CT PHYSICS
Registry Review

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Slide # 1

X-ray tube/Focal spot
Filter (beam filter)
Pre-patient Collimator (patient protection and slice thickness)
High frequency generator, now shown.
Makes beam more homogeneous.
Generates the radiation.

Slide # 2

Pat

Pre-detector Collimator
(post patient collimator and re-defines slice thickness)
Detector
Detects attenuated radiation.
Converts analog signal to digital.

Slide # 3

• X-rays are produced, emitted, filtered, and collimated
• X-ray penetration occurs - data collection schemes or beam geometries
  Transmission measurements from the patient are obtained and converted to digital signals (involves detectors detector electronics)

Data Acquisition

Slide # 4

Slide # 5

Slide # 6
Slide # 7

Volume (Helical - Spiral) CT
Advantages of Multi-Slice
• Speed of coverage
• Slice reconstruction
• Improved cooperation
• Improved contrast enhancement
• Thinner slices
Resulting in...
“improved”
- MPR
- VR
data sets

Slide # 8

Single-Slice & Multi-slice
Volume CT

MPR = Multi-Planar Reformats
VR = volume rendered

Slide # 9

Multi-slice CT, Detector Evolution

Single               Dual              Quad

Multi-slice systems = Multi – channel systems
Whereby, 64 channels produce 64 slices per rotation!

Then,

8, 16, 32, 40, 64 slice systems

Scan Data to Image Data

• Path x-ray beam travels from the tube to the detector = RAY
• Detector reads each ray & measures beam attenuation
• Measurement = Ray Sum

Ray (Projection)

Each ray produces a single measurement of the x-ray attenuation along a path between the source and a detector
Complete set of Ray Sums = View
“Like looking at an object from a particular angle.” Many views are needed to create an image.

Obtained from a set of measurements across the object at one angular position. Views are made up of rays.

**Image Reconstruction**
- CT system accounts for the attenuation properties of each ray and correlates them with the position of the ray.
- An ATTENUATION PROFILE is created.
- Resulting shadow (analogy).

**Image Reconstruction**
- Attenuation Profile is obtained for each view.
- All profiles are projected back into a matrix.
- A big rectangle divided into smaller squares called pixels.

**Matrix**

**Reconstruction**
- Describes method for converting Scan Data to Image Data.
- x-ray beam-absorbed x-ray info to analog signal converted to digital signal placed on a matrix in the computer-matrix on TV.
**Back Projection Method**

- Oldest means of reconstruction
- An image is created by reflecting attenuation profiles in the same direction they were obtained
- Produces streak artifacts
- 1st attempt at CT imaging

**Back Projection**

- $B_P_1$
- $P_1$
- $P_2$
- $P_3$
- $B_P_2$
- $B_P_3$
- $B_P_4$

**Back Projection Method**

- Artifacts are not in the scanned image
- Appear due to the reconstruction process (Back Projecting)
- “placing” information on a matrix

**Reconstruction**

**Scanning**

- Movement of the Tube and Detectors with X-ray transmission
- Tube and detectors are Co-linear (in alignment) and at the same speed

**Back Projection**

In CT, the x-ray tube rotates around the “phantom.” In this case, the x-ray beam is attenuated by the water in the phantom, and therefore “projects” a “shadow” within the detectors.
**Back Projection - Reconstruction**

- **Projection #1**
  - If we draw lines from the actual phantom to the projections,
  - Where the lines intersect should be a cup of water.

- **Projection #2**
  - If, however, a third projection is acquired,
  - Continue to connect "lines" from the actual phantom to the projection.
  - Now, the locations where the lines intersect, represent the actual cups of water.

- **Projection #3**
  - If, however, a third projection is acquired,
  - Continue to connect "lines" from the actual phantom to the projection.
  - Now, the locations where the lines intersect, represent the actual cups of water.

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**Image Reconstruction**

- Artifacts minimized by changing the shapes of the attenuation profiles before back projection to a matrix.
- Reconstruction “filter” is applied to the Raw Data or Scan data
- 1st type of “recon” = Filtered back Projection

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**Filtered Back Projection**

- Reconstruction filter
- Kernel, Algorithm, Math Filter
- Process of applying Mathematical filtration to the raw data = Convolution

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**Image Reconstruction**

- Mathematical filtration
- Kernel
- Algorithm

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**Algorithms**

- Mathematical method for solving a problem that involves repetition of an operation.
Types of Reconstruction

- 2nd type avail today
- Fourier Reconstruction
- any function or variation of a quantity in time or space can be expressed as a sum of sine and cosine waves
- frequencies instead of profiles

Reconstruction

- involves millions of data points
- ARRAY PROCESSOR
- dedicated to rapid calculations involved in reconstruction
- large numbers of calculations needed to convert data to image

Mathematical Filters Algorithms

- High Pass (Sharp, Bone)
- primarily used in high contrast regions (temporal bones)
- areas of sudden "large" drops in CT numbers (extreme tissue density)

High Pass Algorithms

- Optimizes spatial resolution, Edge enhancement.
- Decreases blurring of edges
- Bone, sharp, detail algorithm

Low Pass filters / algorithms

- Soft tissue algorithms
- standard, smooth
- area of gradual tissue change
- optimizes contrast resolution
- smoothness of larger objects

Raw Data

- Includes all measurements obtained from detector array
- Within the SFOV specialized reconstruction
- attenuation information
Image Data
- Data displayed on the monitor
- Operator chooses to view
- Manipulated using window level and window width

Image Display
MATRIX
- CT Image is represented by a matrix of numbers
- Rows and Columns of pixels
- 512 x 512 Matrix = 262,144 Pixels
- 256, 340, 512, 768, 1024
- 80, 160, 180 not used today

THE IMAGE IS MADE OF BLOCKS

MATRIX
- The bigger the matrix, the smaller the pixel size
- Reduces partial volume averaging
- Effects image quality
- Effects reconstruction time

Volume Element
- Voxel
- Three dimensional representation of tissue
- Pixel Area x Section Thickness
- Voxel Depth determined by ST
### Picture Element
- Pixel
- Two dimensional representation of the tissue volume
- Pixel Size = FOV divided by Matrix size

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- Within the SFOV
  - specialized reconstruction
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### Imaging Matrix
- Digital images are created with a matrix
- Smallest unit of the digital image is a pixel
  - 6 x 6
  - 3 x 3
**Matrix & Pixel Size**
- Size effects resolution
- The bigger the matrix, the better the resolution.
- The bigger the matrix, the more pixels you have, smaller too.
- The more “little blocks” you have to make the image, the more detail...

**Calculating Pixel & Voxel Size**
- Isotropic voxel
- Pixel size
- Area of the Pixel
- Voxel Volume

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Voxel Volume = Pixel Size x Slice Thickness
Pixels & Voxels
- In CT slices are acquired
- The voxel is a 3D volume element
- The face of the voxel is the pixel

FOV, Matrix, Thickness & Voxels
- The size of the area imaged in CT is the field of view (FOV)
- The number of pixels (rows x columns) is the matrix
- The depth is the slice thickness

How Much “Meat” is in the Box? vs. Signal?
- The larger the pixel (voxel)
- The more “meat” tissues / protons
- The larger the CT signal
- But… since signals get averaged together
- The lower the spatial resolution

How Much “Meat” is in the Box? vs. Resolution?
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Partial Volume Averaging
- Signals signals get averaged together in large voxels
- The lower the spatial resolution

Calculating Pixel Size
- to calculate the pixel size
- to calculate the voxel size
Partial Volume Averaging Artifact

- PVA = The inability to distinguish separate structures within a single pixel or voxel …
- To reduce PVA (Partial Volume Averaging)
  - Reduce FOV
  - Slice Thickness
  - Increase Matrix

Matrix and Spatial Resolution

Pixel size = FOV / Matrix

Scan vs. Reconstructed FOV

- Large acquired FOV
- Large reconstructed FOV
- Small reconstructed FOV
Scan FOV

Large Scan FOV

Small Reconstructed FOV

Magnification vs. Reconstruction

Targeting Vs Zooming

CT Numbers

The reconstruction process assigns an integer value to each voxel that is linearly related to the attenuation coefficient (μ) of the tissue(s) within a voxel.
Key Terms - Linear Attenuation Coefficient

**Linear Attenuation Coefficient** - a quantitative measurement of attenuation per cm of an absorber (i.e. bone or soft tissue) Represented by the greek letter μ

In CT, μ needs to be calculated for each voxel in the patient in order to obtain a CT number (Hounsfield Unit) which is the ultimate goal of reconstruction. μ = (1/x) * ln(I0/I)

(Algebraic manipulation of the original formula)

CT NUMBERS

- unit for attenuation values within a pixel (brightness)
- brightness value is determined by the detector signal
- linear attenuation coefficient
- absorption measurement
- Hounsfield Unit

CT Numbers

- HU values generated by a CT scanner are only valid for the effective kVp used to generated the image
The voxel values are normalized to the $\mu$ of water to obtain CT numbers.

A 1% difference in $\mu = 10$ HU

Hounsfield Units (HU)

CT number = $\frac{\mu_{\text{material}} - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1000$

CT numbers are called HOUNSFIELD UNITS (HU)

Comparison of linear attenuation coefficient of tissue to linear attenuation coefficient of water

$\mu_{\text{water}} - \mu_{\text{tissue}}$

$\mu_{\text{water}}$

multiplied by 1000

Greek letter mu

linear attenuation coefficient

CT numbers

Hounsfield Unit

Absorption measurement

Region Of Interest … ROI

Mean 54
STD 2.4

attenuation > water = +
attenuation of water = 0
attenuation < water = -

A 1% difference in $\mu = 10$ HU

Since CT scanners operate at high x-ray energies, Compton interaction is predominate. The probability of a Compton interaction depends primarily on the density of the tissue.

CT numbers are closely related to tissue density
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CT numbers are closely related to tissue density

FYI...“A Compton interaction is one in which only a portion of the energy is absorbed and a photon is produced with reduced energy.”

**CT Numbers**

- Less than water = Negative Number
- Greater than water = Positive Number
- 0 = water, 1000 = bone
- -100 = fat, -1000 = air

**CT Numbers**

Normal Range

- Air
- Water
- Bone
- -1000
- 0
- +1000

**The Hounsfield Scale**

- Calcified Bone
- Congealed Blood
- Gray Matter
- White Matter
- Blood
- Water
- Fat
- Air

**Extended Range**

- Air
- Water
- Bone
- -1000
- 0
- +3000

11 bit (-1000 to +2000)
12 bit (-1000 to +3000)

**Window Width / Level**

possible range of pixel values

width

level
Introduction to “Windowing”

**WW (Window Width)** = Range of Gray Shades that the user chooses to display for a given clinical situation

**WL (Window Level)** = Center of Gray Shades that the user chooses to display for a given clinical situation

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**Narrow Window Width**

Narrow Window Width – only two shades of gray (black & white)

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**Wide Window Width**

Wide Window Width – Many shades of gray

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Window Width and Level

Possible range of pixel values

-1000 -1143 0 +1875 +3000

-1000 0 +3000

Wide Window Width

Grayscale with Narrow Window Width

Grayscale with Wide Window Width

Low level (darker) settings on an Axial CT image of the chest

High level settings (whiter) on an Axial CT image of the chest
You do not have to have raw data in order to alter window width / level.
CT Numbers

• Linear attenuation coefficients are converted to CT Numbers so conversion to a visual grayscale is possible

Signal Numbers

➢ The numbers contained in each matrix pixel are assigned a shade of gray
➢ Giving each pixel a number allows for visualization of an image on a TV screen

Windowing

• Each Pixel is represented by 4096 gray levels
• Larger than display range of monitors or film

Numbers and Shades

➢ The number or shade of gray that is assigned to each pixel
➢ Is determined and proportional to the electrical signal from the detector

Basics of Digital Images

Image Matrix
Signals  Pixel Brightness

WINDOWING

- Computer can “see” more gray shades than the human eye
- Mathematically brings density or contrast differences into the visual range.
- WINDOW WIDTH (WW)
- WINDOW LEVEL (WL)

Window Width (WW)

- Range of CT numbers for the gray scale
- Range of gray shades used to display the image
- Defines contrast of the image

Window Level (WL)

- Center of the gray Scale
- Density of the image

Wide Window Widths

- Tissues of greatly differing attenuation
- Lung air spaces and vessels
- Bone
**Narrow Window Widths**
- Display soft tissues
- within structures containing different tissues with similar densities
- Brain & Liver

**Window Levels**
- Select Near average attenuations of tissues of interest
- Not too high, obscure pathology (brain bleed)

**WINDOW LEVEL (WL)**
- Center of the Gray Scale
- Center of the Range of gray shades used for viewing an image.
- Density of the image
- WL increases, Density increases.