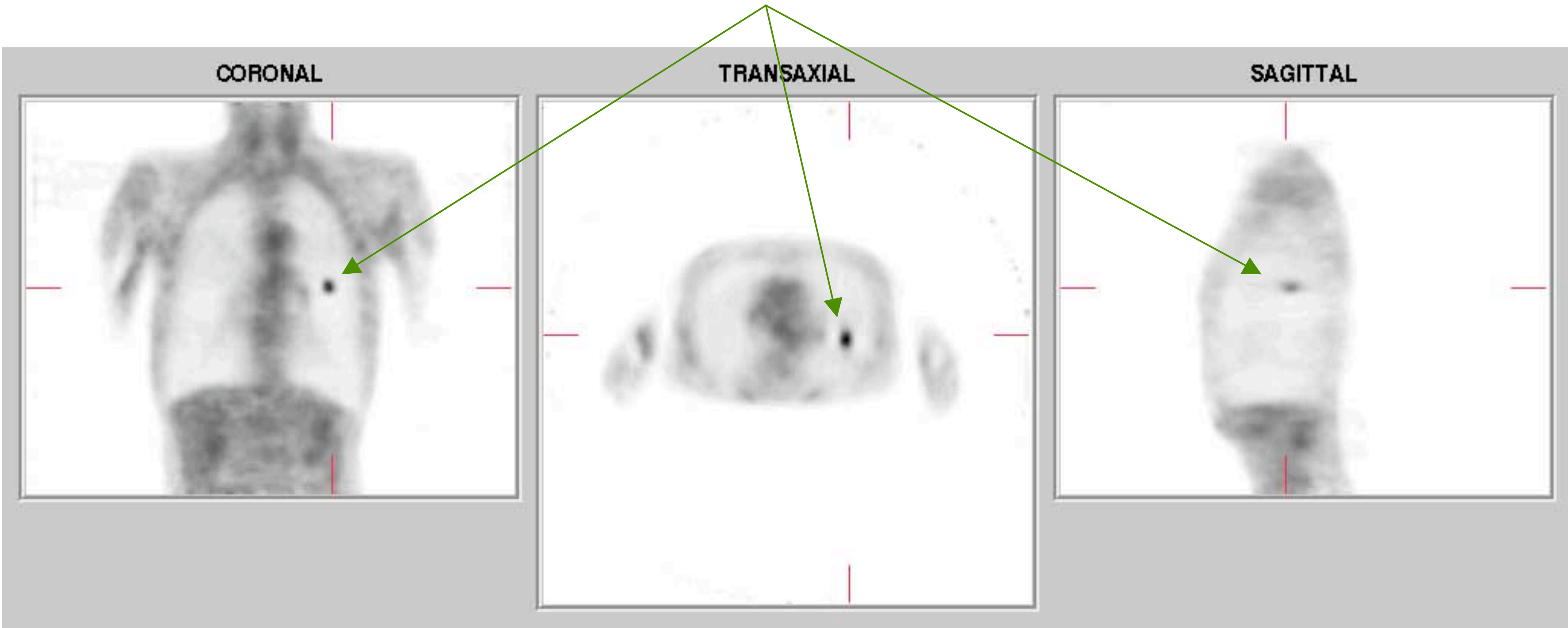
Typical PET Image

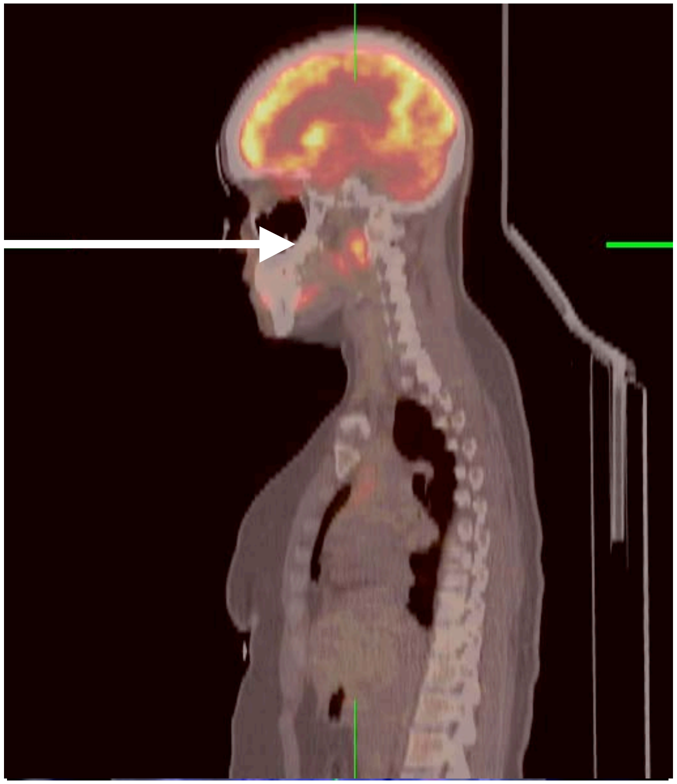
Elevated uptake of FDG (related to metabolism)



Lung cancer example: But where exactly is it located?

PET/CT Oncology Imaging

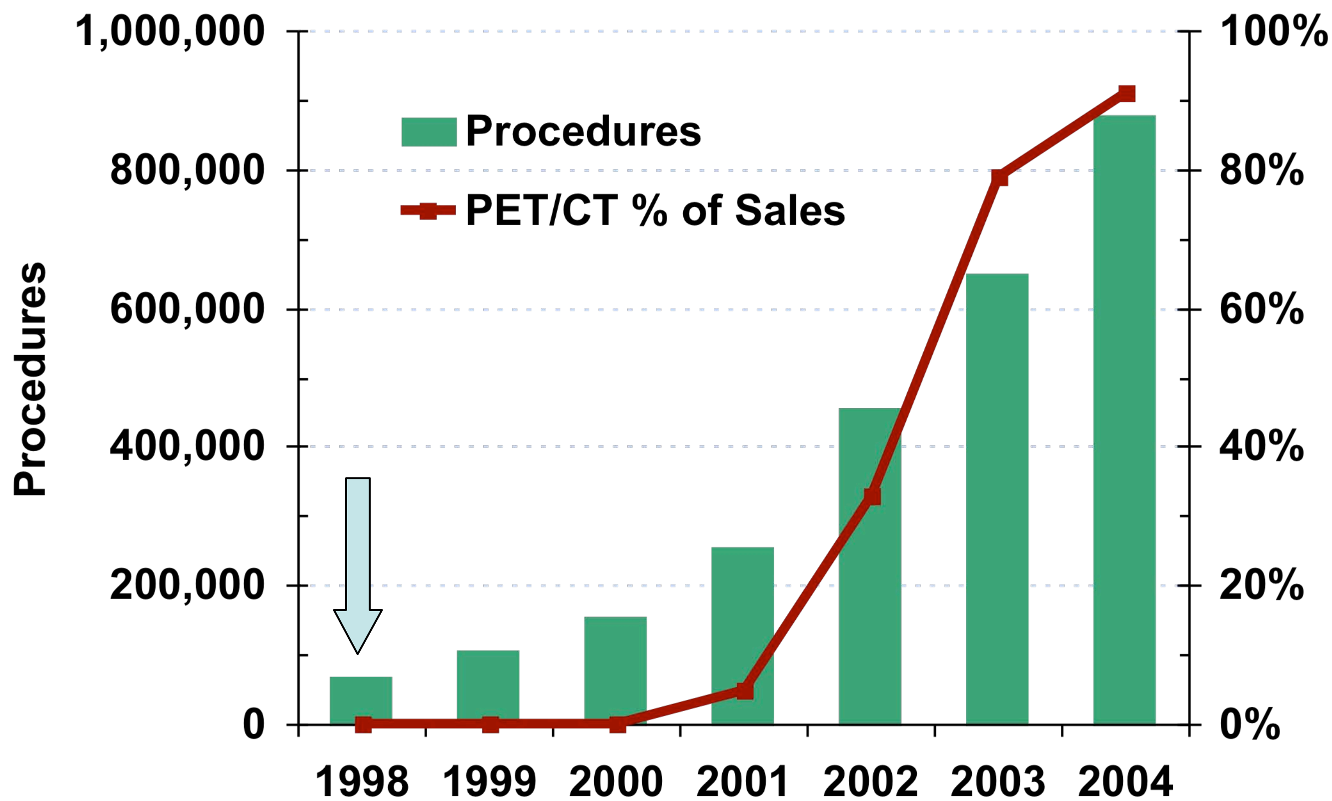
- "Anatometabolic" fusion images are useful in the management of patients with cancer (Wahl, JNM, 1993)
- PET/CT scanners are used to provide accurately aligned functional and anatomical information (Beyer, JNM 2000)



recurrent thyroid cancer localized to the right retropharyngeal space.

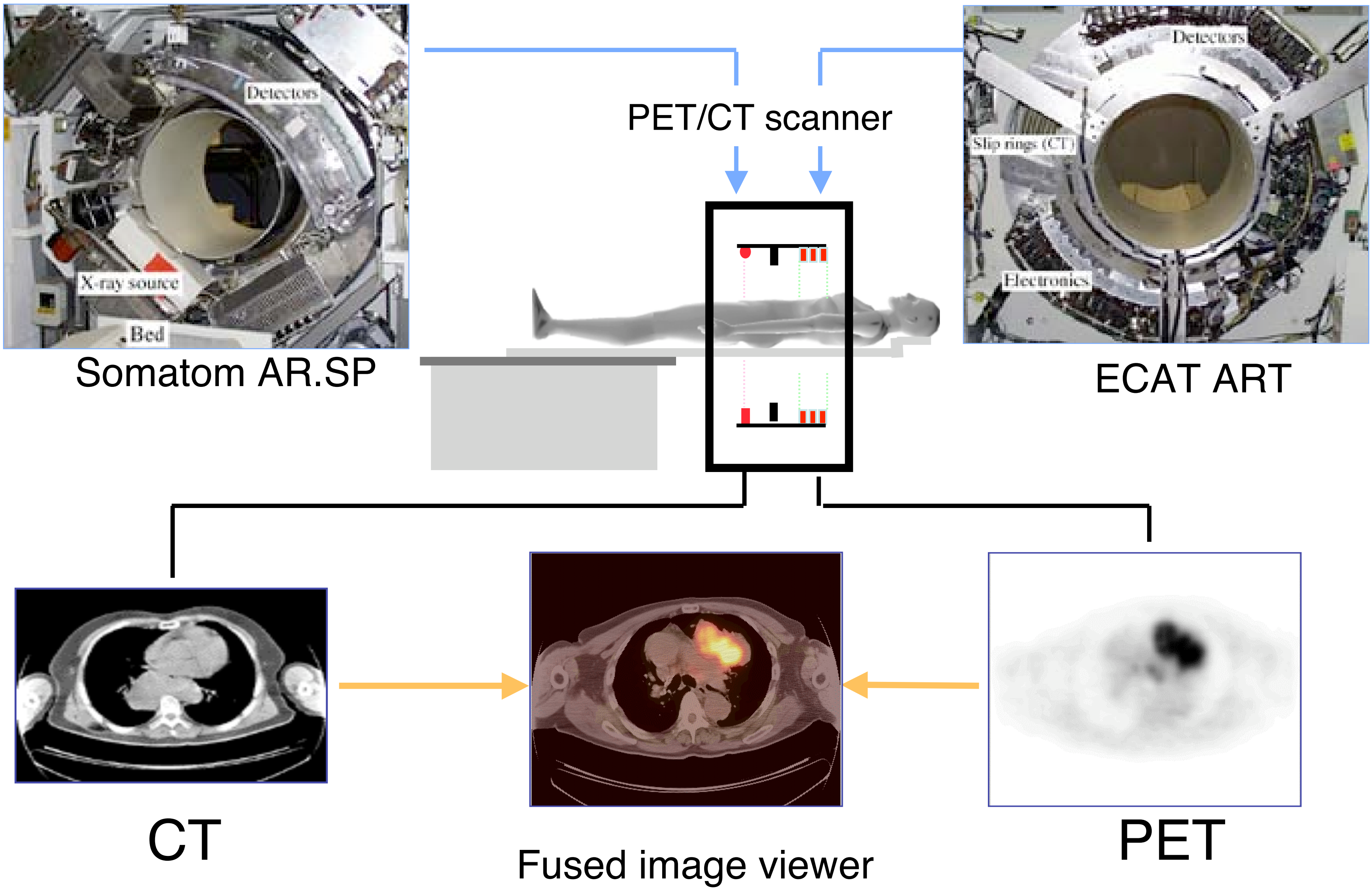
- A *secondary* synergy of PET/CT scanners is to use the CT image for attenuation correction of the PET emission data (Kinahan, Med Phys 1998)
  - low-noise attenuation correction factors
  - no transmission scan -shorter total scan time
  - no bias from emission contamination of post-injection transmission scans

Growth of PET procedures in the U.S.



- 1998: Reimbursement for FDG-PET. 1st PET/CT prototype built
- The number of procedures has been doubling every 19 months
- Over 90% are FDG cancer imaging for diagnosis and staging
- Recent figures indicate 40% annual growth in number of procedures

1998: Pittsburgh PET/CT prototype

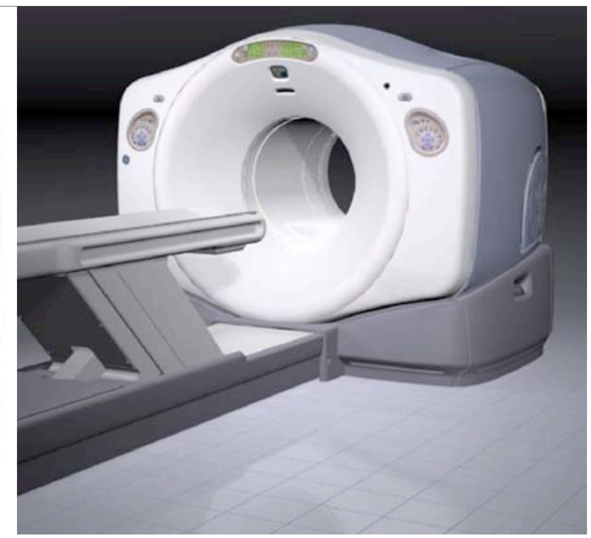


2006: Six Commercial PET/CT Scanners

- All rely on CT-based attenuation correction

Siemens
-Biograph Pico and Hires
(LSO)

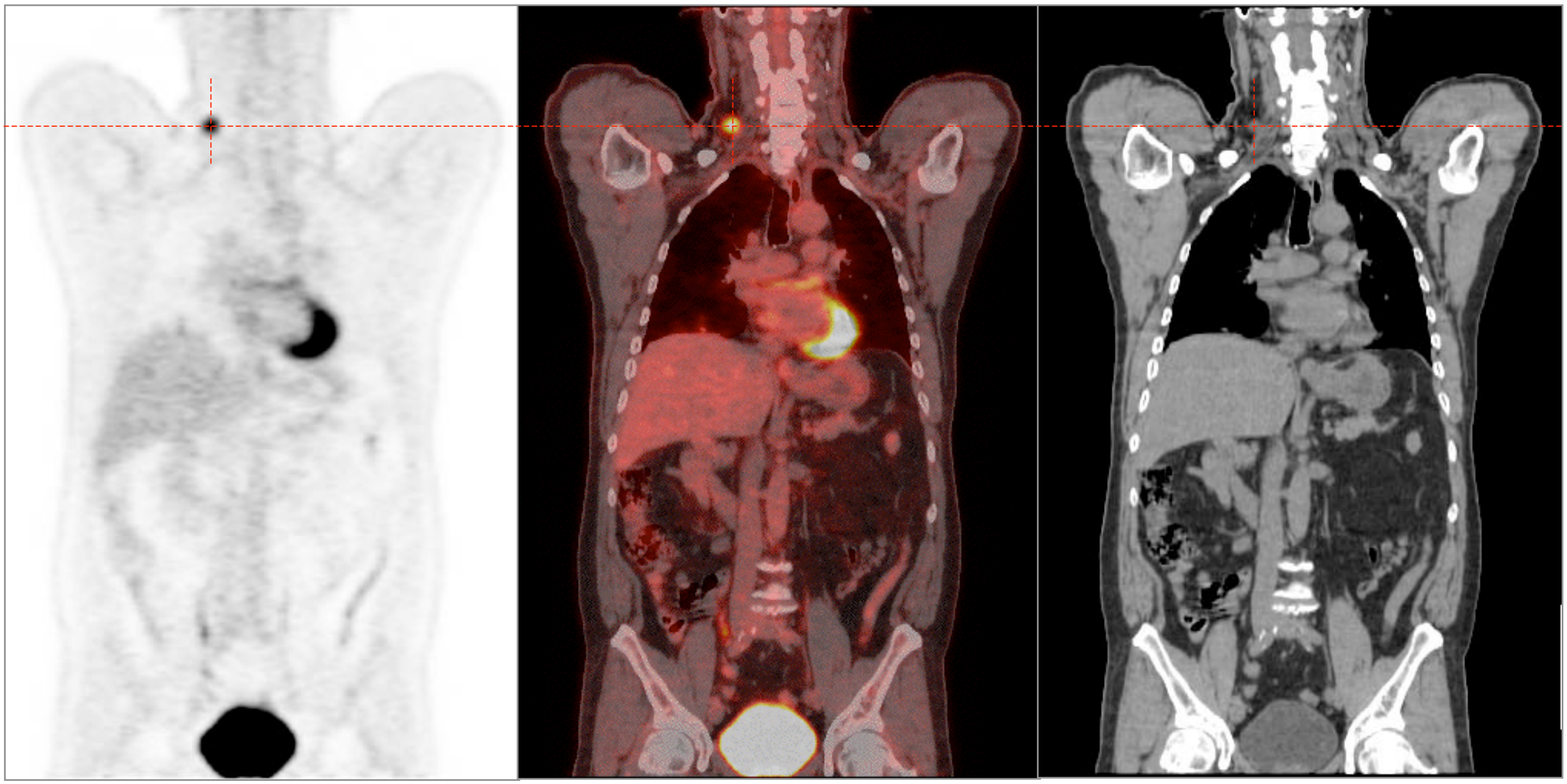
Phillips
-Gemini, GXL, and TF
(GSO, LYSO)



General Electric
-Discovery ST and DSTE
(BGO)

Imaging FDG uptake (PET) with anatomical localization (CT)

- Thyroid(?) cancer example

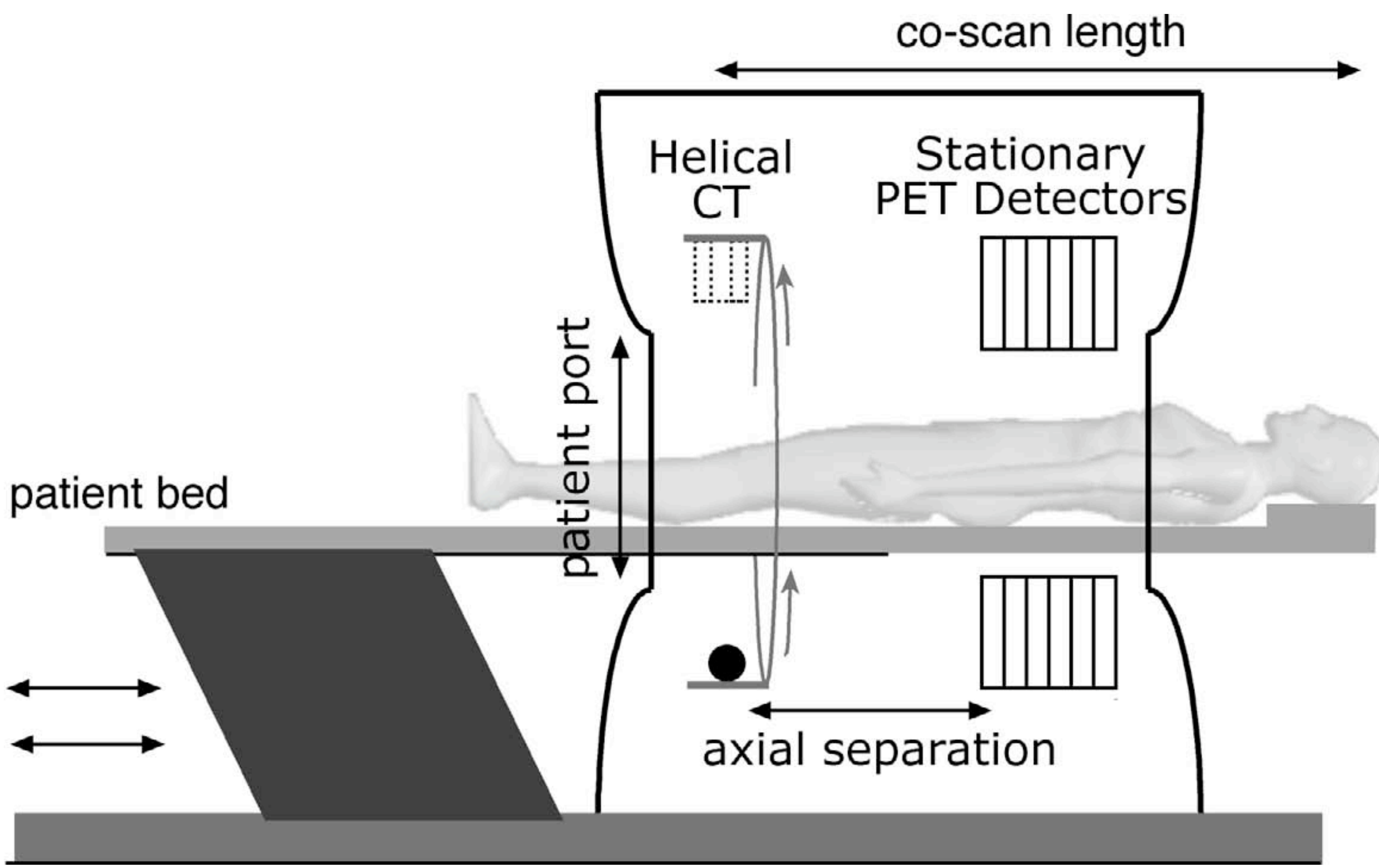


Function Function+Anatomy Anatomy

Improved Integration of PET and CT

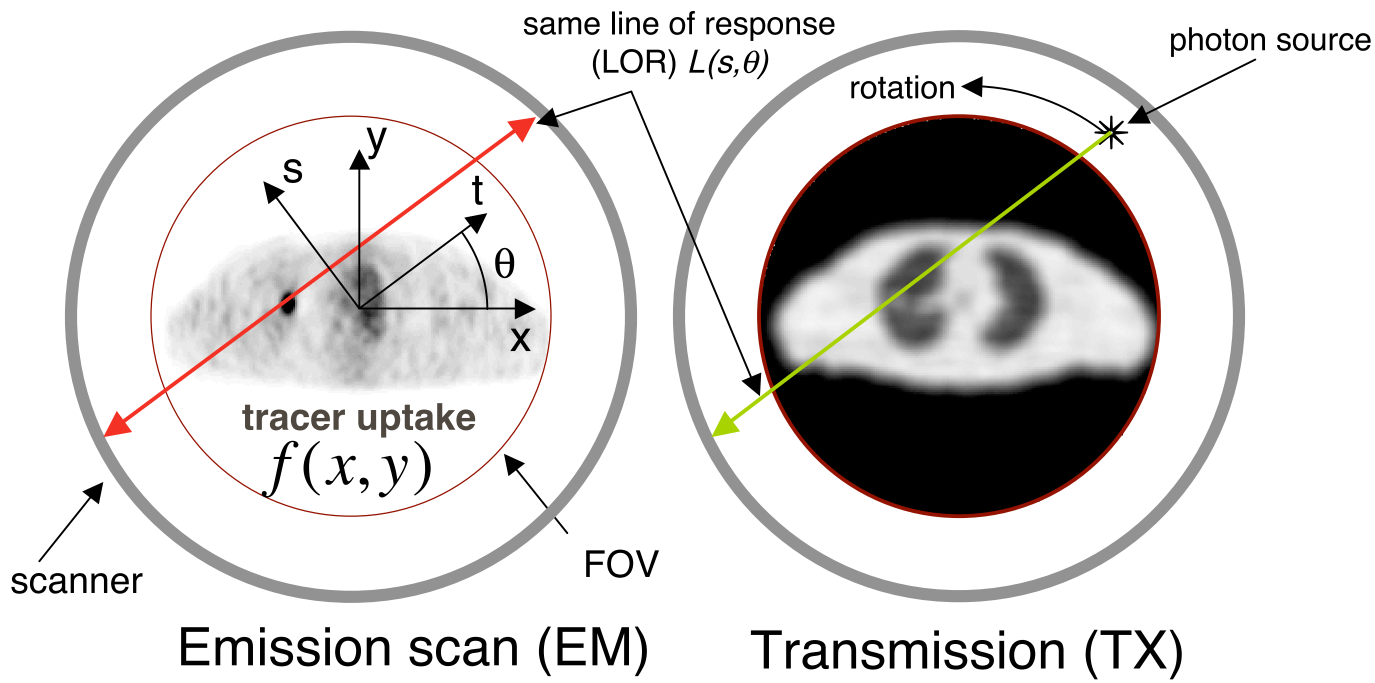
- Scanners now support list-mode, flexible protocols, and improved display facilities

Basic PET/CT Architecture

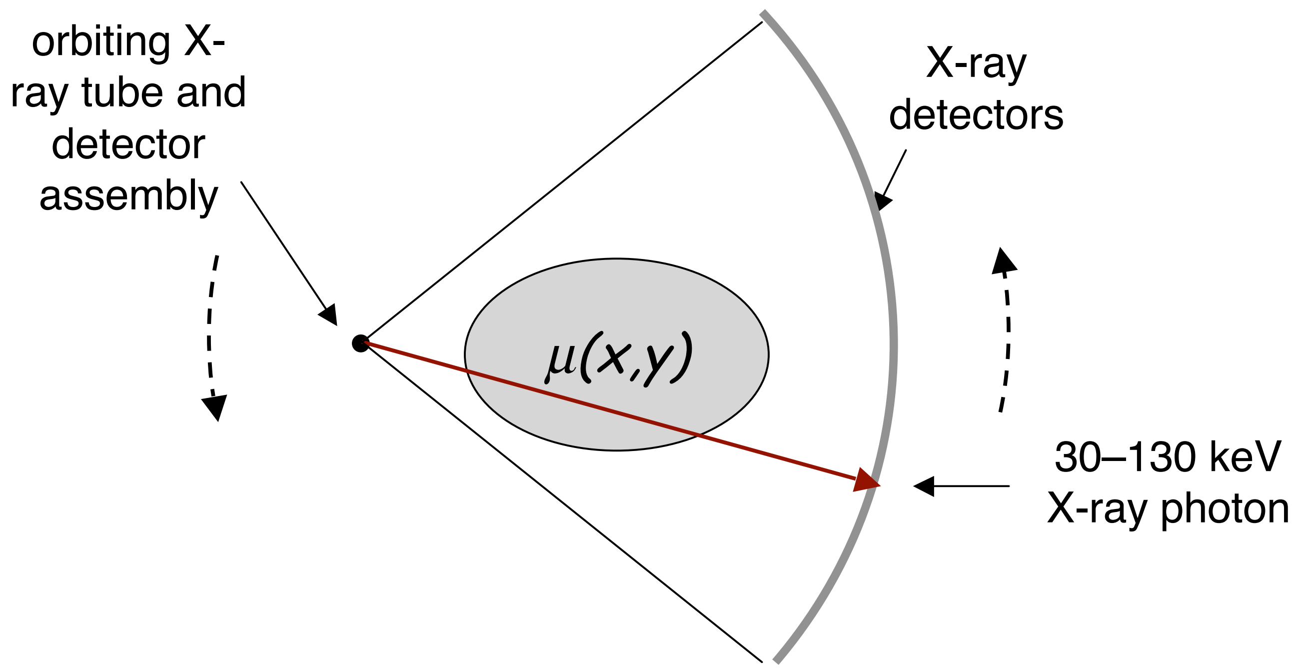


Attenuation Correction

- Transmission scanning with an external photon source is used for attenuation correction of the emission scan
- The fraction absorbed in a transmission scan, along the same line of response (LOR) can be used to correct the emission scan data
- The transmission scan can also be used to form a 'transmission' or 'attenuation' image



And, if you have PET/CT scanner: X-ray TX



- Photon flux is <u>very</u> high, so very low noise
- Greatly improved contrast at lower photon energies.
- Scatter and beam-hardening can introduce bias.
- $\mu(x,y,E)$ is measured as an weighted average from ~30-120 keV, so $\mu(x,y,511\text{keV})$ must be calculated, potentially introducing bias

X-ray and Annihilation Photon Transmission Imaging for Attenuation Correction

X-ray (~30-120 keV)

Low noise

Fast

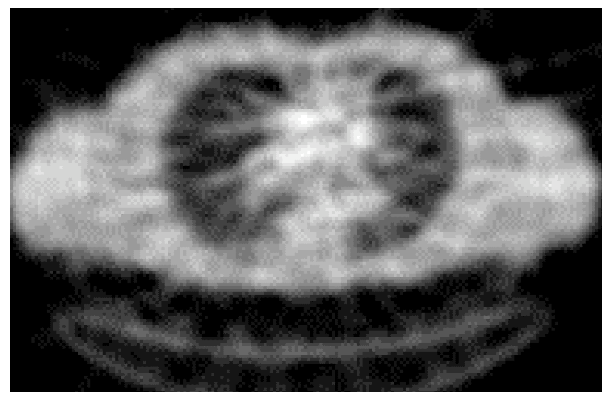
Potential for bias when scaled to 511 keV

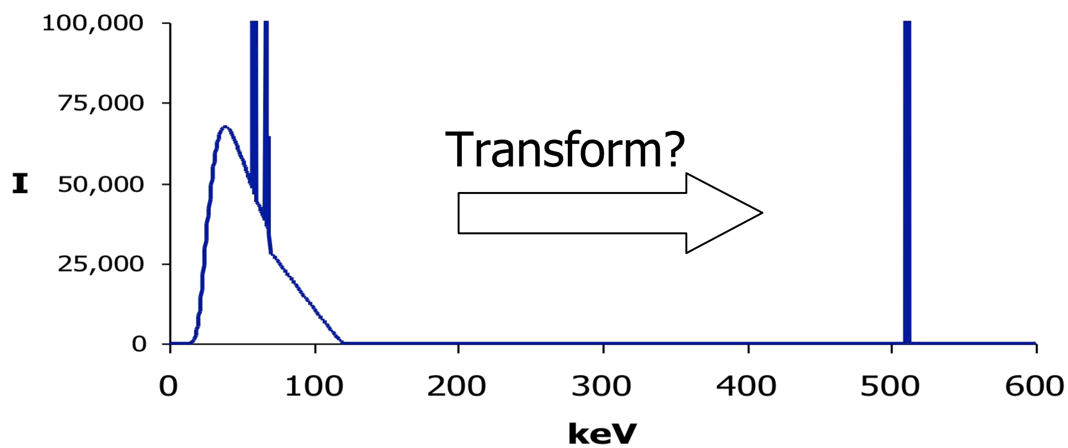
PET Transmission (511 keV)

Noisy

Slow

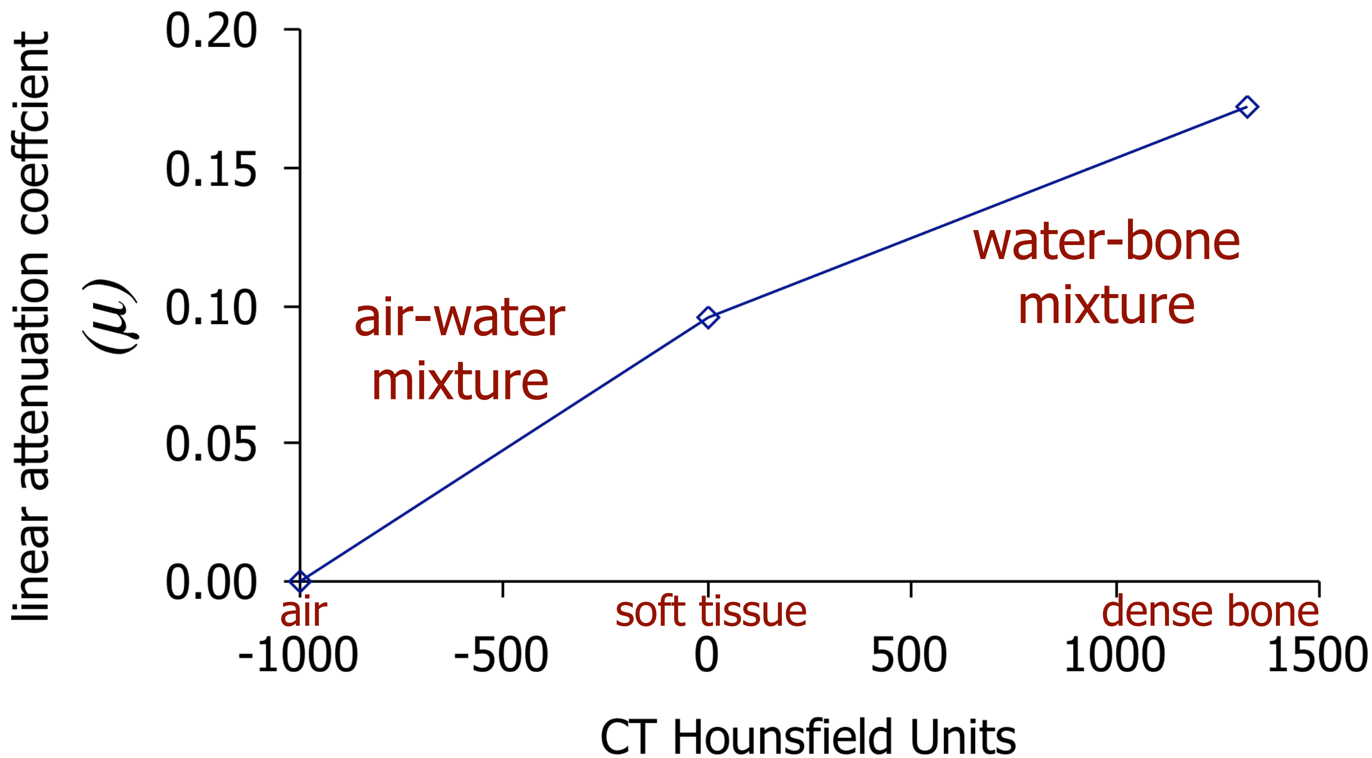
Quantitatively accurate for 511 keV





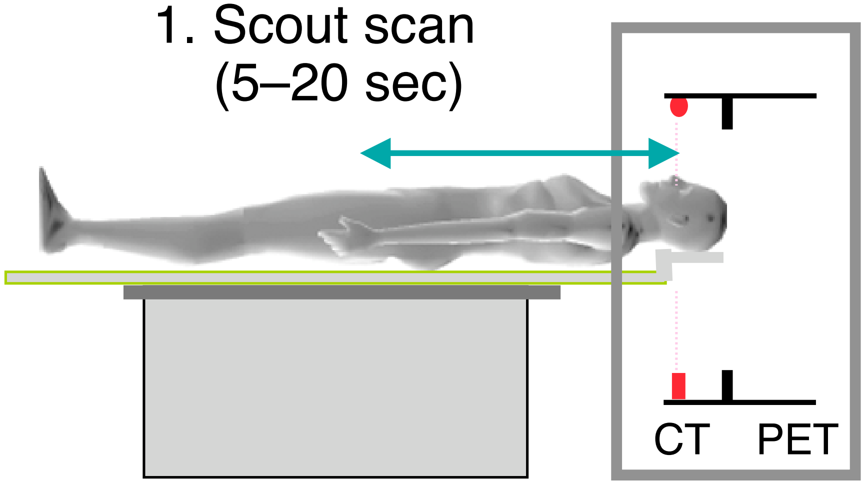
CT-based Attenuation Correction

- Bi-linear scaling methods apply different scale factors for bone and non-bone materials
- Should be calibrated for every kVp and/or contrast agent

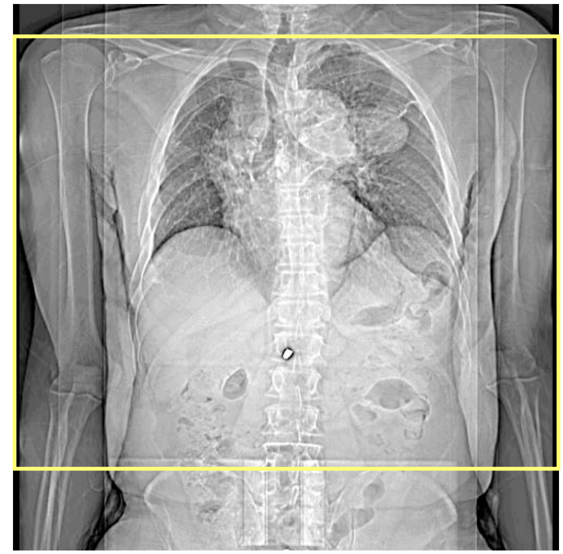


Typical PET/CT scan protocol

1. Scout scan
(5–20 sec)

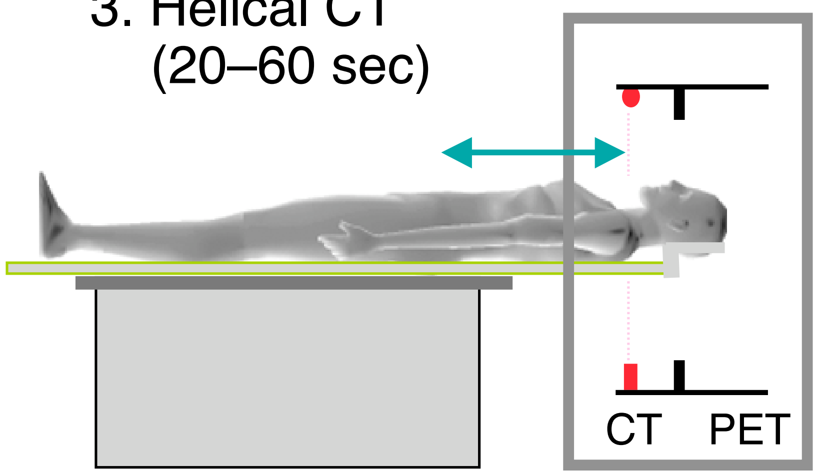


2. Selection of scan region (1–2 min)

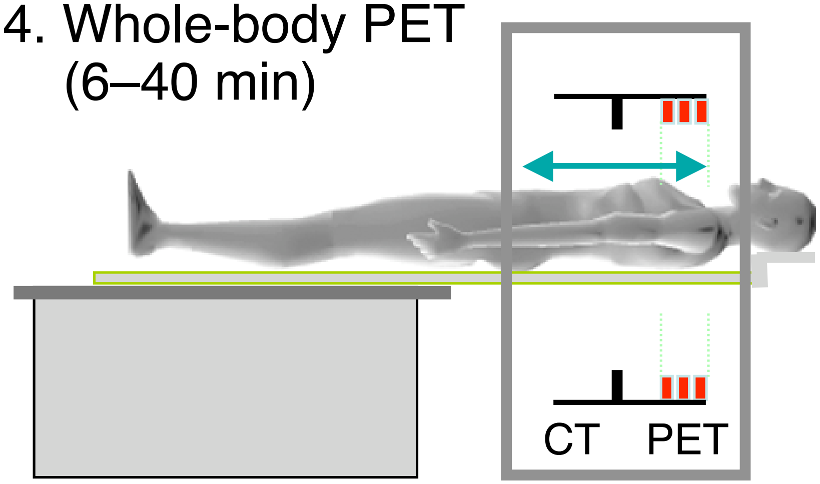


Scout scan image

3. Helical CT
(20–60 sec)

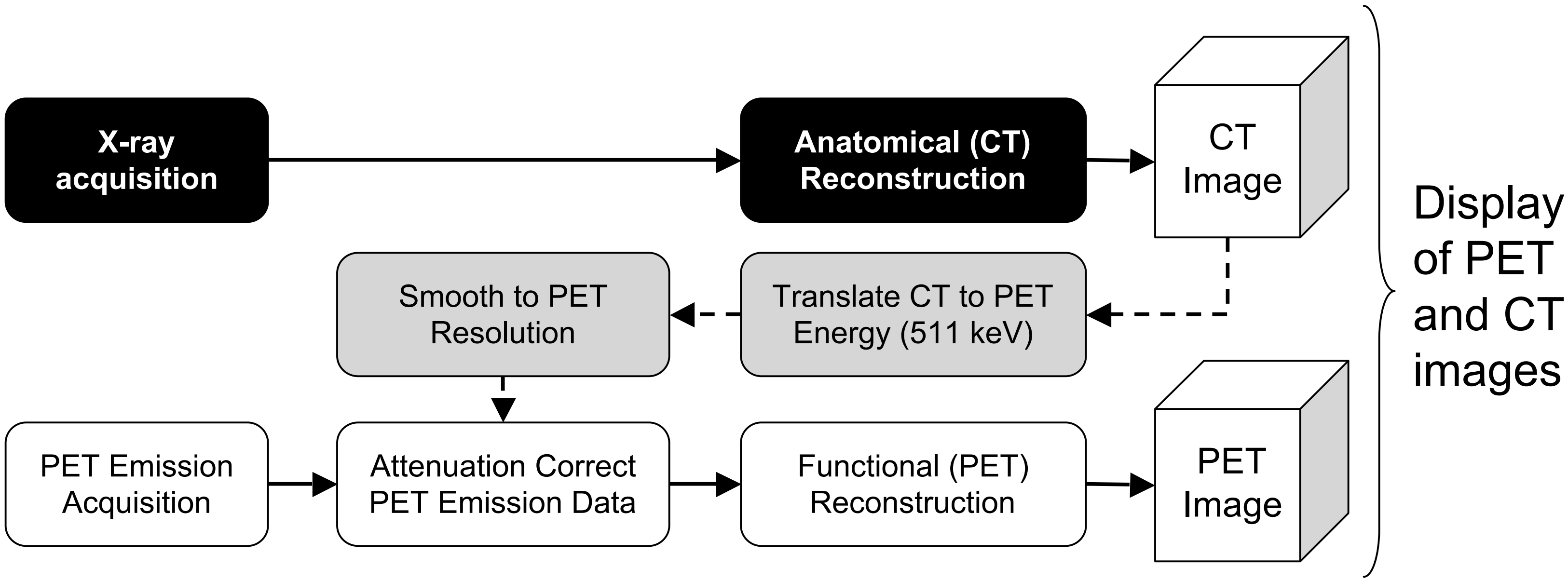


4. Whole-body PET
(6–40 min)



Data flow

- CT images are also used for calibration (attenuation correction) of the PET data



- Note that images are not really fused, but are displayed as fused or side-by-side with linked cursors

Potential problems for CT-based attenuation correction

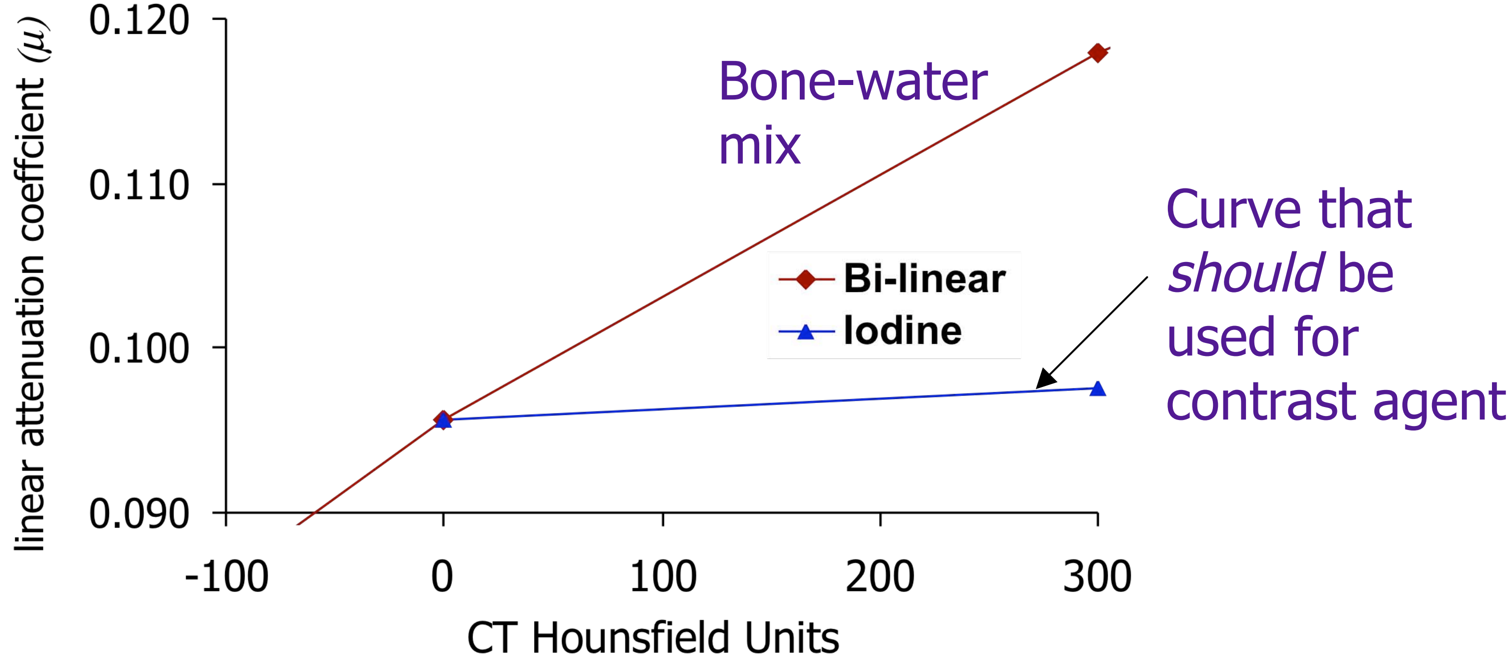
- Artifacts in the CT image propagate into the PET image, since the CT is used for attenuation correction of the PET data
- Difference in CT and PET respiratory patterns
  - Can lead to artifacts near the dome of the liver
- Use of contrast agent or implants
  - Can cause incorrect values in PET image
- Truncation of CT image due to keeping arms in down in the field of view to match the PET scan
  - Can cause artifacts in corresponding regions in PET image
- Bias in the CT image due to beam-hardening and scatter from the arms in the field of view

Effect of Contrast Agent on CT to PET Scaling

The presence of Iodine confounds the scaling process as Iodine cannot be differentiated from bone by CT number alone.

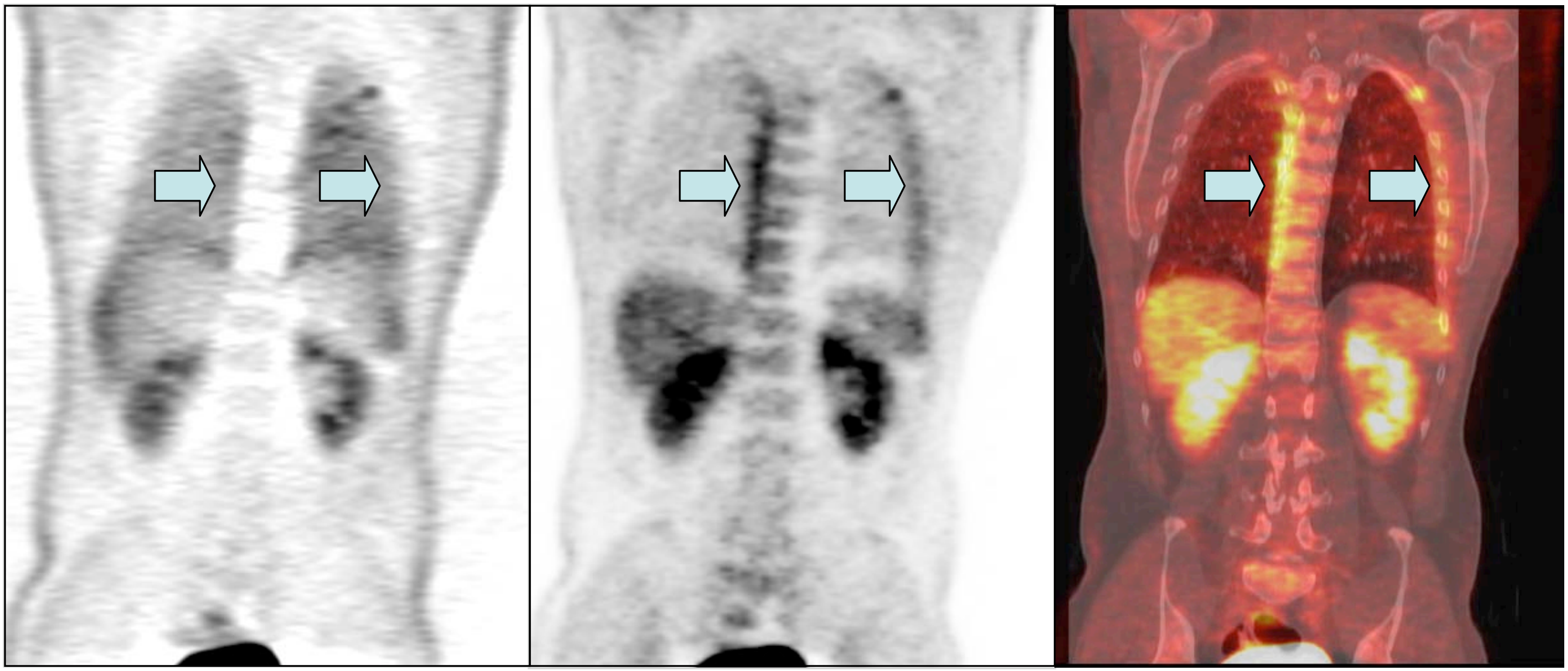
In general does not seem to lead to artifacts

Can use contrast scaling, but then bone values are incorrect



Patient shifting

- Large change in attenuation going from spine to lung



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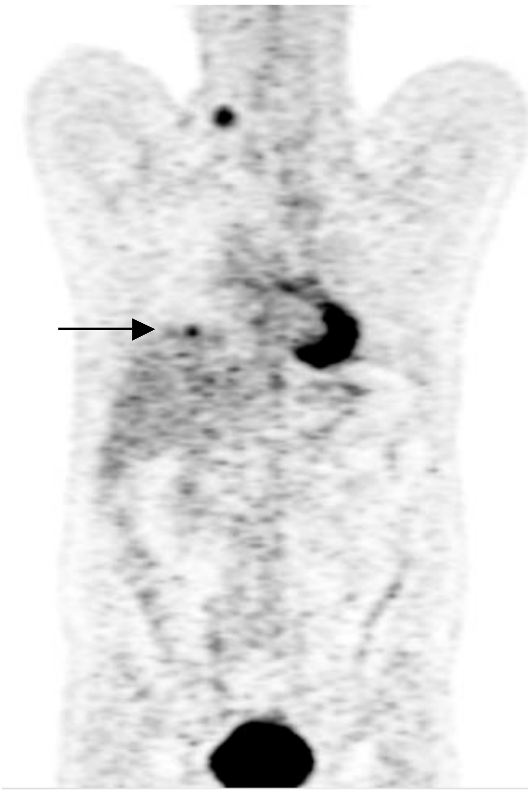
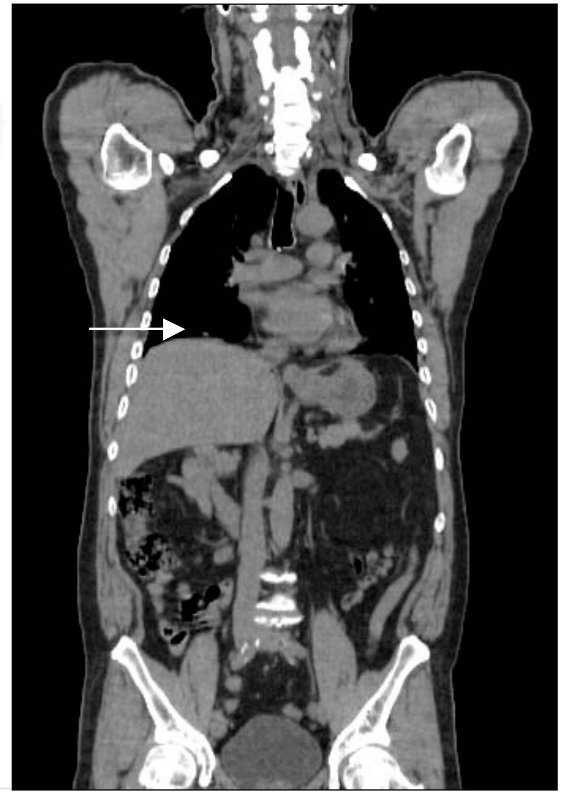
Impact of Whole-body Respiratory Gated PET/CT in worst case

Static wholebody



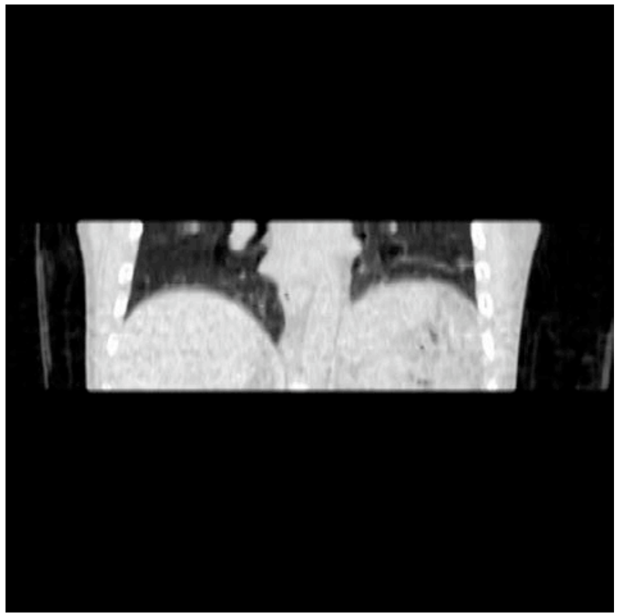
Single respiratory phase (1 of 7, so noisier)



1 cc lesion on CT

- The value of the lesion goes from 2 in the static image to 6 in one phase of the respiratory-gated image sequence

Respiratory Gated CT images: 10 phases



8 mAs 5mm slices

Wholebody Respiratory Gated PET - 9 phases

Note changes in lesion intensity

PET/CT Applications and Challenges

Primarily for Cancer Imaging -- works very well

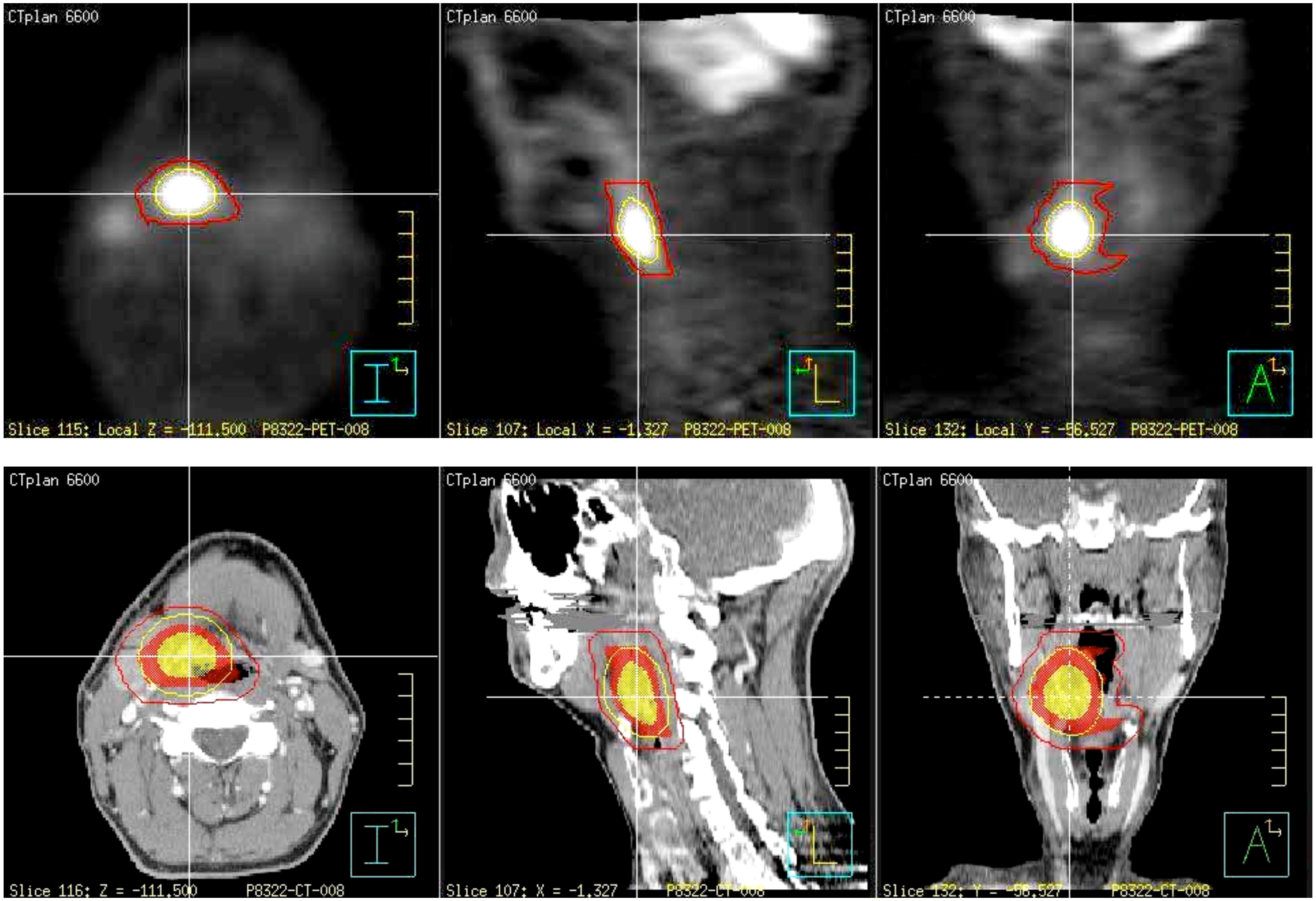
- Diagnostic imaging and staging for cancer

Expanding Areas -- with significant challenges

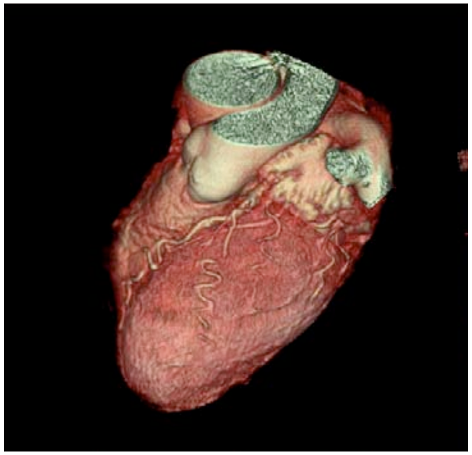
- Radiation treatment planning using PET and CT
- Cardiac imaging
- Assessment of therapeutic response

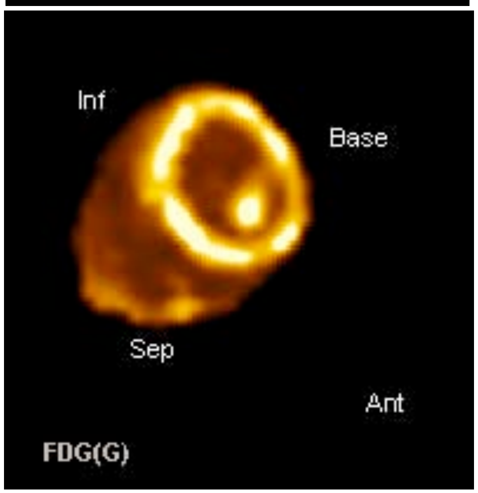
PET/CT and RTP using BTVs

FDG-based boost volumes



Anatomical/Functional Mapping of the Heart

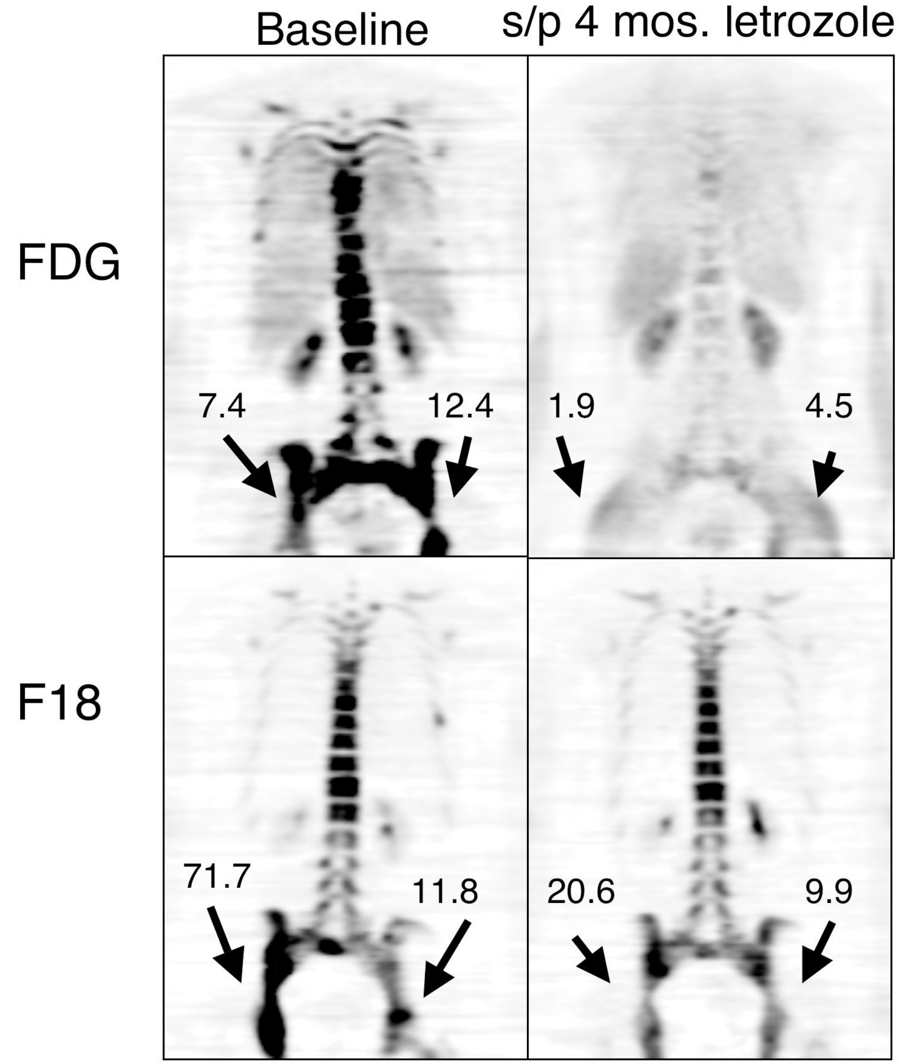




- Rest – Stress (Rb, NH_3, H_2O…)
- Quantification (MBF, MFR)
- Combining coronary imaging (CT) with perfusion (PET)

Quantitative Assessment of Response to Therapy

- Example: Change in SUV measures of FDG and fluoride incorporation for bony metastases from breast cancer before (left) and after hormonal therapy (right)
- Bone images look similar but have very different values
- CT helps with precise realignment of ROIs in serial studies



SPECT/CT Hybrid Systems

- Like PET/CT, SPECT/CT acquires both scans with the patient in the same position
- Very new type of system, not clear how this will be useful clinically, but a lot of interest
- CT is also used for attenuation correcton of SPECT data
- Having the gamma camera and CT scanner on the same gantry allows straightforward fusion of the two data sets
- The CT provides accurate anatomical localisation of the functional information within the gamma camera scan
- It is claimed that the accuracy of radionuclide therapy planning can be increased by using the CT attenuation corrected SPECT data
- Applications in development include combined coronary CT angiography and myocardial perfusion imaging.

SPECT/CT Hybrid Systems

- Very different approaches by the 'big 3'

Siemens

Entry-level CT

Philips

High-end CT

GE

not a real CT