CT Physics in PET/CT

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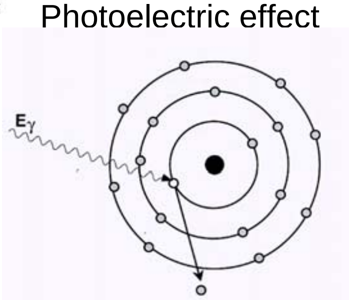
Outline

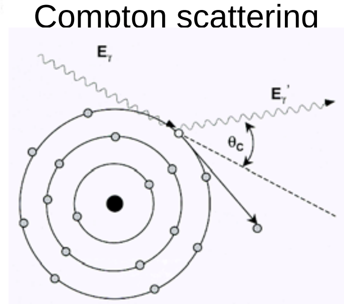
- Review of Photon Interactions
- Principles of multi-slice helical CT
- CT acquisition parameters and protocols
- Multimodality image registration and fusion
- Motivations for combined PET/CT
- PET acquisition protocols
- Dosimetry considerations
- CT-based attenuation correction
- Attenuation correction artifacts

Photoelectric effect



- All of photon energy is transferred to inner shell electron causing ionization

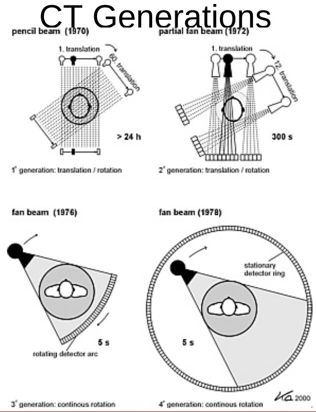
Compton scattering



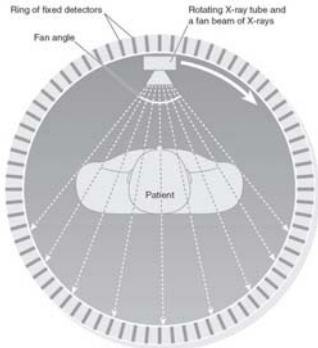
- Part of photon energy is transferred to outer shell electron
- Photon is deflected and electron recoils

Principles of Multi-slice Helical CT

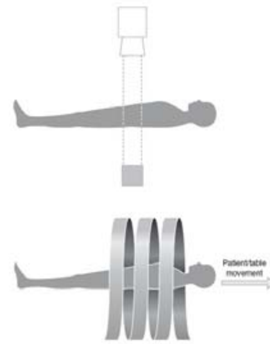
CT Generations



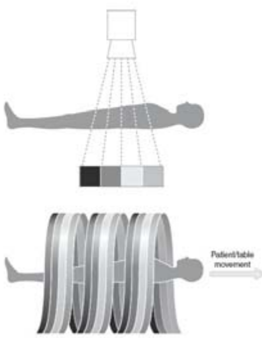
4th Generation CT scanner



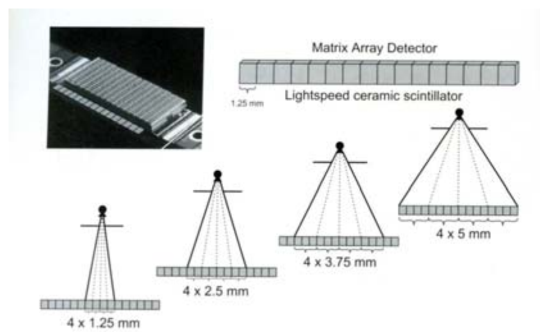
Single-slice Helical CT



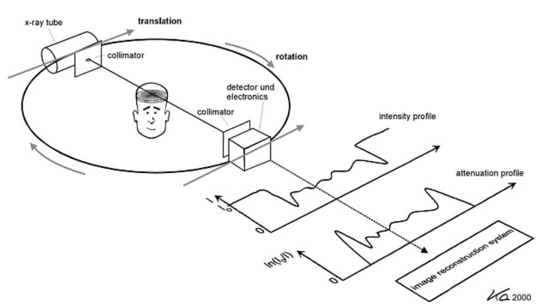
Multi-slice Helical CT



16-slice Detector



CT measurement



CT Units: Hounsfield Scale

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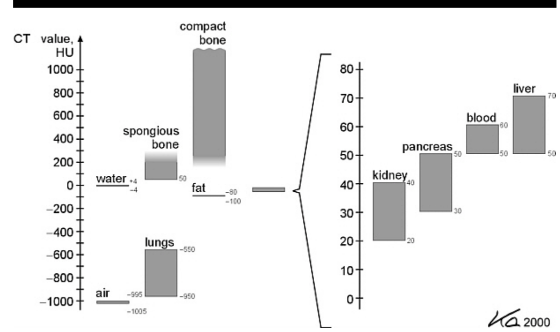


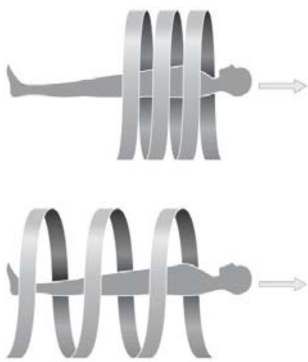
CT acquisition parameters

- Rotation speed (0.33-1 sec)
  - Affects temporal resolution, scan time, dose
- Tube current (20-400 mA)
  - Proportional to number of x-rays and dose
- Tube voltage (80-140 kVp)
  - Determines X-ray energy
- Table feed (10-100 mm/rot)
  - Proportional to scan time
- Collimation
  - Affects axial resolution and scan time
- Scan length

CT calculated parameters

- Exposure (mAs) = current x rotation speed
- Total slice collimation = number of detectors x slice width (e.g. 16 x 1.25 = 20)
- Pitch = table feed / total slice collimation
- Effective mAs = mAs / pitch

Pitch



Options with Helical CT Acquisition

- Intravenous and/or oral contrast media
- Breathing protocols (breath hold)
- Arms up for diagnostic quality thorax/abdomen
- Arms down for head/neck
- Dynamic and gated acquisition
- Dual Energy

CT technique options in PET/CT

- Low dose (e.g. 0.4 rem): for attenuation correction of PET images
- Moderate dose (e.g. 0.85 rem): attenuation correction, and anatomical localization of focal FDG uptake
- Diagnostic dose (e.g. 1.7 rem): attenuation correction, anatomical localization, and diagnostic interpretation of CT images

Multimodality imaging

Definitions

- Image registration: Process of matching the spatial coordinates between two or more images
- Image fusion: Process of combining multiple images of a scene to obtain a single composite image
- Digital compositing: Method of combining two or more images in a way that approximates the inter-visibility of the scenes that gave rise to those images

Software-based image registration

- Rigid versus non-rigid
- Manual
- Landmark-based
- Surface matching
- Image intensity-based
  - Ratio
  - Cross-correlation
  - Mutual Information

Image registration: un-registered images

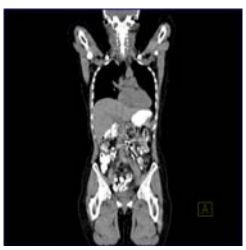
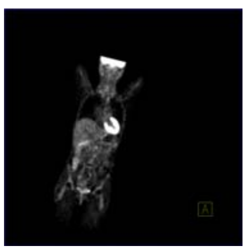



Image registration: the problem

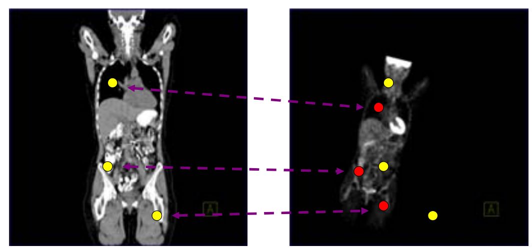


Image registration: Zoom

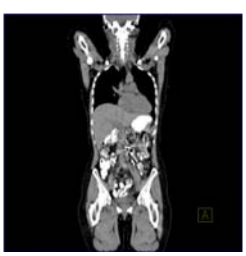
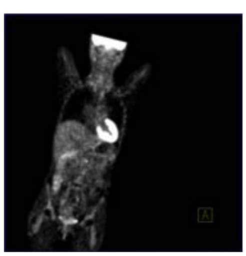



Image registration: Rotation

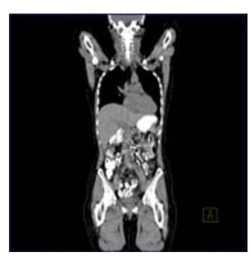
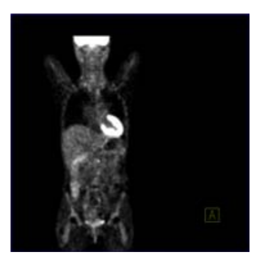
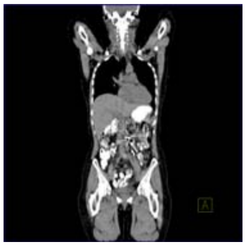



Image registration: Translation



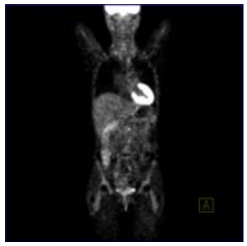
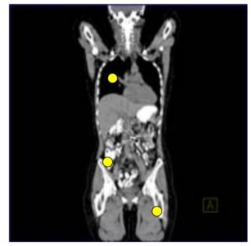
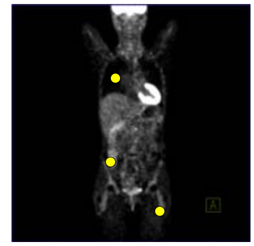


Image registration: Complete

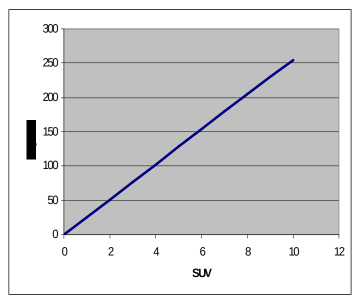


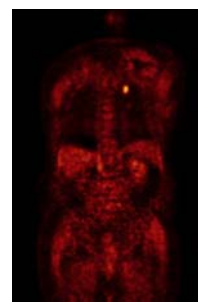


2D display methods

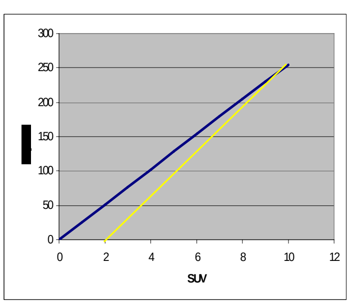
- 2 dimensional reconstructed planes: transaxial, sagittal, coronal, oblique
- Gray scale versus color tables
- Windowing (contrast enhancement)
  - PET: linear scale specified by min and max
  - CT: linear scale specified by center and width

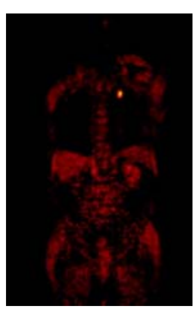
PET windowing: Bottom = 0, Top = 10



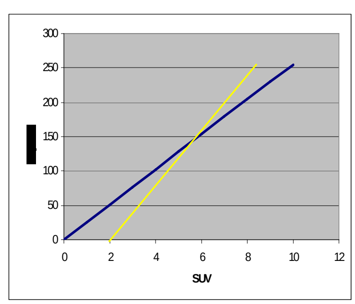


PET windowing: Bottom = 2, Top = 10

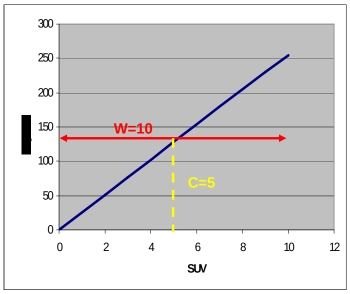


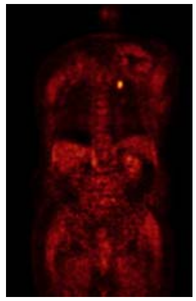


PET windowing: Bottom = 2, Top = 8



CT windowing notation: Center = 5, Width = 10

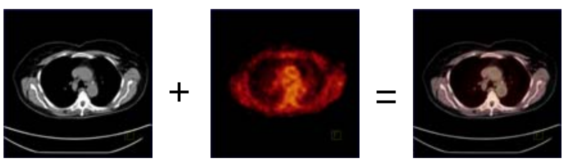




CT Windowing

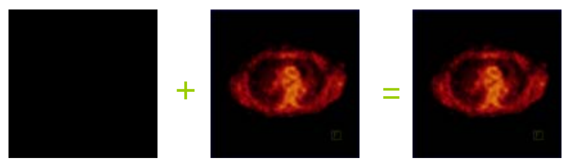
Lung Window	Soft Tissue Window	Bone Window
Center: -600 Width: 1700	Center: 400 Width: 40	Center: 1000 Width: 2500

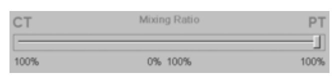
PET/CT Fusion Display



1. Select color tables for CT and PET images
2. Select window settings for CT and PET images
3. Select opacity (alpha channel) and display super-imposed CT and PET images

PET/CT Fusion

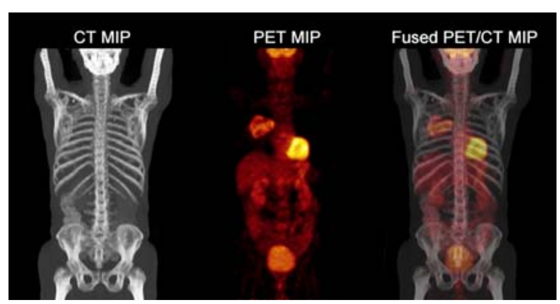




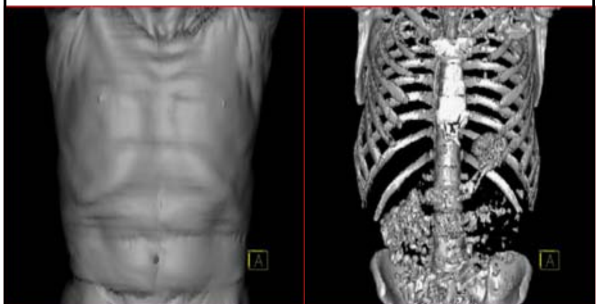
3D display methods

- Maximum intensity projection: Displays the maximum intensity along each projection
- Shaded surface: Displays lighted surface of segmented voxels
- Volume rendering: Displays multiple rendered objects with various transparencies and color tables

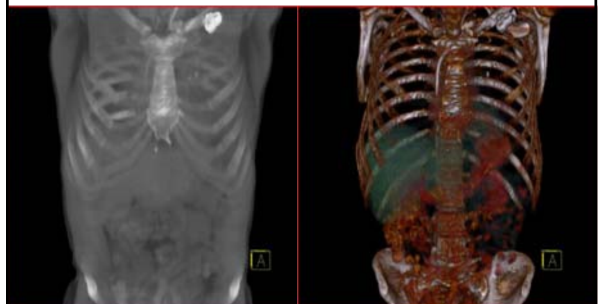
Maximum Intensity Projection (MIP)



3D Display:
Shaded Surface (SSD)



3D Display:
Volume Rendering Technique (VRT)



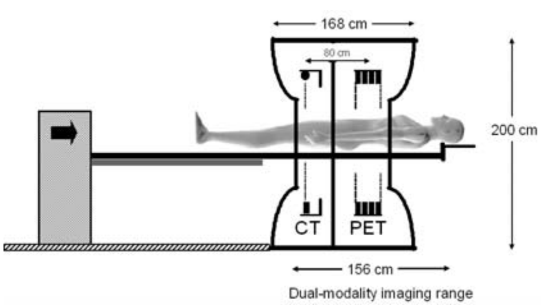
Motivations for dual-modality scanners

- Eliminates differences in patient positioning, scanner beds, timing
- Intrinsic co-registration between anatomic and functional modalities
- Single scanning session for both acquisitions
- Shorter scanning time by eliminating transmission scanning

Multimodality Scanners

- SPECT/CT
  - Prototype (Bruce Hasegawa, UCSF)
  - Commercial Systems
- PET/SPECT
- PET/CT
  - Prototype (David Townsend, UPMC)
  - Commercial Systems
- microPET/SPECT/CT
- MR/PET

Commercial PET/CT Design



Current PET/CT Scanners

biograph classic

Gemini GXL

SceptreP3

Discovery LS

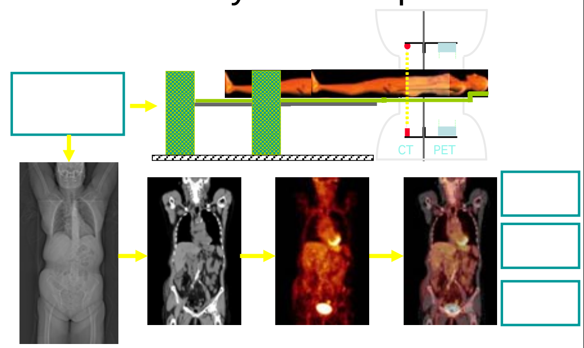
Discovery ST 16, 64

biograph 6, 16, 64

PET Acquisition modes

- PET transmission
- PET emission
  - Static
  - Wholebody (step and shoot or continuous)
  - List mode
  - Dynamic
  - Gated (cardiac and/or respiratory)
- 2D vs 3D

Whole-body PET/CT protocol



Factors affecting radiation dose due to PET emission

- Injected activity
- Isotope characteristics
- Radiotracer biodistribution and clearance kinetics
- Patient size
- Hydration/urinary clearance

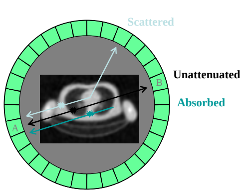
FDG PET/CT radiation dose: DFCI whole-body protocol

- CT exam is 0.85 rem
  - 2.83 x average annual background in U.S.
  - 17% of annual occupational limit
- 20 mCi FDG PET
  - 4.67 x average annual background in U.S.
  - 30% of annual occupational limit
- 20 mCi FDG PET/CT
  - 7.5 x average annual background in U.S.
  - 45% of annual occupational limit

What is "attenuation"?

Loss of radiation from a beam due to:

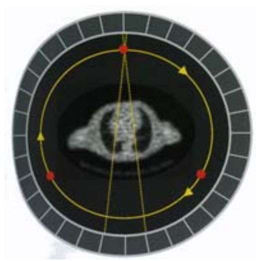
- Scatter (Compton or Rayleigh interactions)
- Absorption (photoelectric interaction)



Corrections: Attenuation

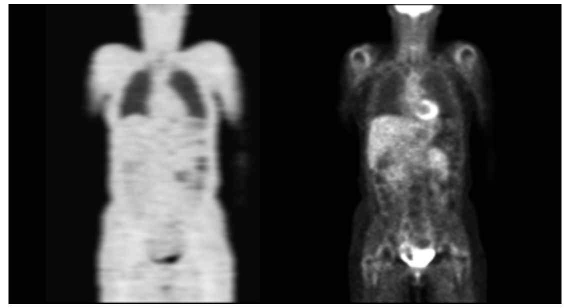
- Calculation
- Cylindrical source
- Ring sources
- Rotating rod or point sources
- Rotating singles point sources
- Segmentation
- CT-based correction factors

PET transmission-based attenuation correction



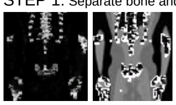
PET transmission-based attenuation correction

PET Transmission PET Emission

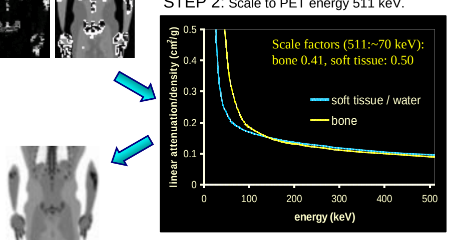


CT-based attenuation correction: threshold method

STEP 1: Separate bone and soft tissue using threshold of 300 H.U.



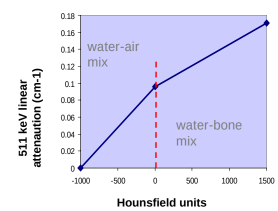
STEP 2: Scale to PET energy 511 keV.



STEP 3: Forward project to obtain attenuation correction factors.

Kinahan PE, Townsend DW, Beyer T, et al. *Med Phys*. 1998; 25(10): 2046-2053.

CT-based attenuation correction: mixing model



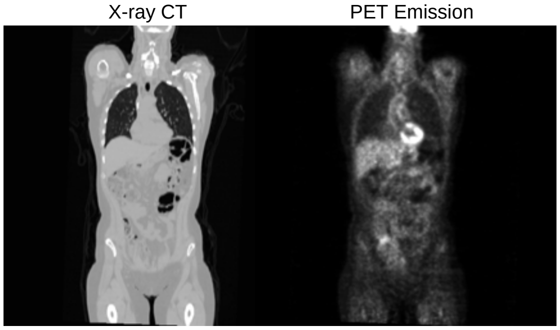
Assume Hounsfield unit is determined by a mixture of two components with known densities and scale factors.

Break point H.U. < 0 water-air mixture

Break point H.U. > 0 water-dense bone mixture

X-Ray CT-based attenuation correction

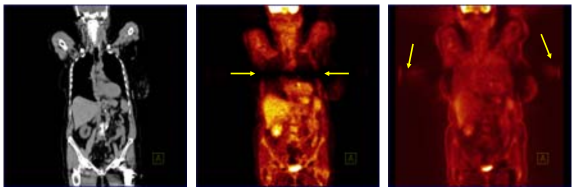
X-ray CT PET Emission



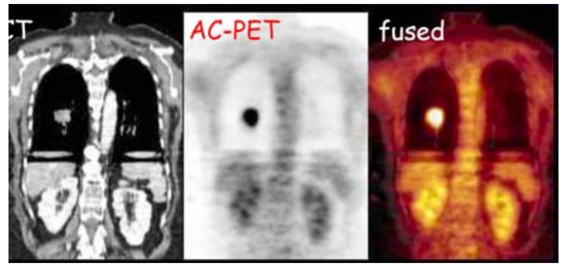
Attenuation correction artifacts

CT-Based attenuation artifacts: (voluntary) patient movement

CT PET Uncorrected PET

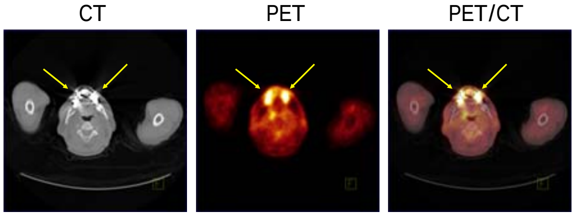


CT-Based attenuation artifacts: respiratory motion



CT-based attenuation artifacts: dental work

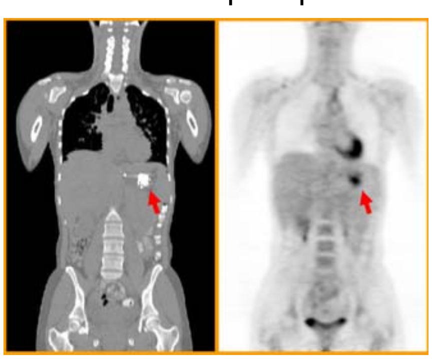
CT PET PET/CT



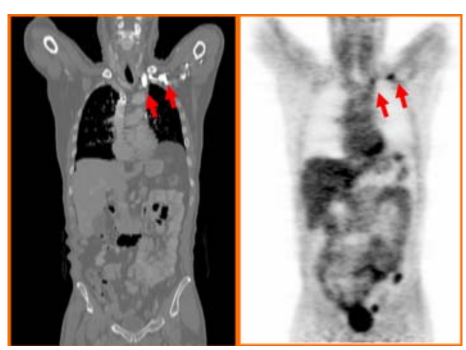
CT-based attenuation artifacts: chemotherapy port

CT PET PET/CT

CT-based attenuation artifacts: oral contrast precipitation



CT-based attenuation artifacts: iv contrast



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Benefits of PET/CT

- Improved anatomical localization of uptake
  - Reduce false positives to physiologic uptake
  - Decrease false negatives with moderate uptake
- Changes in patient management
- 2 procedures in one scanning session
- Faster scanning with CT-based attenuation correction
- Ideal for image-guide therapies requiring anatomy

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References

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