy of the x-ray and the atomic number of the tissue
- Higher energy x-ray - more likely to pass through
- Higher atomic number - more likely to absorb the x-ray

Atom number & density

<table>
<thead>
<tr>
<th>Matter</th>
<th>Atom Numb.</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle</td>
<td>7.4</td>
<td>1</td>
</tr>
<tr>
<td>Fat</td>
<td>6.3</td>
<td>0.91</td>
</tr>
<tr>
<td>Lungs</td>
<td>7.4</td>
<td>0.32</td>
</tr>
<tr>
<td>Air</td>
<td>7.6</td>
<td>0.0013</td>
</tr>
<tr>
<td>Bone</td>
<td>13.8</td>
<td>1.85</td>
</tr>
</tbody>
</table>
The 5 X-ray densities

- Low density material such as air is represented as black on the final radiograph. Very dense material such as metal or contrast material is represented as white. Bodily tissues are varying degrees of grey, depending on density, and thickness.

X-ray tissue densities

- Here are the four natural tissue densities seen on a chest radiograph. Note there is a range of greyness, depending on the thickness of each tissue.

Natural tissue densities

- 1 - Air/Lung
- 2 - Fat (layer between soft tissues)
- 3 - Soft tissue
- 4 - Bones

X-ray tissue densities

- The greatest contrast is found in areas of greatest difference in density of adjacent structures (red circle).
Factors Affecting Patient Dose (Also affects X-ray Intensity & Quantity and radiographic film density)

• **Milliamperage-second (mAs)**
  – Governs the amount of X-Rays reaching the film.
  – Is calculated as Tube Current (mA) X Exposure Factor (s).
  – Too low (underexposure) results in a pale film.
  – Too high (overexposure) results in a dark film.

• **Tube Voltage (Kilovoltage peak; kVp)**
  – Is the peak voltage applied to the x-ray tube.
  – Determines the highest energy of x-ray photon.
  – High kVp produces a long scale of contrast, which is necessary for soft tissue radiographs.
  – Low kVp produces short scales of contrast that are necessary for bone visualization.
Factors Affecting Patient Dose

- **mAs**
  - Double the mAs, double the intensity.
  - Beam quality not affected.

- **kVp**
  - Intensity (radiation dose) $\alpha (kVp)^2$
  - Penetrating power increases if kVp increases.
  - Increasing the kVp will decrease the contrast seen between soft tissue and bone.

- **Filtration**
  - Inherent Filters (glass window, 0.5 mm Al)
  - Added Filters (Al & Cu)

- **Focus to skin distance (FSD)**
Filtration (Inherent & Al and Cu filtration)

Reduced dose to patient, *but*...

Increased mean energy reduces radiographic contrast

Energy (keV)

Intensity
Focus to skin distance (FSD)

The Inverse Square Law

\[
\frac{I_i}{I_f} = \frac{(d_f)^2}{(d_i)^2}
\]

Initial intensity from X-ray source

Final intensity

Final distance from X-ray source

If the intensity of radiation at 1 meter from the source is 100 mR/hr,

Then, the intensity radiation at 2 meters from the source is \(\frac{1}{4}\) or 25 mR/hr in the same unit area.

And at 3 meters from the source, the intensity of radiation is \(\frac{1}{9}\) the original or 11.1 mR/hr.
**AP v PA magnification**

- **Anterior-Posterior (AP) magnification**
  - The X-ray beam for an anterior-posterior (AP) view of the chest exaggerates heart size as the heart is relatively near to the beam source.

- **Near beam magnification**
  - A source that is too near the patient will further exaggerate the size of structures nearest to that source.

- **Posterior-Anterior (PA) projection**
  - A posterior-anterior (PA) beam view of the chest allows more accurate representation of heart size as the heart is positioned closer to the detector and is therefore less magnified.
<table>
<thead>
<tr>
<th>Examination</th>
<th>Tube Potential (kV)</th>
<th>(mAs)</th>
<th>FSD (cm)</th>
<th>Filtration (mm Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest PA</td>
<td>55 - 90</td>
<td>4 - 16</td>
<td>110 - 180</td>
<td></td>
</tr>
<tr>
<td>Chest LAT</td>
<td>62 - 100</td>
<td>4 - 32</td>
<td>100 - 180</td>
<td>2.00 - 2.50</td>
</tr>
<tr>
<td>Skull AP</td>
<td>50 - 80</td>
<td>16 - 32</td>
<td>100 - 150</td>
<td></td>
</tr>
<tr>
<td>Lumbar Spine AP</td>
<td>54 - 75</td>
<td>16 - 50</td>
<td>100 - 150</td>
<td></td>
</tr>
</tbody>
</table>
Compton Scattering & Potter-Bucky Diaphragm

Antiscatter grid design

Primary x-rays

Scattered X-rays

Spacing

Lead strips
Mammography

Is a specific type of breast imaging that uses low-dose x-rays (usually around 30 kVp) to detect cancer early in women who have no signs or symptoms of the disease.
Nearly 23,000 breast cancer deaths occurred in Turkey during the period 1987-2008, with the average annual age-standardized mortality rate (ASR) being 11.9 per 100,000 women. In the last five years, significant increases were observed in all age groups, but there was no significant change over the age of 65 (Dogan & Toprak, 2014).
• Screening mammograms can also find microcalcifications (tiny deposits of calcium) that sometimes indicate the presence of breast cancer.

• Screening mammography can help reduce the number of deaths from breast cancer among women ages 40 to 74, especially for those over age 50.

• Mammography is recommended once a year for women aged between 40 and 70 or once in two years for women aged over 70.
Bone Densitometry (DEXA)

- DEXA uses a very small dose of x-rays (varies from 70 to 140 kVp) to produce pictures of the inside of the body (usually the lower spine and hips) to measure bone loss.
- It is commonly used to diagnose osteoporosis and to assess an individual’s risk for developing fractures.
- DEXA is simple, quick and noninvasive. It’s also the most accurate method for diagnosing osteoporosis.
• **Bone density testing is strongly recommended if you:**
  • are a post-menopausal woman and not taking estrogen.
  • have a personal or maternal history of hip fracture or smoking.
  • are a post-menopausal woman who is tall (over 5 feet 7 inches) or thin (less than 125 pounds).
  • are a man with clinical conditions associated with bone loss.
  • use medications that are known to cause bone loss, including corticosteroids such as Prednisone, various anti-seizure medications such as Dilantin and certain barbiturates, or high-dose thyroid replacement drugs.
  • have type 1 (formerly called juvenile or insulin-dependent) diabetes, liver disease, kidney disease or a family history of osteoporosis.
  • have high bone turnover, which shows up in the form of excessive collagen in urine samples.
  • have a thyroid condition, such as hyperthyroidism.
  • have a parathyroid condition, such as hyperparathyroidism.
  • have experienced a fracture after only mild trauma.
  • have had x-ray evidence of vertebral fracture or other signs of osteoporosis.
Bones get its peak mass at 30 years of age…
T-Score

Compared your results to a healthy young adult age 20-35.

Z-Score

Compared your results to a person of the same gender and age as yourself.

Expressed as standard deviations from the mean. 0 means you're equal to the norm. Compare your T-score and Z-score to these numbers to see what they mean.

-1.5 to -2.4 may indicate osteopenia

less than -2.5 may indicate osteoporosis
Fluoroscopy

Calcium tungstate, cadmium sulfide or caesium iodide
Coronary Angiography
Angiography
Computerized Tomography (CT or CAT Scan)
Terms

- **Attenuation** is a reduction of the beam intensity on passing through the body section.

- **Scan** is made up of multiple x-ray attenuation measurements around a section.

- **Slice** is the cross sectional portion of the body.

- **Voxel** is a 3D version of the pixels.

- **CT number** is a number which represents the x-ray attenuation.
What do we scan for in the body?

• CAT scans internal organs, bones, soft tissue, and blood vessels.
• CAT scans provide better clarity than X-rays and reveals more important details than X-rays too.
Benefits of CT Scan

• It is painless, noninvasive, and very accurate.

• CT scans can provide information on bone, soft tissue, and blood vessels all at the same time.

• Fast and simple

• Provides real time imaging

• No radiation remains in patients body after CT scan.
Risks of CT scans

- Slight chance of cancer from excessive exposure to radiation.
- Pregnant women should not use CT scans unless needed to because of the potential risk to the baby.
- Children should not have too many CT scans because they are more sensitive to radiation.
The CAT scan shoot X-ray beams at every angle for 360° around the body.

- X-ray detectors absorbs the penetrated X-rays, measures the X-ray amount, and transmits the data to a computer system.
- Computer system calculates and analyzes data from each detector in each level, and finally reconstructs multiple, two-dimensional, cross-sectional images.

Components of CT System:

- The scanning unit is consists of the gantry with tube and detectors.
- The patient table
- The computer system for image reconstruction
- Monitor and record system
• X-rays density is measured before and after passing through the body section.

• The difference between measurements are recorded as attenuation of section which across the detector.

• The computer system converts digital data which comes from detectors to CT numbers of voxels for each section.
Image Reconstruction-2

The pixel value is colored white, black or gray according to the mean attenuation of the section that it corresponds to the Hounsfield scale.
Imaging Dimensions of CT Scan

- 512 X 512
- 1024 X 1024
- 2048 X 2048
Cardiac CAT Scan (CCAT) in 3D
Ionising radiation - Protection Dose quantities in SI units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Absorbed dose (D_T)</th>
<th>Equivalent dose (H_T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI unit or modifier</td>
<td>gray (Gy)</td>
<td>sievert (Sv)</td>
</tr>
<tr>
<td>Derivation</td>
<td>joule/kg</td>
<td>Dimensionless factor</td>
</tr>
<tr>
<td>Meaning</td>
<td>Energy absorbed by irradiated sample of matter - a physical quantity.</td>
<td>Biological effect of radiation type (R) with weighting factor (W_R). Multiple radiation types require calculation for each, which are then summed.</td>
</tr>
</tbody>
</table>
High risk (WT = 0.12): stomach, colon, lung, red bone marrow
Moderate risk (WT = 0.05): urinary bladder, oesophagus, breast, liver, thyroid
Low risk (WT = 0.01): bone surface, skin
### Table 3. Comparisons of Effective Radiation Dose with Background Radiation Exposure

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Effective Radiation Dose, mSv</th>
<th>Comparable to Natural Background Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abdominal Region:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT, abdomen and pelvis</td>
<td>10</td>
<td>3 y</td>
</tr>
<tr>
<td>CT, body</td>
<td>2-10</td>
<td>8 mo to 3 y</td>
</tr>
<tr>
<td>Intravenous pyelogram</td>
<td>3</td>
<td>1 y</td>
</tr>
<tr>
<td>X-ray lower GI tract</td>
<td>8</td>
<td>3 y</td>
</tr>
<tr>
<td>X-ray upper GI tract</td>
<td>6</td>
<td>2 y</td>
</tr>
<tr>
<td><strong>Bone:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine X-ray</td>
<td>1.5</td>
<td>6 mo</td>
</tr>
<tr>
<td>Extremity X-ray</td>
<td>0.001</td>
<td>Less than 1 d</td>
</tr>
<tr>
<td><strong>Central Nervous System:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT head</td>
<td>2</td>
<td>8 mo</td>
</tr>
<tr>
<td>CT spine</td>
<td>6</td>
<td>2 y</td>
</tr>
<tr>
<td>Myelogram</td>
<td>4</td>
<td>16 mo</td>
</tr>
<tr>
<td><strong>Chest:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT chest</td>
<td>7</td>
<td>2 y</td>
</tr>
<tr>
<td>CT chest-low dose</td>
<td>1.5</td>
<td>6 mo</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>0.1</td>
<td>10 d</td>
</tr>
<tr>
<td><strong>Heart:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac CT for calcium scoring</td>
<td>2</td>
<td>8 mo</td>
</tr>
<tr>
<td><strong>Face and Neck:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CT sinuses</strong></td>
<td>0.6</td>
<td>2 mo</td>
</tr>
<tr>
<td><strong>Women's Imaging:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mammmography</td>
<td>0.7</td>
<td>3 mo</td>
</tr>
</tbody>
</table>

CT = computed tomography; GI = gastrointestinal.

Contrast Media used in CT Scan

• Positive contrast media (have a high atomic number and appears more radiopaque (white) than the surrounding tissue)
  – Iodinized (Intravascular)
    • Iodinic
    • Non-iodinic
  – Barium sulphate (gastro-intestinal)
• Negative contrast media (appears radiolucent (black))
  – Air
  – O₂
  – CO₂
# Commonly used iodinated contrast agents

<table>
<thead>
<tr>
<th>Compound</th>
<th>Name</th>
<th>Type</th>
<th>Iodine content</th>
<th>Osmolality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic</td>
<td><strong>Diatrizoate</strong> (Hypaque 50)</td>
<td>Monomer</td>
<td>300 mg/l/ml</td>
<td>1550</td>
</tr>
<tr>
<td>Ionic</td>
<td><strong>Metrizooate</strong> (Isopaque 370)</td>
<td>Monomer</td>
<td>370 mg/l/ml</td>
<td>2100</td>
</tr>
<tr>
<td>Ionic</td>
<td><strong>Ioxaglate</strong> (Hexabrix)</td>
<td>Dimer</td>
<td>320 mg/l/ml</td>
<td>580</td>
</tr>
<tr>
<td>Compound</td>
<td>Name</td>
<td>Type</td>
<td>Iodine content</td>
<td>Osmolality</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------</td>
<td>---------</td>
<td>----------------</td>
<td>------------</td>
</tr>
<tr>
<td>Non-ionic</td>
<td>lopamidol (Isovue 370)</td>
<td>Monomer</td>
<td>370 mg/l/ml</td>
<td>796</td>
</tr>
<tr>
<td>Non-ionic</td>
<td>Iohexol (Omnipaque 350)</td>
<td>Monomer</td>
<td>350 mg/l/ml</td>
<td>884</td>
</tr>
<tr>
<td>Non-ionic</td>
<td>Ioxilan (Oxilan 350)</td>
<td>Monomer</td>
<td>350 mg/l/ml</td>
<td>695</td>
</tr>
<tr>
<td>Non-ionic</td>
<td>Iopromide (Ultravist 370)</td>
<td>Monomer</td>
<td>370 mg/l/ml</td>
<td>774</td>
</tr>
<tr>
<td>Non-ionic</td>
<td>Iodixanol (Visipaque 320)</td>
<td>Dimer</td>
<td>320 mg/l/ml</td>
<td>290</td>
</tr>
</tbody>
</table>
• Barium enema (large bowel investigation) and DCBE (double contrast barium enema)
• Barium swallow (oesophagael investigation)
• Barium meal (stomach investigation) and double contrast barium meal
• Barium follow through (stomach and small bowel investigation)
• CT pneumocolon / virtual colonoscopy
MRI  
(Mangetic Resonance Imaging)

- X-rays are very effective for showing doctors broken bones, but if they want a look at a patient’s soft tissue, then they’ll likely want a MRI.

- Uses a strong magnetic field and pulses of radio wave energy to make pictures of organs and structures without the use of any damaging radiation.

- Provides delicate detail of brain, spinal cord and vascular anatomy, and has the advantage of being able to visualize anatomy in all three planes: axial, sagittal and coronal.
Body sections are divided by planes

- Sagittal plane (median plane)
- Transverse plane (horizontal plane)
- Coronal plane (frontal plane)
• An MRI of the brain and spinal cord looks for:
  – Blood vessel damage
  – Brain injury
  – Cancer
  – Multiple sclerosis
  – Spinal cord injuries
  – Stroke

• An MRI of the heart and blood vessels seeks for:
  – Blocked blood vessels
  – Damage caused by a heart attack
  – Heart disease
  – Problems with the structure of the heart

• An MRI of the bones and joints searches for:
  – Bone infections
  – Cancer
  – Damage to joints
  – Disc problems in the spine
Can also be done to check the health of these organs:

- Breasts (women)
- Liver
- Kidneys
- Ovaries (women)
- Pancreas
- Prostate (men)
Why hydrogen?

• Oxygen, hydrogen, carbon, nitrogen elements constitute 96% of human body mass.
• Oxygen is 65% of body mass; carbon is 18.5%, nitrogen 3.2%, and hydrogen 9.5%.
• Simplest element with an atomic number of 1 and an atomic weight of 1
• When in ionic state (H+), it is nothing but a proton.
• Proton is not only positively charged, but also has magnetic spin.
• MRI utilizes this magnetic spin property of protons of hydrogen to elicit images!!!
In natural state...

- Protons, like Hydrogen ions in body, are spinning in a random fashion, and cancel all the magnetism.
When the protons are placed in an external magnetic field...

- Protons can be aligned with an external magnetic field.
- The protons may align in two different ways:
  - Parallel
  - Anti-parallel to the applied magnetic field.
In the presence of an external magnetic field...

protons show a certain type of movement called precession.
• It is important to know how fast proton precess.

• The number of times proton precess per second is called **precession frequency** and is calculated using **Larmor Equation**:

\[
\omega = \gamma B_0
\]

where:
- \( \omega \) is the angular precessional frequency of proton
- \( \gamma \) is the gyromagnetic ratio
- \( B_0 \) is the strength of external magnetic field

\( \gamma_{\text{Hydrogen}} = 42.5 \text{ MHz/T} \)
Representation of magnetic force in Z axis, Proton vector as red arrow
• Proton pointing in opposite direction cancels each others magnetic effect in respective direction.
  – For example: 9 proton align up and 5 down, resulting in 4 proton up force (Net magnetization).
• As there are more protons aligned parallel to external magnetic field, there is net magnetic movement aligned with or longitudinal to the external magnetic field.
• In a strong external magnetic field a new magnetic vector is induced in the patient, who becomes magnet himself.

• This new magnetic vector is aligned with the external magnetic field, and thus called **longitudinal magnetization**.
Can we measure the magnetization along an external magnetic field directly?
To measure this magnetization...

- A magnetization **transverse** to the applied external magnetic field is required.

- For this purpose, radiofrequency (RF) pulses are used. Which is **only possible if RF pulses has the same frequency** as the protons precession frequency.
• Some of the protons pick up the energy and move from lower energy level to higher energy level.
• This means that some of the protons that were previously pointing along the magnetic field align against the magnetic field.
• This causes the longitudinal magnetization to decrease.
The RF pulse causes the protons to precess in sync.

They now point in the same direction at the same time, thus their magnetic forces add up in the direction they are pointing.

This results in a magnetic vector pointing to the side to which the protons precess (X-Y plane).

This is called transversal magnetization.
• **Before RF pulse there was only longitudinal magnetization.**

• **After 90° RF pulse there is only transversal magnetization and this spinning around.**

• **With time after the removal of RF pulse, the transversal magnetization decreases and longitudinal magnetization increases in spiral motion (grows back to its original value).**

• **Longitudinal relaxation or spin lattice relaxation.**
T1-weighted contrast

Pooley, R. A. Radiographics 2005;25:1087-1099

Remember FLUID IS BLACK on T1WI.
• With time after the removal of RF pulse, protons lose phase coherence and get out of step.

• Transverse relaxation
T2-weighted contrast

T2WI refers to loss of transverse magnetization.

Practically we need to know FLUID IS BRIGHT on T2WI !!!
<table>
<thead>
<tr>
<th>Tissue</th>
<th>T1 (msec)</th>
<th>T2 (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water/CSF</td>
<td>4000</td>
<td>2000</td>
</tr>
<tr>
<td>Gray matter</td>
<td>900</td>
<td>90</td>
</tr>
<tr>
<td>Muscle</td>
<td>900</td>
<td>50</td>
</tr>
<tr>
<td>Liver</td>
<td>500</td>
<td>40</td>
</tr>
<tr>
<td>Fat</td>
<td>250</td>
<td>70</td>
</tr>
<tr>
<td>Tendon</td>
<td>400</td>
<td>5</td>
</tr>
<tr>
<td>Proteins</td>
<td>250</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>Ice</td>
<td>5000</td>
<td>0.001</td>
</tr>
</tbody>
</table>
What does it look like?
What kind of images?

- T1WI
- T2WI
- PDWI
- DWI
- ADC
- GE
- Perfusion images
- fMRI
- BOLD images
- MRA
- MRV
- Post-Gd images
- Volumetric images
- MR arthrograms
- FLAIR
- STIR
- Etc etc etc
<table>
<thead>
<tr>
<th>T1WI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dark</strong></td>
</tr>
<tr>
<td>- Air, mineral rich tissue (cortical bone, stones), fast-flowing blood</td>
</tr>
<tr>
<td>- Collagenous tissue (ligaments, tendons, scars), high free water tissue (kidneys, gonads, edema, fluids [urine, bile], simple cysts, bladder, gallbladder, spleen, CSF), high bound water tissues (liver, pancreas, adrenals, hyaline cartilage, muscle)</td>
</tr>
<tr>
<td>- Proteinaceous tissue (abscess, complex cysts, synovial fluid)</td>
</tr>
<tr>
<td>- Fat, fatty bone marrow, blood products (methemoglobin [metHb]), slow-flowing blood, radiation change, paramagnetic contrast agents</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bright</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Intermediate</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>T2WI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dark</strong></td>
</tr>
<tr>
<td>- Air, mineral rich tissue (cortical bone, stones), fast-flowing blood</td>
</tr>
<tr>
<td>- Collagenous tissue (ligaments, tendons, scars), bone islands</td>
</tr>
<tr>
<td>- High bound water tissues (liver, pancreas, adrenals, hyaline cartilage, muscle)</td>
</tr>
<tr>
<td>- Fat, fatty bone marrow</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bright</th>
</tr>
</thead>
</table>

| Intermediate  |

<table>
<thead>
<tr>
<th>Low</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bright</th>
</tr>
</thead>
</table>

| **High free water tissue** (kidneys, gonads, edema, fluids [urine, bile], simple cysts, bladder, gallbladder, spleen, CSF), **proteinaceous tissue**, **blood products** (oxyhemoglobin, extracellular metHb) |
Before entering tunnel, there is a checklist!

- No mobiles, no credit cards!
- Known potential safety concerns due to large static magnetic field:
  - Internal cardiac pacemakers
  - Steel cerebral aneurysm clips (ferromagnetic)
  - Small steel slivers embedded in eye
  - Life-support equipment with magnetic steel
  - Cochlear implants
  - Stents anywhere in the body
Is entering the tunnel safe?

• No definite long-term harmful effects.
• Pregnancy is a relative contraindication, as we will never be able to tell with 100% certainty that MRI is 100% safe during pregnancy!
• Babies and children need sedation.
• Some people fear tunnels (claustrophobia).
What happens in MRI?

• Stay still for 15 minutes to 45 minutes!
• Noise, Noise and Noise!
• Alien (radiographers) like voices in between, “another 5 minutes to go”, or, “please stay still”.
• End of the procedure...

When to MRI?
When everything else fails, there is MRI.
Advantages of MRI

1. No ionizing radiation & no short/long-term effects demonstrated
2. Variable thickness, any plane
3. Better contrast resolution & tissue discrimination
4. Various sequences to play with to characterise the abnormal tissue
5. Many details without I.V contrast
Disadvantages of MRI

- Time consuming
- Not easily available (long waiting list)
- No on-call service
- Need to tweak sequences as per the clinical questions; hence cannot be generalised
  - Pain abdomen - ? cause
We presumed MR contrast is safe

- No side effects
- No allergy (as with Iodine)
- Can be used in renal impairment
- Can be used as CT contrast when a patient has impaired renal functions!
<table>
<thead>
<tr>
<th>CT</th>
<th>MR</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Faster</td>
<td>• No ionising radiation</td>
</tr>
<tr>
<td>• Less expensive</td>
<td>• Greater details, hence more sensitive and more specific</td>
</tr>
<tr>
<td>• Less sensitive to patient movements</td>
<td>• Any plane scanning</td>
</tr>
<tr>
<td>• Easier in claustrophobics</td>
<td>• Contrast less allergic</td>
</tr>
<tr>
<td>• Acute haemorrhage</td>
<td>• No beam hardening artefact</td>
</tr>
<tr>
<td>• Calcification</td>
<td></td>
</tr>
<tr>
<td>• Bone details</td>
<td></td>
</tr>
<tr>
<td>• Foreign body</td>
<td></td>
</tr>
</tbody>
</table>
Body sections are divided by planes

- Sagittal plane (median plane)
- Transverse plane (horizontal plane)
- Coronal plane (frontal plane)
### Contrast Medias for MRI

<table>
<thead>
<tr>
<th>Target/Active Moiety</th>
<th>Contrast Agent</th>
<th>Trade Name (Manufacturer)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extracellular space</strong></td>
<td>Gadolinium</td>
<td>Gadoterate dimeglumine (Gd-DTPA)</td>
<td>Magnevist (Berlex, Schering)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gadodiamide</td>
<td>Omniscan (Nycomed Amersham)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gadodaterate dimeglumine</td>
<td>Dotarem (Guerbet)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gadoteridol</td>
<td>ProHance (Schering)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gadobutrol (Gd-DOTA, nonionic)</td>
<td>Gadovist (Schering)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gadobenate dimeglumine</td>
<td>MultiHance (Braeco Diagnostics)</td>
</tr>
<tr>
<td><strong>Intracellular space</strong></td>
<td>Manganese</td>
<td>Mangafodipir trisodium</td>
<td>Teslascan (Nycomed Amersham)</td>
</tr>
<tr>
<td><strong>Intravascular space</strong></td>
<td>Iron (ultrasmall particles)</td>
<td>NC100150 Injection</td>
<td>Clariscan (Nycomed Amersham)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ferumoxtran (AMI-227)</td>
<td>Combidx (Advanced Magnetics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AG-USPIO (BMS-180549)</td>
<td>Sinerem (Guerbet)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SH-US55A</td>
<td>Resovist (Schering)</td>
</tr>
<tr>
<td></td>
<td>Gadolinium in macromolecules</td>
<td>MS-325</td>
<td>AngioMARK (Epix)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gd-DTPA-dextran</td>
<td>(Nycomed Amersham)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gadomer-17</td>
<td>(Schering)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gd-DTPA-polylysine</td>
<td>(Schering)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gd-DTPA-carboxymethylxextran</td>
<td>(Guerbet)</td>
</tr>
</tbody>
</table>

### Table 1. Currently available GBCAs

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Trade Name</th>
<th>Structure</th>
<th>Ionocity</th>
<th>Concentration (M)</th>
<th>Clinical Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gadoterate dimeglumine</td>
<td>Dotarem</td>
<td>Macrocyclic</td>
<td>Ionic</td>
<td>0.5</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Gadobutrol</td>
<td>Gadovist</td>
<td>Macrocyclic</td>
<td>Nonionic</td>
<td>1.0</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Gadoteridol</td>
<td>ProHance</td>
<td>Macrocyclic</td>
<td>Nonionic</td>
<td>0.5</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Gadopentetate dimeglumine</td>
<td>Magnevist</td>
<td>Linear</td>
<td>Ionic</td>
<td>0.5</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Gadoversetamide</td>
<td>OptIMAFL</td>
<td>Linear</td>
<td>Nonionic</td>
<td>0.5</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Gadodiamide</td>
<td>Omniscan</td>
<td>Linear</td>
<td>Nonionic</td>
<td>0.5</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Gadofosveset trisodium</td>
<td>Ablavar</td>
<td>Linear</td>
<td>Ionic</td>
<td>0.25</td>
<td>Blood Pool</td>
</tr>
<tr>
<td>Gadoxetic acid</td>
<td>Eovist</td>
<td>Linear</td>
<td>Ionic</td>
<td>0.25</td>
<td>Liver</td>
</tr>
<tr>
<td>Gadobenate dimeglumine</td>
<td>MultiHance</td>
<td>Linear</td>
<td>Ionic</td>
<td>0.5</td>
<td>Multipurpose</td>
</tr>
<tr>
<td>Generic Name</td>
<td>Trade Name</td>
<td>Injection Route</td>
<td>Lymph Node Specificity</td>
<td>Compound Type</td>
<td>Human Application</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------------------</td>
<td>----------------------------------</td>
<td>------------------------</td>
<td>---------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Gadolinium-based contrast media</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gadopentetate dimeglumine</td>
<td>Magnevist</td>
<td>Interstitial</td>
<td>No Chelate</td>
<td>Liposome</td>
<td>Yes</td>
</tr>
<tr>
<td>Gadoterate meglumine</td>
<td>Dotarem</td>
<td>Interstitial</td>
<td>No Chelate</td>
<td>Liposome</td>
<td>Yes</td>
</tr>
<tr>
<td>Gadodiamide</td>
<td>Omniscan</td>
<td>Interstitial</td>
<td>No Chelate</td>
<td>Liposome</td>
<td>Yes</td>
</tr>
<tr>
<td>Gadobutrol</td>
<td>Gadovist</td>
<td>Interstitial</td>
<td>No Liposome encapsulated</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>Gadopentetate dimeglumine-PE</td>
<td>-</td>
<td>Interstitial</td>
<td>No Liposome encapsulated</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>Gadopentetate dimeglumine-PGM</td>
<td>-</td>
<td>Interstitial/Intravenous</td>
<td>Yes Polymer</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>PAMAM dendrimer based medium</td>
<td>-</td>
<td>Interstitial</td>
<td>No Polymer</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>SHL643A</td>
<td>Gadoemer-17</td>
<td>Interstitial</td>
<td>No Polymer</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>NC22181, NC66386</td>
<td>-</td>
<td>Interstitial</td>
<td>No Polymer</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>Gadomeilol</td>
<td>Vistarem</td>
<td>Interstitial</td>
<td>No Polymer</td>
<td>Liposome</td>
<td>Yes</td>
</tr>
<tr>
<td>Gadofosveset trisodium</td>
<td>Vasovist</td>
<td>Interstitial</td>
<td>Yes Albumin binding</td>
<td>Liposome</td>
<td>Yes</td>
</tr>
<tr>
<td>Gadofluorine 8</td>
<td>-</td>
<td>Interstitial/Intravenous</td>
<td>Yes Micelle</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>Gadofluorine M</td>
<td>-</td>
<td>Interstitial/Intravenous</td>
<td>Yes Micelle</td>
<td>Liposome</td>
<td>No</td>
</tr>
<tr>
<td>Iron oxide-based contrast media</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferumoxide</td>
<td>Feridex/Endorem</td>
<td>Interstitial</td>
<td>No SPIO</td>
<td>SPIO</td>
<td>Yes</td>
</tr>
<tr>
<td>Ferumoxtran-10</td>
<td>Combidex/Sinerem</td>
<td>Interstitial/Intravenous</td>
<td>Yes USPIO</td>
<td>USPIO</td>
<td>Yes</td>
</tr>
<tr>
<td>MION-46, 47</td>
<td>-</td>
<td>Interstitial</td>
<td>Yes USPIO</td>
<td>USPIO</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Gadoxetic acid</th>
<th>Gadobenate dimeglumin</th>
<th>Mangafodipir trisodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviated name</td>
<td>Gd-EOB-DTPA</td>
<td>Gd-BOPTA</td>
<td>Mn-DPDP</td>
</tr>
<tr>
<td>Mechanism</td>
<td>Uptake by hepatocyte</td>
<td>Uptake by hepatocyte</td>
<td>Uptake by hepatocyte</td>
</tr>
<tr>
<td>Transporter</td>
<td>OATP 1B1, 1B3</td>
<td>OATP 1</td>
<td>Vitamin B6 receptor</td>
</tr>
<tr>
<td>Biliary excretion</td>
<td>50% of dose</td>
<td>3-5% of dose</td>
<td>&gt;50% of dose</td>
</tr>
<tr>
<td>Contrast obtained</td>
<td>T1 shortening</td>
<td>T1 shortening</td>
<td>T1 shortening</td>
</tr>
<tr>
<td></td>
<td>White liver/ black lesion</td>
<td>White liver/ black lesion</td>
<td>White liver/ black lesion</td>
</tr>
<tr>
<td>Blood pool agent (Dynamic)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Optimal imaging time</td>
<td>20 minutes after injection</td>
<td>1-4 hours after injection</td>
<td>20 minutes after injection</td>
</tr>
</tbody>
</table>
What is Sound?

- Mechanical and Longitudinal waves wave that can transfer a distance using a media.
- Cannot travel through Vacuum.
Basic Ultrasound Physics

Velocity

Amplitude

Wavelength

Frequency
Velocity

• Speed at which a sound wave travels through a medium (cm/sec)
• Determined by density and stiffness of media
  – Slowest in air/gas
  – Fastest in solids
• Average speed of ultrasound in body is 1540 m/sec.
Frequency

- Number of cycles per second
- Units are Hertz
- **Ultrasound imaging frequency range**
  2-20Mhz
Velocity ($v$), Frequency ($f$), & Wavelength ($\lambda$)

- Given a constant velocity, as frequency increases wavelength decreases

$$v = f \lambda$$
Amplitude

• The strength/intensity of a sound wave at any given time.
• Represented as height of the wave.
• Decreases with increasing depth.
Amplitude

*Defines the Brightness of the image*

*Returning Waves*

The Higher the Amp the brighter the image and the lower the more darker the images
Piezoelectric Effect of Ultrasound

1. Electrical Energy converted to Sound waves

2. The Sound waves are reflected by tissues

3. Reflected Sound waves are converted to electrical signals and later to Image
Pulse-Echo Method

- Ultrasound transducer produces “pulses” of ultrasound waves
- These waves travel within the body and interact with various tissues
- The reflected waves return to the transducer and are processed by the ultrasound machine
- An image which represents these reflections is formed on the monitor
Interactions of Ultrasound with tissue

- Reflection
- Transmission
- Attenuation
- Scattering
Reflection

- Occurs at a boundary between 2 adjacent tissues or media
- The amount of reflection depends on differences in acoustic impedance ($z$) between media
- The ultrasound image is formed from reflected echoes

$$Z = \text{Density} \times \text{Velocity}$$
Scattering

• Redirection of sound in several directions
• Caused by interaction with small reflector or rough surface
• Only portion of sound wave returns to transducer
Transmission

- Not all the sound wave is reflected, some continues deeper into the body
- These waves will reflect from deeper tissue structures
Attenuation

Absorption
The Longer it travels the more less Resolution

High Freq  Low Freq

Reflection
The Signal behind the bone is Ane-echoic

Attenuation Coefficient

• Gas | Fluid – Low AttCo – allow Wave to pass
• Bones – High AttCo – will block
Echogenicity (caused by Reflection)

Ane-Echoic  Hypeo-Echoic  Hyper-Echoic
Acoustic Impedance

• The product of the tissue’s density and the sound velocity within the tissue
• Amplitude of returning echo is proportional to the difference in acoustic impedance between the two tissues
• Velocities:
  – Soft tissues = 1400-1600 m/sec
  – Bone = 4080
  – Air = 330
• Thus, when an ultrasound beam encounters two regions of very different acoustic impedances, the beam is reflected or absorbed
  – Cannot penetrate
  – Example: soft tissue – bone interface
Acoustic Impedance

- Two regions of very different acoustic impedances, the beam is reflected or absorbed.
\[ I = 2\pi f^2 \cdot d \cdot v \cdot A^2 = \frac{p^2}{2 \cdot d \cdot v} \]

A: amplitude of sound waves, P: amplitude of pressure, v: sound speed, d: density, f: frequency

<table>
<thead>
<tr>
<th>Body Tissue</th>
<th>Acoustic Impedance (10^6 Rayls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.0004</td>
</tr>
<tr>
<td>Lung</td>
<td>0.18</td>
</tr>
<tr>
<td>Fat</td>
<td>1.34</td>
</tr>
<tr>
<td>Liver</td>
<td>1.65</td>
</tr>
<tr>
<td>Blood</td>
<td>1.65</td>
</tr>
<tr>
<td>Kidney</td>
<td>1.63</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.71</td>
</tr>
<tr>
<td>Bone</td>
<td>7.8</td>
</tr>
</tbody>
</table>
What determines how far ultrasound waves can travel?

- The FREQUENCY of the transducer
  - The **HIGHER** the frequency, the **LESS** it can penetrate
  - The **LOWER** the frequency, the **DEEPER** it can penetrate
  - Attenuation is directly related to frequency

- The frequency of a transducer is labeled in Megahertz (MHz)
How is an image formed on the monitor?

- The **amplitude** of each reflected wave is represented by a dot.
- The **position** of the dot represents the depth from which the echo is received. 
- The **brightness** of the dot represents the strength of the returning echo.
- These dots are combined to form a complete image.
Position of Reflected Echoes

• How does the system know the depth of the reflection?

• TIMING
  – The system calculates how long it takes for the echo to return to the transducer
  – The velocity in tissue is assumed constant at 1540 m/sec

\[
\text{Velocity} = \frac{\text{Distance} \times \text{Time}}{2}
\]
Reflected Echoes

- **Strong Reflections = White dots**
  - Pericardium, calcified structures, diaphragm
- **Weaker Reflections = Grey dots**
  - Myocardium, valve tissue, vessel walls, liver
- **No Reflections = Black dots**
  - Intra-cardiac cavities, gall bladder
A mode
B mode
Myocardial wall imaging with M mode
The Doppler Effect

- Apparent change in received frequency due to a relative motion between a sound source and sound receiver.

- Sound **TOWARD** receiver = frequency

- Sound **AWAY** from receiver = frequency
Doppler in Ultrasound

• Used to evaluate and quantify blood flow
  – Transducer is the sound source and receiver
  – Flow is in motion relative to the transducer

• Doppler produces an audible signal as well as a graphical representation of flow = Spectral Waveform
Doppler in Ultrasound

- The **Doppler shift** produced by moving blood flow is calculated by the ultrasound system using the following equation:

\[
\text{Doppler frequency (} f_d \text{)} = \frac{2 \cdot f_t \cdot V \cdot \cos \theta}{c}
\]

- \( f_d \) = doppler shift
- \( f_t \) = transmitted beam
- \( c \) = speed of sound in tissue
- \( V \) = velocity of blood flow
- \( \theta \) = angle of incidence between the ultrasound beam and the direction of flow.
Doppler Display

• The spectral waveform represents the audible signal and provides information about:
  – the *direction* of the flow
  – how fast the flow is traveling (*velocity*)
  – the *quality* of the flow (normal vs. abnormal)
Why use Colour?

• To visualise blood flow and differentiate it from surrounding tissue

• The basic questions are
  – Is there flow present?
  – What direction is it traveling?
  – How fast is it traveling?
What is Colour Doppler?

- Utilizes pulse-echo Doppler flow principles to generate a colour image
- This image is superimposed on the 2D image
- The red and blue display provides information regarding DIRECTION and VELOCITY of flow
Direction of Flow with Colour

• Regardless of colour, the top of the bar represents flow coming towards the transducer and the bottom of the bar represents flow away from the transducer.
Comparing medical imaging technologies

<table>
<thead>
<tr>
<th>Type of technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Common uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT scan</td>
<td>Fast, detailed images in three dimensions.</td>
<td>Requires the most radiation. A chest CT is equivalent to about 100 chest X-rays.</td>
<td>Detecting solid tumors and other problems in the abdomen and chest.</td>
</tr>
<tr>
<td>Magnetic resonance imaging (MRI)</td>
<td>Can be more detailed than CT and uses no radiation.</td>
<td>More expensive than CT. Requires patients to remain still for a half hour or more.</td>
<td>Detecting brain abnormalities and diagnosing soft-tissue injuries.</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>Cheaper than CT and uses no radiation.</td>
<td>Lower image quality than CT, with effectiveness largely dependent on technician skill.</td>
<td>Fetal ultrasound and diagnosing appendicitis in children.</td>
</tr>
<tr>
<td>X-ray</td>
<td>Fast and cheap, with a relatively low radiation dose.</td>
<td>Provides only a 2-D image, with far less detail than other methods.</td>
<td>Diagnosing broken bones, pneumonia and intestinal blockages.</td>
</tr>
</tbody>
</table>

Sources: Howstuffworks.com, New England Journal of Medicine, IMV Medical Information Division, Medical Imaging & Technology Alliance, Times reporting