Computed Tomography
Computed Tomography

- Introduction

- *Computed Tomography*, CT for short (also referred to as CAT, for Computed Axial Tomography), utilizes X-ray technology and sophisticated computer software to create images of cross-sectional “slices” through the body.

- CT exams and CAT scanning provide a quick overview of pathologies/anatomy and enable rapid analysis and treatment plans.

- Tomography is a term that refers to the ability to view an anatomic section or slice through the body.

- Anatomic cross sections are most commonly referred to as transverse axial tomography.

- The CT scanner was developed by Godfrey Hounsfield in the late 1960s.

- This x-ray-based system created projection information of x-ray beams passed through the object from many points across the object and from many angles (projections).

- CT produces cross-sectional images and also has the ability to differentiate tissue densities, which creates an improvement in contrast resolution.
Computed Tomography

- Introduction

- The x-ray tube in a CT scanner is designed to produce a fan shaped beam of x-rays that is approximately as wide as your body.

- The x-ray tube on a CT scanner is more heavy duty than tubes used for standard film imaging since the unit rotates and they operate at slightly higher energies.

- Opposite the patient is an array of detectors that measure the intensity of the x-ray beam at points laterally across the patient's body.

- Modern CT scanners use solid state detectors that have very high efficiencies.

- Solid state detectors are made of a variety of materials that create a semiconductor junction similar to a transistor.

- Ultrafast ceramic detectors use rare earth elements such as silicon, germanium, cadmium, yttrium or gadolinium, which create a semiconducting p-n junction.

- Ceramic solid-detectors are very fast, can be extremely stable, and are produced to form an array of very small, efficient detectors that can cover a large area.
Computed Tomography
- *The basics*

- The x-rays are produced in a part of the ring and the ring is able to rotate around the patient.

- The target ring contains an array of detectors and is internally cooled to reduce electronic noise in the detectors and to cool the anode.

- The patient is put into the system using a precise high speed couch.
Computed Tomography
- The basics of image formation

- The x-ray tube and detectors rotate around the patient and the couch moves into the machine.

- This produces a helical sweep pattern around the patient.

- The patient opening is about 70cm in diameter.

- The data acquired by the detectors with each slice is electronically stored and are mathematically manipulated to compute a cross sectional slice of the body.

- Three-dimensional information can be obtained by comparing slices taken at different points along the body.

- Or the computer can create a 3D image by stacking together slices.

- As the detector rotates around many cross-sectional images are taken and after one complete orbit the couch moves forward incrementally.
Computed Tomography
- *The basics of image formation*

- Here the x-ray tube and detector array makes many sweeps past the patient.
- The x-ray tube and detector array is capable of rotating around the axis of the patient.
- Each scan tries to determine the composition of each transverse cross section.
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- The basics of image formation

- As the x-ray tube and detectors swing around an intensity profile mapping is created.

- This could also be written as an attenuation profile which is the incident intensity minus the transmitted intensity.

- This generates a set of $N \times N$ equations that will be solved simultaneously for $\mu(x,y)$ in the image reconstruction system.
Computed Tomography
- The basics of image formation

In a CT scan we measure the intensity of radiation. The attenuation coefficient, $\mu$, is easily determined if you have a homogeneous object. The incident intensity needs to be known and for inhomogeneous objects we need many scans to determine $\mu(x,y)$. 

$$I = I_o e^{-\mu x} \rightarrow \mu_x = \frac{1}{x} \ln \left( \frac{I}{I_o} \right)$$

$$I = I_o e^{-\mu_1 x_1 - \mu_2 x_2 - \mu_3 x_3 \cdots} = I_o e^{-\int_0^d \mu ds} \rightarrow \mu_i = ?$$

$\mu(x,y) = ?$
Computed Tomography  
- The basics of image formation

- **Pixel** – picture element – a 2D square shade of gray.

- **Voxel** – volume element – a 3D volume of gray.

- This is a result of a computer averaging of the attenuation coefficients across a small volume of material. This gives depth information.

- Each voxel is about 1mm on a side and is as thick as 2 – 10mm depending on the depth of the scanning x-ray beam.
Computed Tomography
- The basics of image formation

The detectors see the forward projected x-rays and measure the intensity, given that the x-ray intensity without the body present is known.

The intensity $I_i$ written as sum of attenuation coefficients along a given x-ray path.

This generates a shade of gray and a number associated with this shade.

Then the detector changes angles and the process repeats.

The images are reconstructed by a method called *back projection*, or tracing backwards along the x-rays forward path to reconstruct the image and calculating the absorption due to a localized region.

This a mathematically tedious process but is handled easily with computers.
Computed Tomography
- The basics of image formation

• The top scan we see that there are lighter and darker regions somewhere in it, but we don't know whether the light/dark regions are high, low, or in the middle. In other words, we know where the light region is horizontally but not vertically.

• So, by stretching it out we're kind of saying, "We don't know where the light spot is vertically, so for now give it all vertical values!”

• Now do a vertical scan and now we've taken the light/dark spots whose location we know vertically and "smeared" it out across all horizontal positions.

• You can see where the light areas cross and it gets even more light there and we can start to form an image.

• By "adding" more shadows, medium light lines would eventually disappear, and we’d have a more complete and higher resolution image.
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- Hounsfield Units or CT numbers

• CT numbers (or Hounsfield units) represent the percent difference between the x-ray attenuation coefficient for a voxel and that of water multiplied by a constant.

• Water has a CT number of zero and the numbers can be positive or negative depending on the absorption coefficient.

• This is how we assign a shade of gray, and 1000 is just a scaling factor set by the CT manufacturer.

\[
CT \# = \left( \frac{\mu_{\text{structure}} - \mu_{\text{water}}}{\mu_{\text{water}}} \right) \times 1000
\]
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- Image Quality

Number of Pixels

- In images a and b we have an 80 x 80 images matrix and you can easily see the discrete pixels.

- In images c and d we have a 1024 x 1024 image matrix. Here the individual pixels are not seen and the image quality increases.
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- Image Quality

• *Contrast Resolution* – The ability to differentiate between different tissue densities in the image

• *High Contrast* - Ability to see small objects and details that have high density difference compared with background.

  - These have very high density differences from one another.

  - Ability to see a small, dense lesion in lung tissue and to see objects where bone and soft tissue are adjacent

• *Low Contrast* - Ability to visualize objects that have very little difference in density from one another.

  - Better when there is very low noise and for visualizing soft-tissue lesions within the liver.

  - Low contrast scans can differentiate gray matter from white matter in the brain.
Computed Tomography

- Imaging artifacts

- Artifacts can degrade image quality and affect the perceptibility of detail.
- Includes
  - Streaks – due to patient motion, metal, noise, mechanical failure.
  - Rings and bands – due to bad detector channels.
  - Shading - can occur due to incomplete projections.

Streaks

Rings and bands

Shading
Computed Tomography
- Advantages & Disadvantages

Advantages:
• Desired image detail is obtained
• Fast image rendering
• Filters may sharpen or smooth reconstructed images
• Raw data may be reconstructed post-acquisition with a variety of filters

Disadvantages
• Multiple reconstructions may be required if significant detail is required from areas of the study that contain bone and soft tissue
• Need for quality detectors and computer software
• X-ray exposure