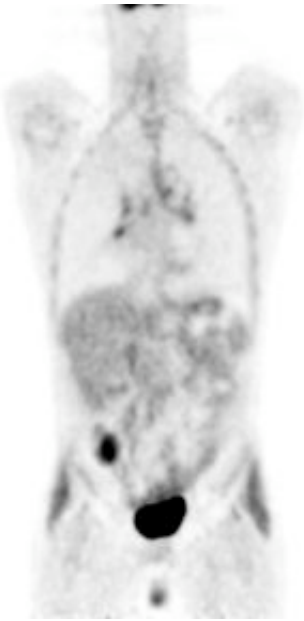
PET/CT Principles



D.W. Townsend, PhD

Departments of Medicine and Radiology,
University of Tennessee, Knoxville, TN

Cancer Imaging and Tracer Development

Advances in PET-SPECT/CT and RTP

Melbourne, Australia December 13th 2005

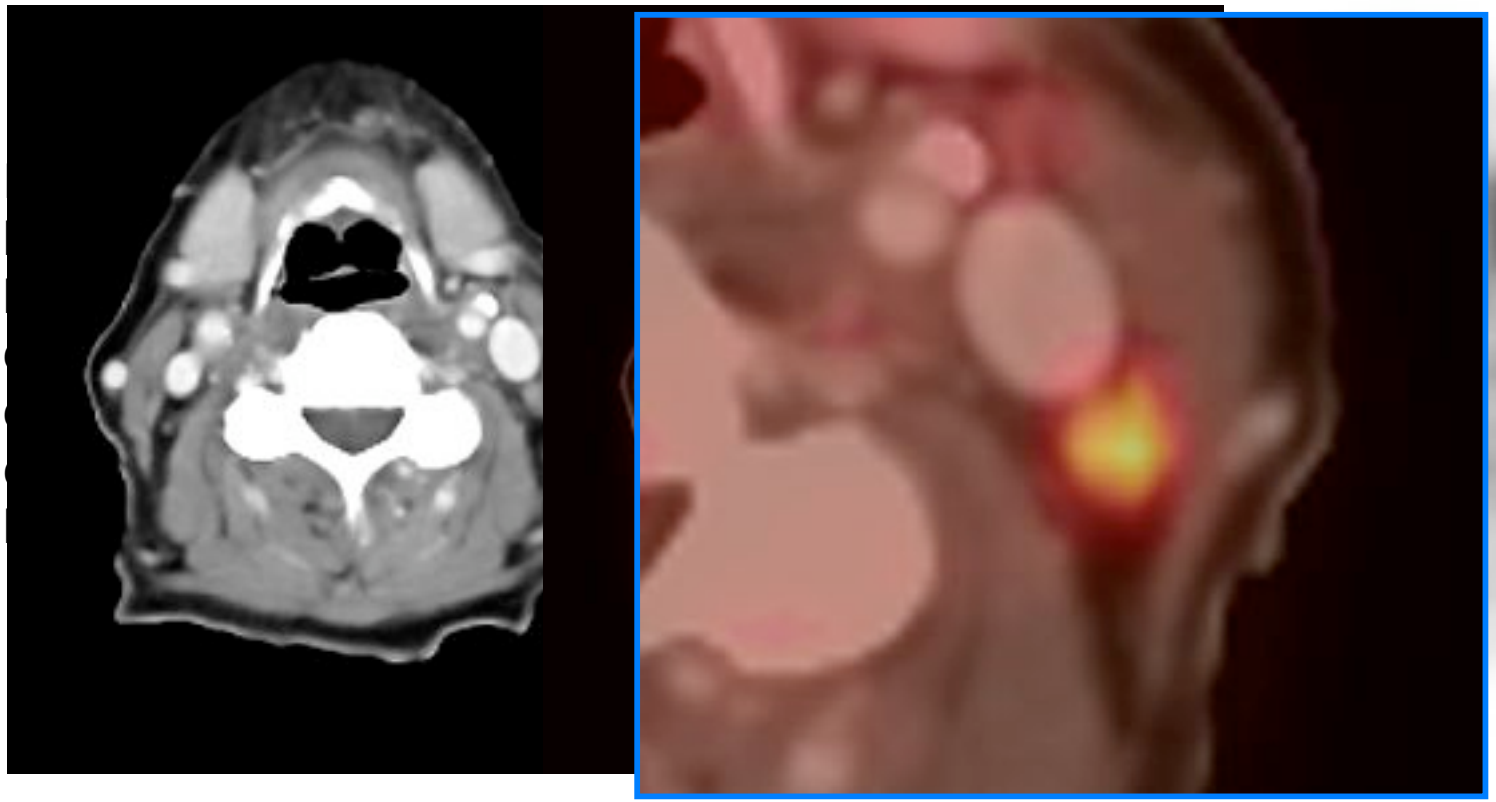
Principles of PET/CT

- principles of design

Hardware fusion: anatomy + function

Why combine anatomy and function?

- to image different aspects of disease
- to identify non-specific tracer uptake
- to facilitate image interpretation
- to provide unique added value to bot

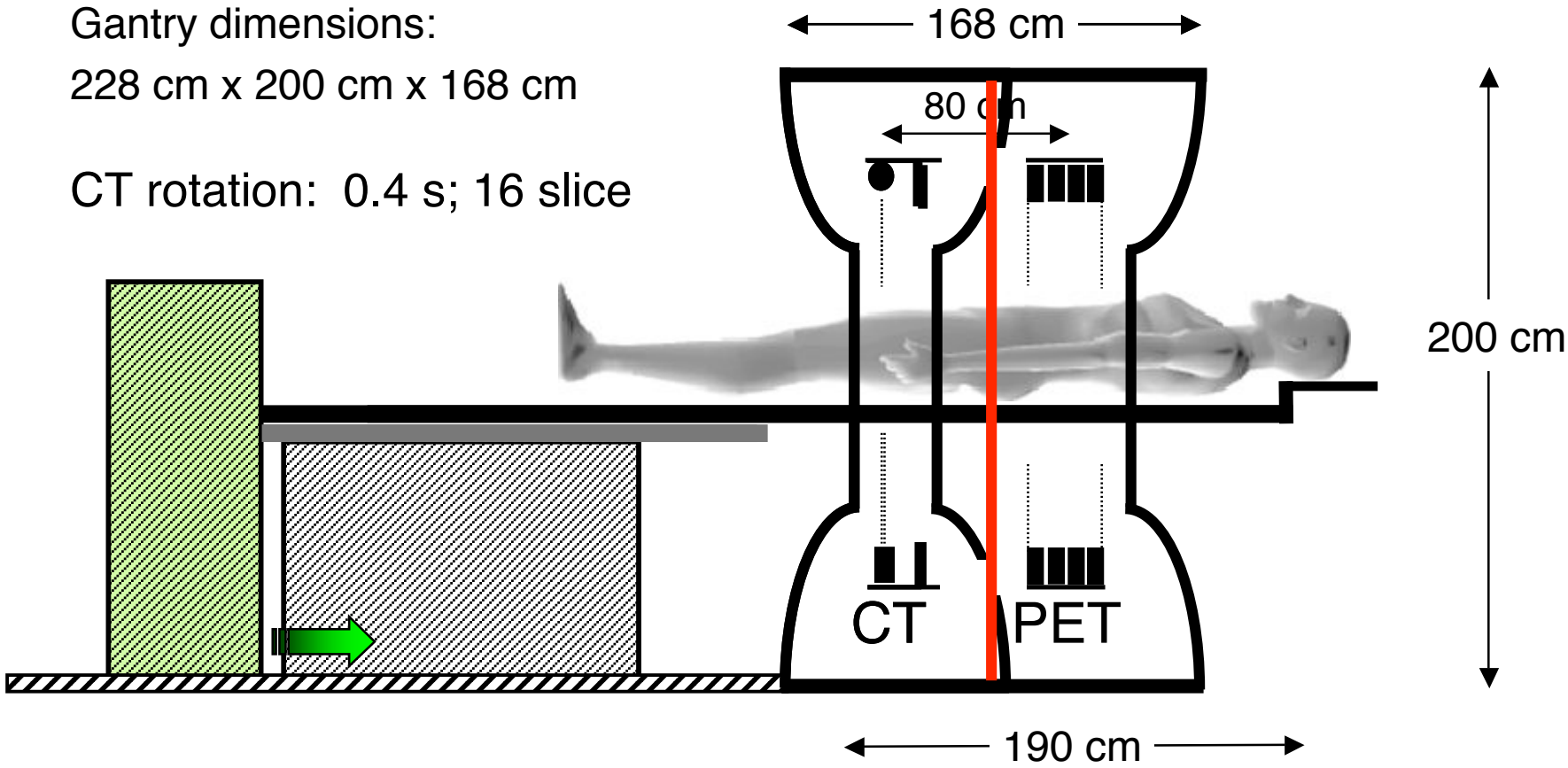


CT (anatomy) PET/CT PET (function)

Designing a PET/CT scanner

Gantry dimensions:
228 cm x 200 cm x 168 cm

CT rotation: 0.4 s; 16 slice



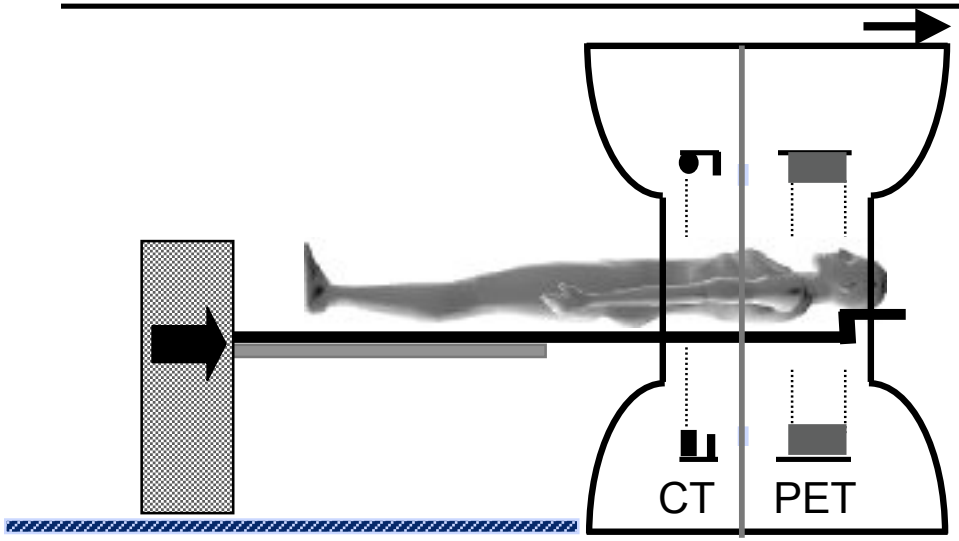
biograph 16

Dual-modality imaging range

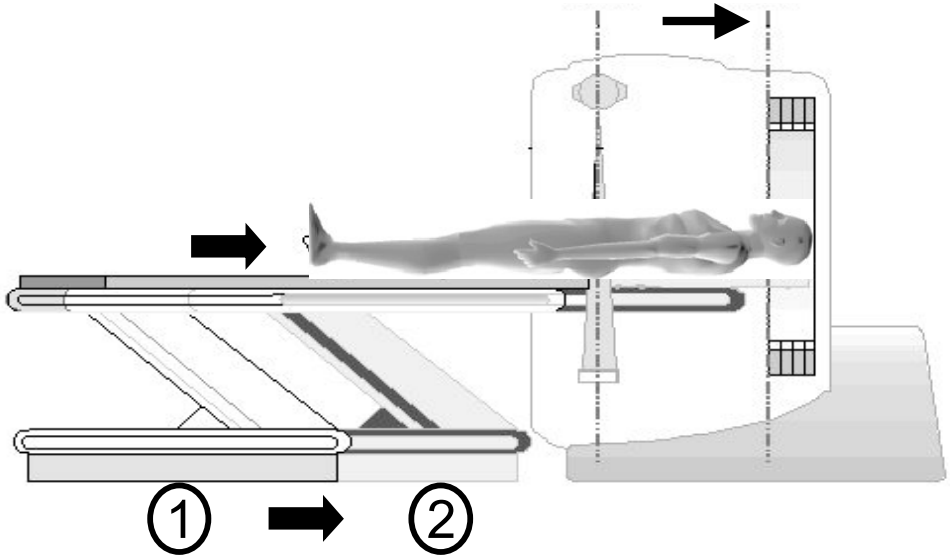
PET/CT design choices

CT parameters		PET parameters	
detectors:	ceramic; 1 – 24	scintillator:	BGO; GSO; LSO
slices:	2, 4, 6, 8, 16, 40, 64	detector size:	4 x 4 mm; 6 x 6 mm
trans. FOV:	45 – 50 cm	trans. FOV:	55 – 60 cm
rotation speed:	0.4 – 2.0 s	resolution:	~ 4 – 6 mm
tube current:	80 – 280 mA	axial extent:	15 – 18 cm
heat capacity:	3.5 – 6.5 MHU	septa:	2D/3D; 3D only
topogram:	128 – 2000 cm	attenuation:	CT-based (rod; point)
time /100 cm:	13 – 90 s	patient port:	60 cm; 70 cm
slice width:	0.6 – 10 mm	peak NECR:	30 @ 9 kBq/ml
patient port:	70 cm	(3D)	– 93 @ 29 kBq/ml

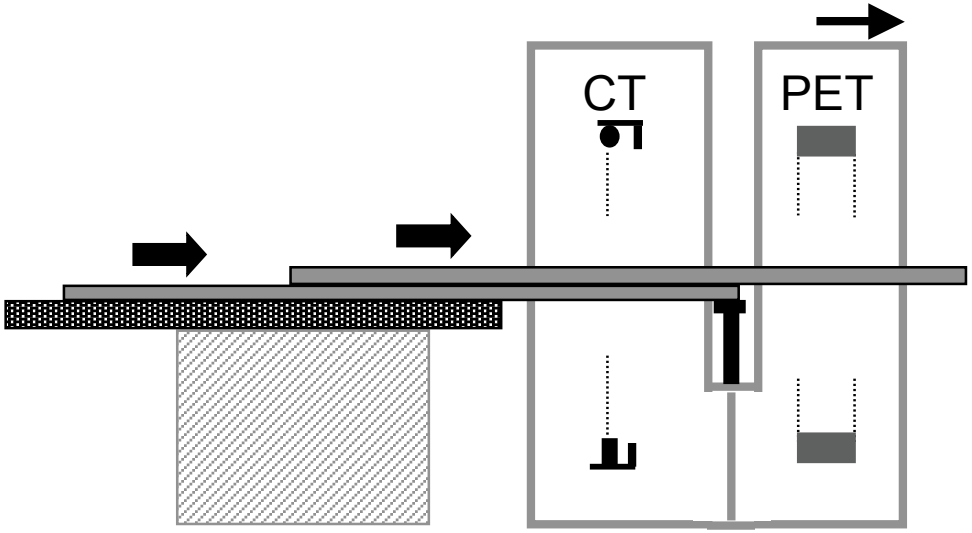
PET/CT patient support designs



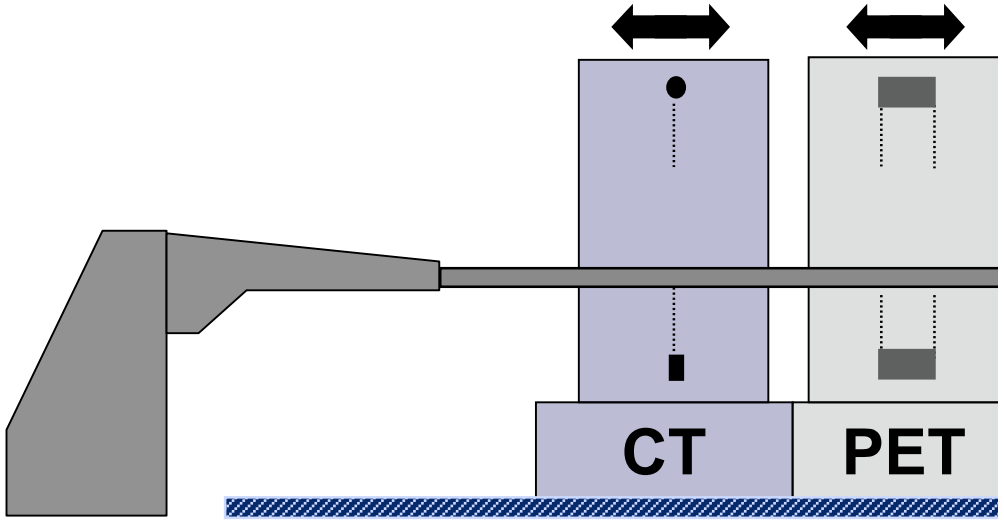
Fixed cantilever point; floor-mounted rails



Variable cantilever point; dual positions

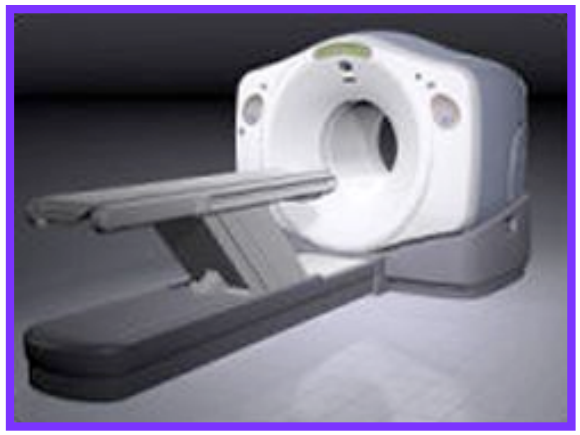


Variable cantilever point; support in tunnel



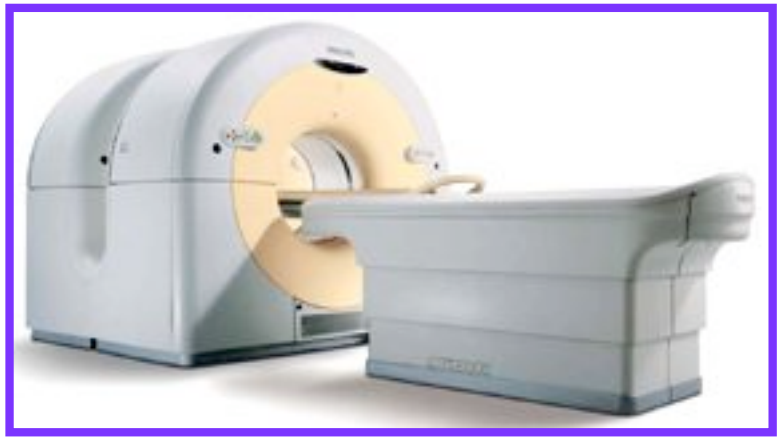
Stationary bed; gantries travel on rails

Current PET/CT scanner designs



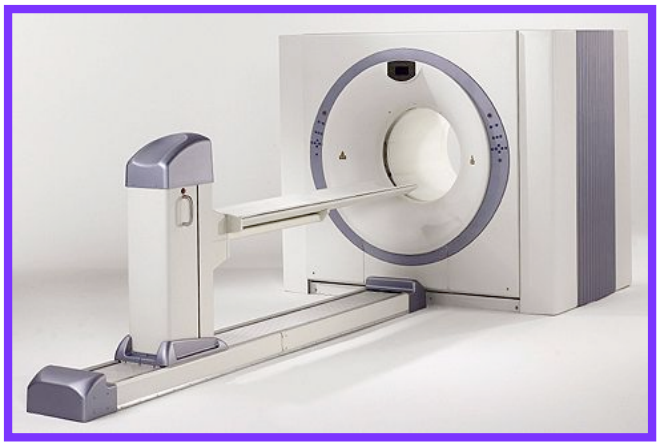
BGO, LYSO
6 x 6 x 30 mm^3
2D/3D (septa)
8, 16, 64 slice CT
70 cm port
dual-position bed

***Discovery* ST, STE, RX**



GSO (Zr)
4 x 6 x 30 mm^3
3D only (no sep
6, 10, 16 slice C
70 cm port
6 ns coincidenc
bed supported

Gemini GXL



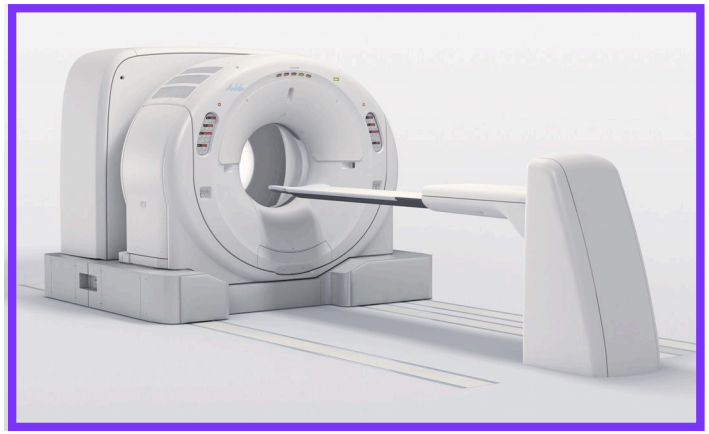
LSO
4 x 4 x 20 mm^3
3D only (no septa)
8, 16, 64 slice CT
70 cm port
4.5 ns coincidence
bed on rails

***biograph* 6, 16, 64**

LSO
6 x 6 x 25 mm^3
3D only; rotating
4 slice CT
70 / 60 cm port
4.5 ns coincider
bed on rails

SceptreP3

Current PET/CT scanner designs (continued)

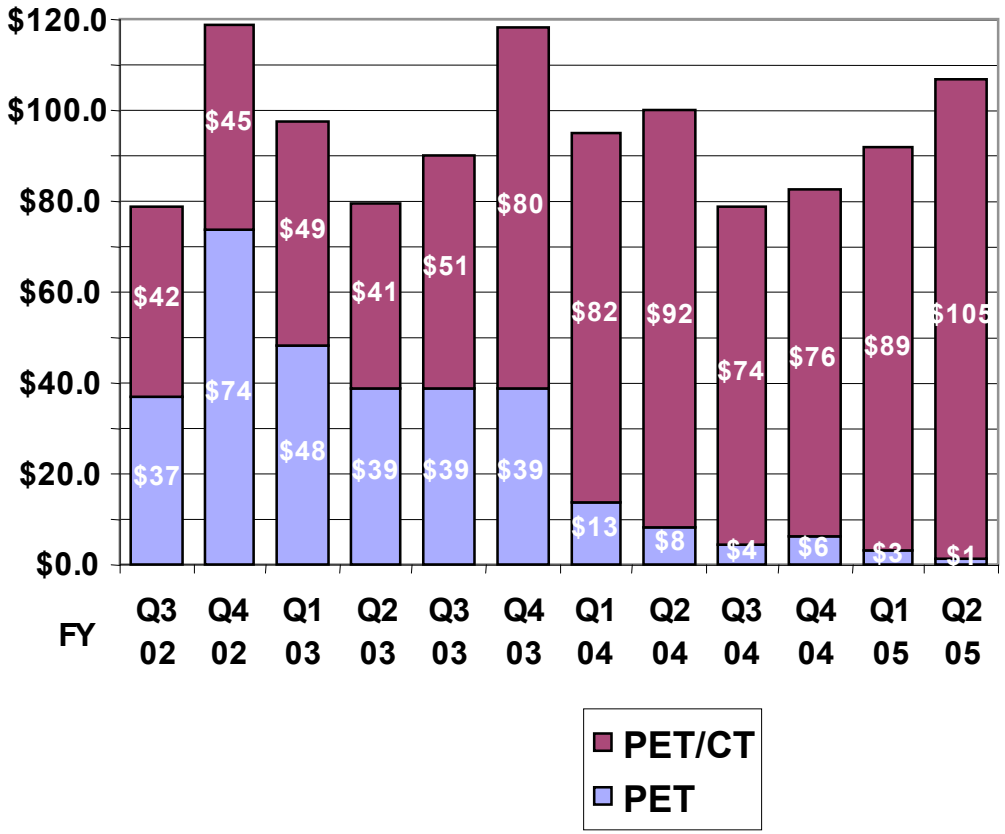


Aquiduo

LSO

4 x 4 x 20 mm^3
3D only (no septa)
16 slice CT
70 cm port
4.5 ns coincidence
gantry on rails

NEMA - US Shipments ($M)



PET/CT clinical impact

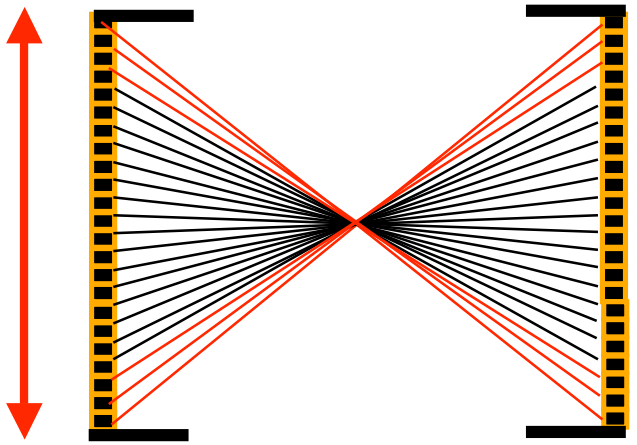
Innovations in PET technology -1-

- *improved PET scintillator performance*
- *increased axial field-of-view for volume sensitivity*

- ***Scintillators***

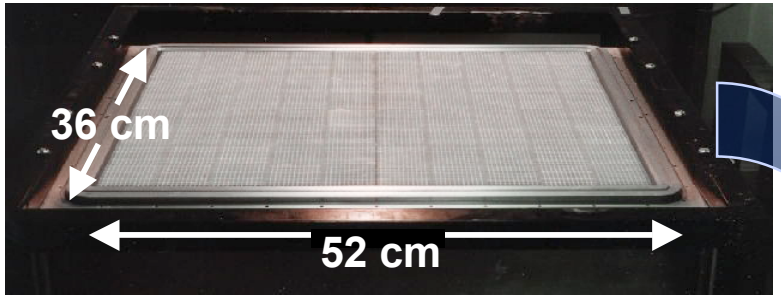
	BGO	LSO	GSO
Density	7.13	7.4	6.7
Z_{eff}	74	66	61
Decay (ns)	300	35-45	30-60
Light	8,200	28,000	10,000
% NaI	15	75	25

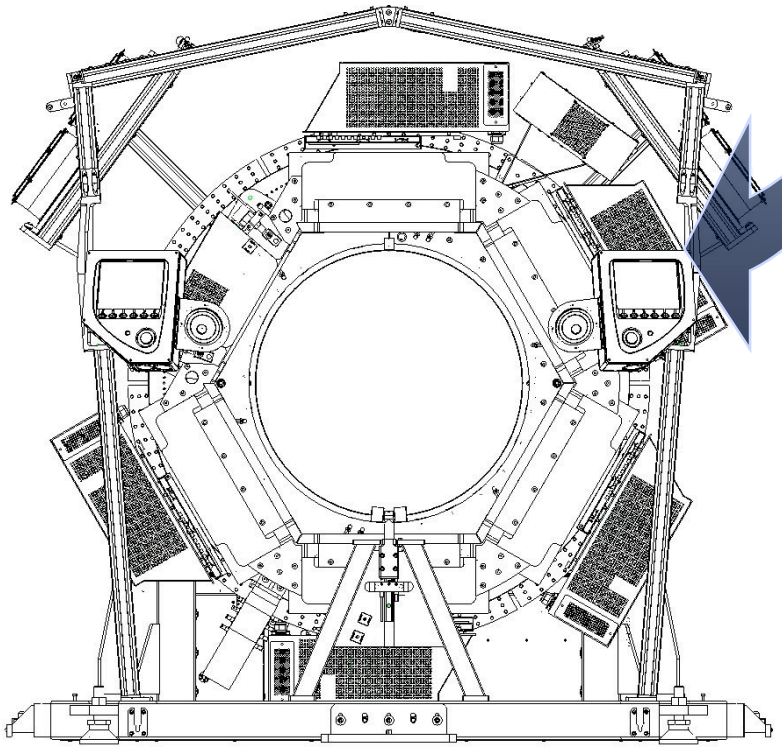
- ***Sensitivity***



3D (septa retracted)

Panel detectors and P-5H scanner



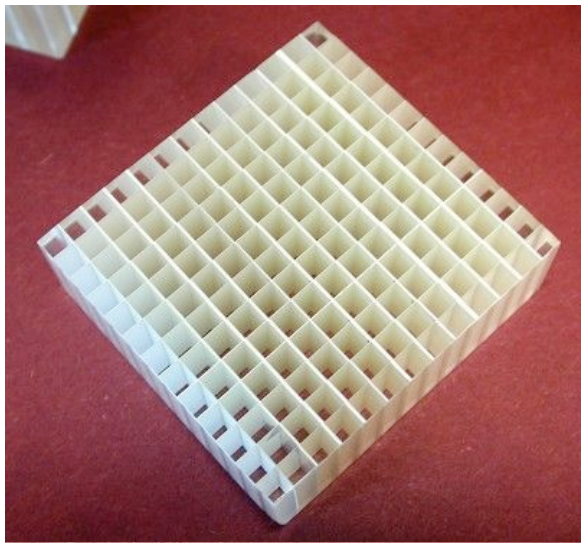


P-5H schematic

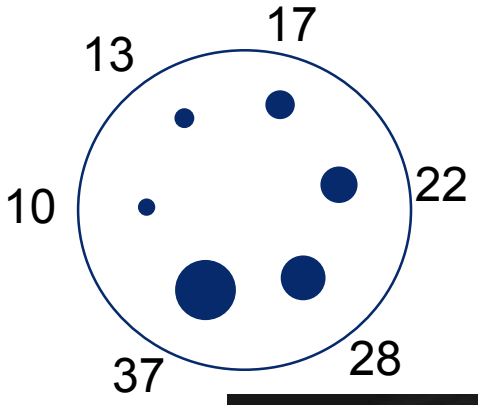
- 5 heads; 30 rpm rotation of assembly
- ^{68}Ge point sources (2 x 10 x 1 mCi)
- list mode Em and Tx acquisition
- simultaneous Em and Tx acquisition

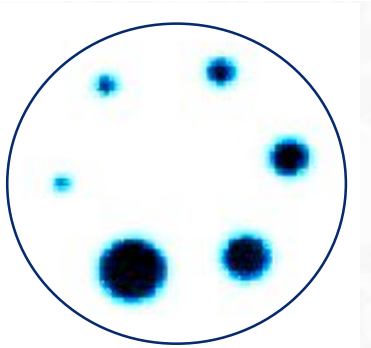
Innovations in PET technology -2-

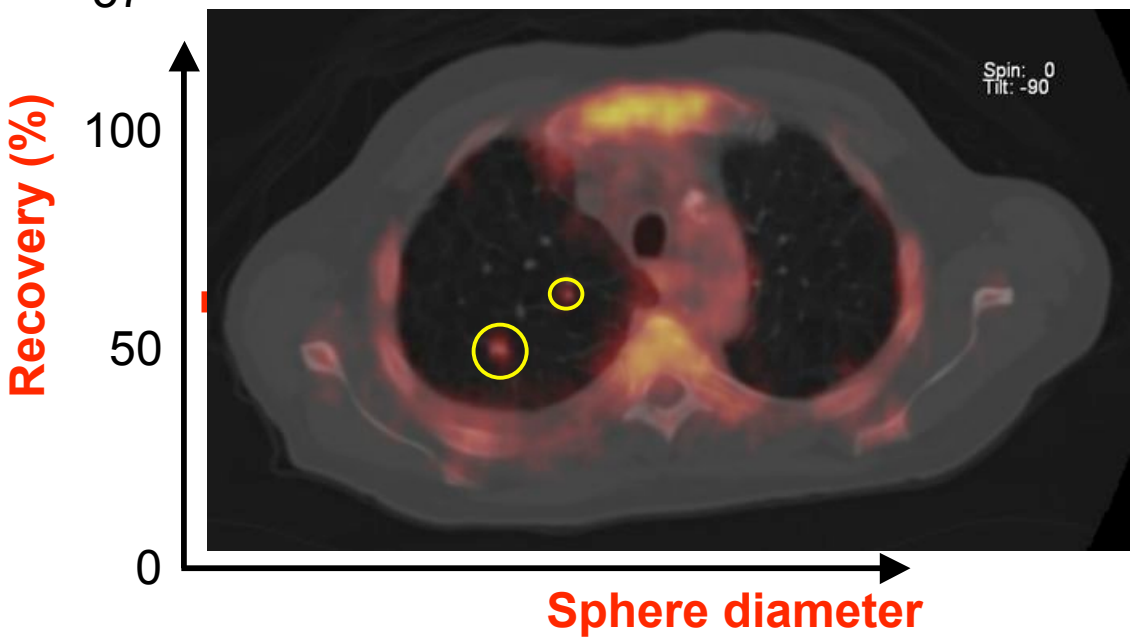
- *improvements in spatial resolution*



4.0 mm x 4.0 mm LSO
13 x 13 crystals/detector
2 mm slice width



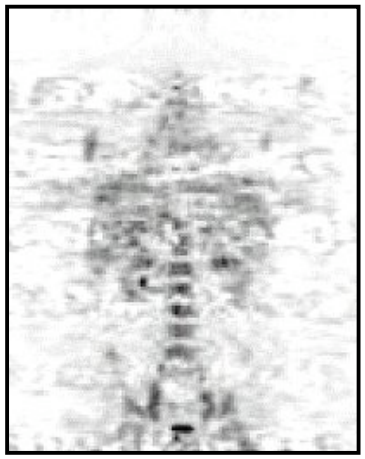




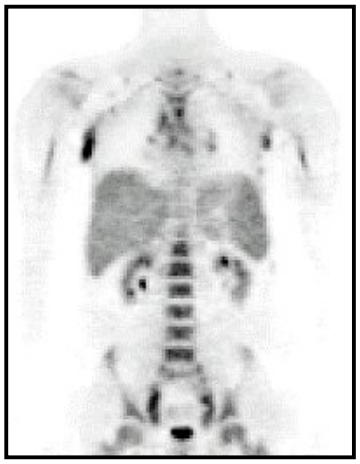
Innovations in PET technology -3-

- *fully 3D statistical reconstruction algorithms*
- *incorporation of time-of-flight (TOF) information*

- ***Reconstruction algorithms***



3DRP



FORE+AWOSEM

- **accurate system model**

- ***Time-of-flight (TOF)***

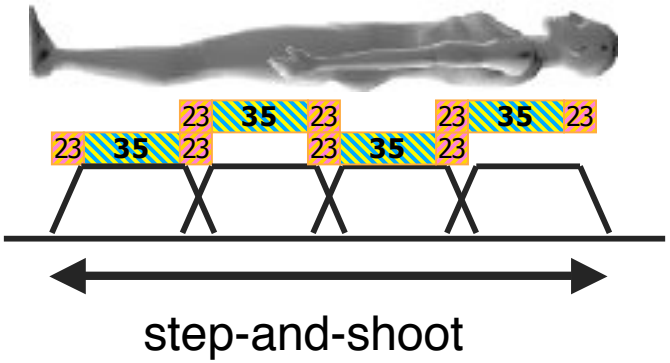
$$\Delta x = \frac{\Delta t}{2} c \qquad SNR_{TOF} \cong \sqrt{\frac{D}{\Delta x}} \cdot SNR_{conv}$$

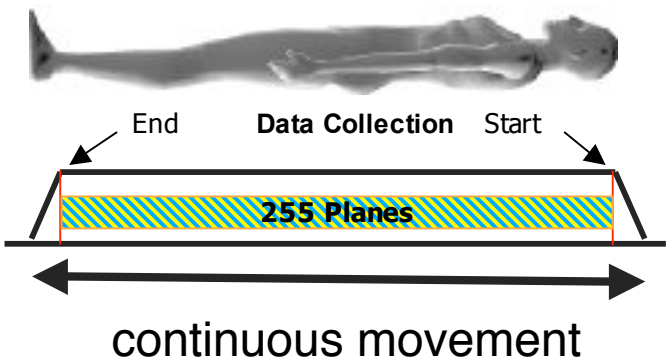
Δt (ns)	Δx (cm)	SNR*
0.1	1.5	5.2
0.3	4.5	3.0
0.5	7.5	2.3
1.2	18.0	1.5

** SNR gain for 40 cm phantom*

Innovations in PET technology -4-

- *continuous bed motion acquisition*





Why acquire PET data with continuous bed motion?

- Uniform axial signal-to-noise
- Eliminate axial under-sampling artifacts
- Reduce the noise from normalization
- Potentially improve lesion detection
- Reduce patient movement artefacts
- Natural way to define the axial FOV

Innovations in CT scanner design

	T_{rot}	collimation	typical 30 cm scan[1]	slices/s
1972	300 s ×4	13 mm	---	0.007 /4
1980	2 s	2 mm	20 mm, 30 s	0.5
1990	1 s	1 mm	10 mm, 30 s	1[2]
1995	0.75 s	1 mm	8 mm, 30 s	1.3[2]
1998	0.5 s	4 × 1 mm	4 × 1 mm, 30 s	12[3]
2002	0.4 s	16 × 0.75 mm	16 × 0.75 mm, 12 s	60[3]
2004	0.3 s	64 × 0.5 mm	64 × 0.5 mm, 3 s	240[3]
2010	0.2 s	512 × 0.5 mm	512 × 0.5 mm, 0.2 s	2500

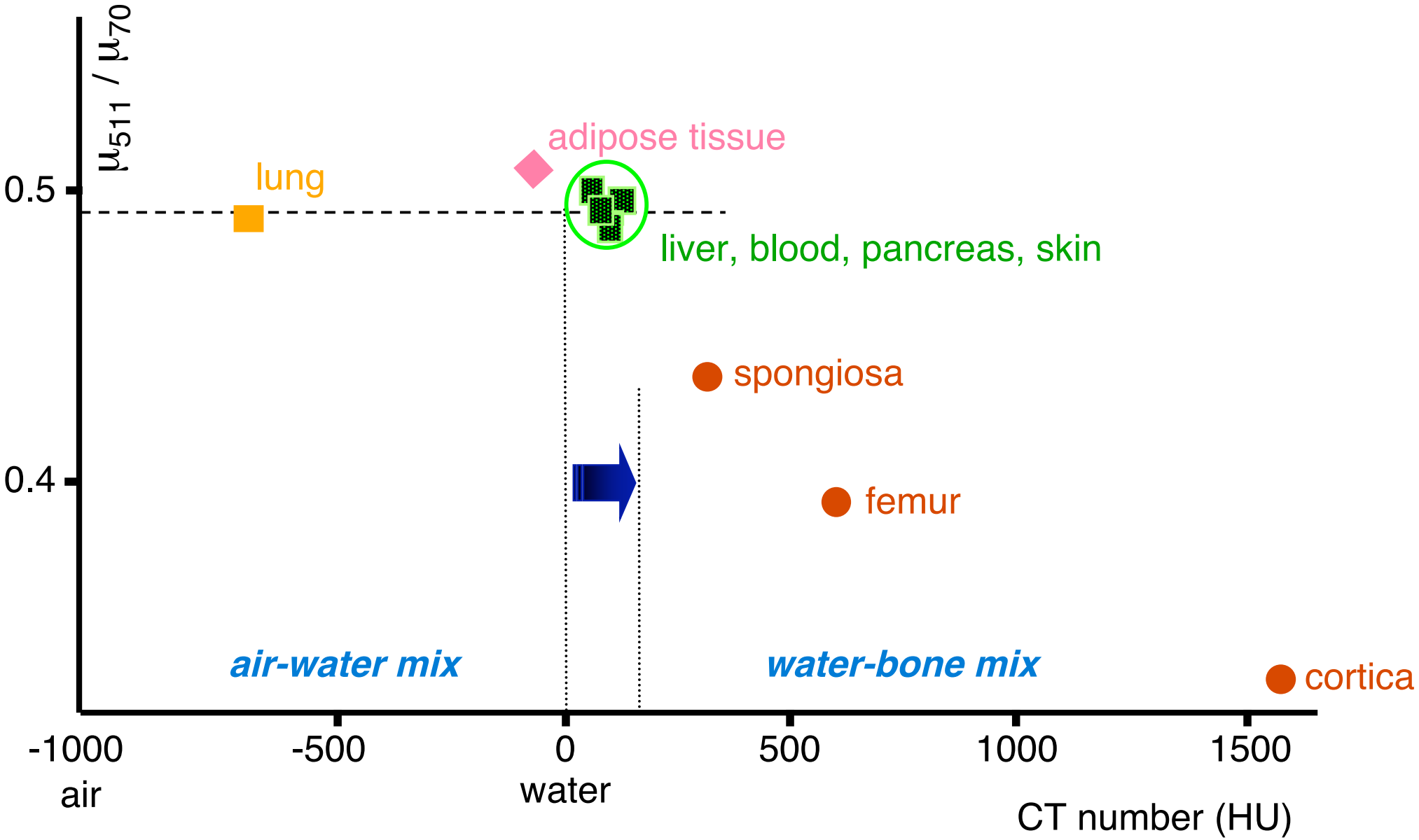
Spiral CT

[1] assuming a breath-hold limit of 30 s
[2] assuming p = 1, otherwise S_{eff} is increased
[3] assuming p = 1.5 since image quality is independent of pitch for MSCT

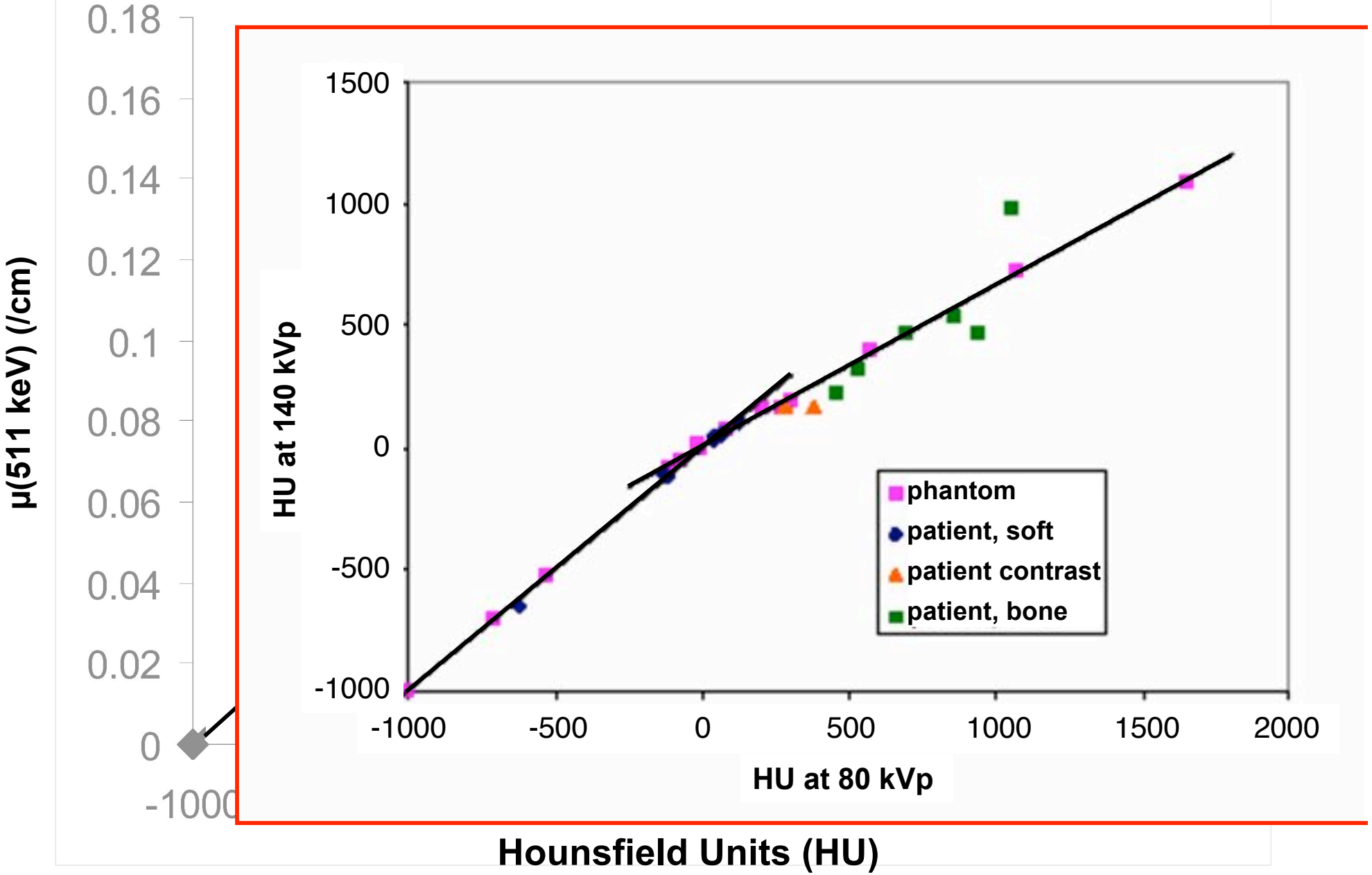
Principles of PET/CT

- principles of operation

CT-based attenuation correction



Mixture Model



PET/CT imaging: some practical issues

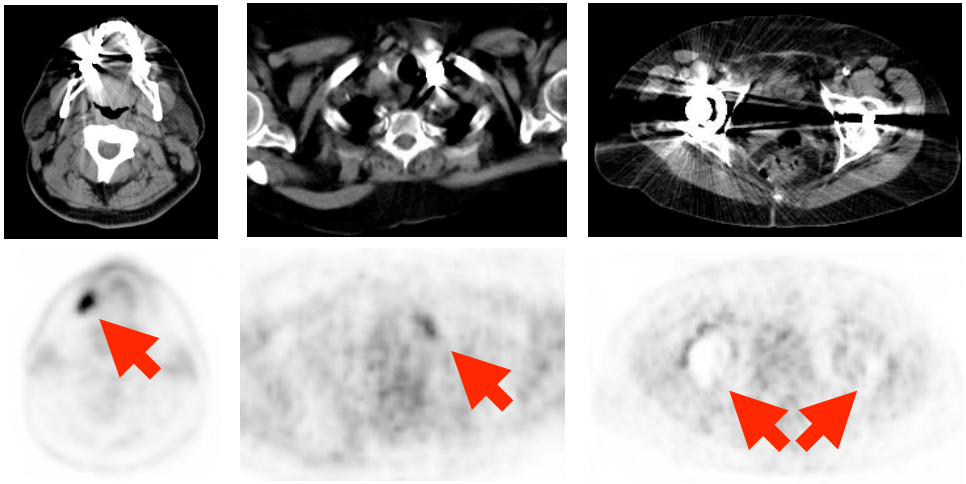
CT breathing protocols

Breath-hold CT in 420 lb patient. Note diaphragm is even resolved from liver. Few artefacts can be seen even with shallow breathing

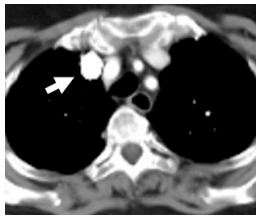
10 s scan time

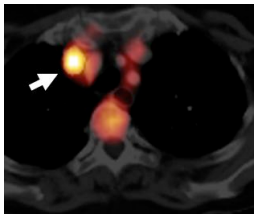
biograph 16

Metal artifacts



Intravenous contrast

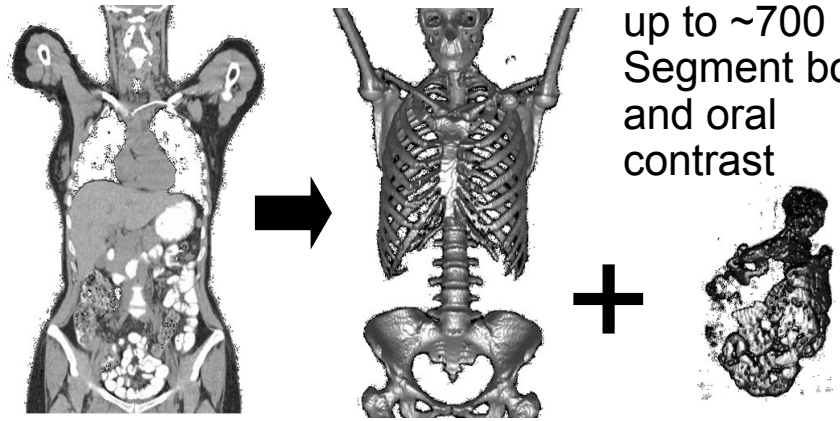




Bolus of iv contrast may cause artefacts in PET image. Can be identified on CT and uncorrected PET image. Use saline flush to reduce effect

Oral contrast

Enhancement up to ~700 HU. Segment bone and oral contrast



Oral contrast CT Bone Barium contrast

Summary: CT-based attenuation correction

- bi-linear scaling model validated in human tissue
- no diagnostic issues with iv contrast (dual injector)
- oral contrast effect can be corrected if wamted
- negative contrast (water) can be used instead
- CT and non-corrected PET used as reference
- respiration protocol, particularly for lung cancer
  - ✓ CT acquired with breath hold at partial expiration
  - ✓ PET gated for improved match of lung lesions

PET/CT radiation dosimetry: scan protocols

Effective FDG dose: $E_{int} = \Gamma_{FDG} \cdot A$, where $\Gamma_{FDG} = 19\ \mu Sv/MBq$

Effective CT dose: $E_{ext} = \Gamma_{CT} \cdot CTDI_{vol}$, where $\Gamma_{CT} = 1.47$ mSv/MGy

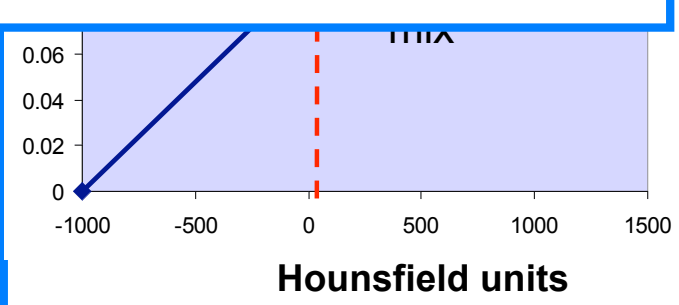
Scout	Spiral CT	PET	PET/CT
			
0.2-0.8 mSv	D-CT: 5 - 30 mSv LD-CT: 0.5 - 3 mSv	5 - 7 mSv	D-CT: 10.2 – 37.8 mSv LD-CT: 5.7 – 10.8 mSv LD + D: 10.7 – 40.8 mSv

Average total dose: 25 mSv

PET/CT scan protocol

- arms up (except neck)
- acquired with breath hold
- partial or full expiration
- 10 – 15 s scan time
- intravenous +/- oral contrast
- 120 kVp, 140 - 160 mAs

gram spiral CT



sed attenuation correction

- bi-linear scaling model
- threshold at ~ 50 HU
- kVp-dependent scaling
- correction for oral contrast
- little error from iv contrast
- artifacts from metal implants
- use CT or non-corrected PET
- ACF error < 15%
- validated in human tissue

- 10 mCi
- 90 min u
- 2 - 6 mi
- 4 - 15 b
- 10 - 40 min scan durati
- respiratory gating

- 2D-OSEM, 4i/8s; fully 3D-OSEM
- 5 mm axial smoothing

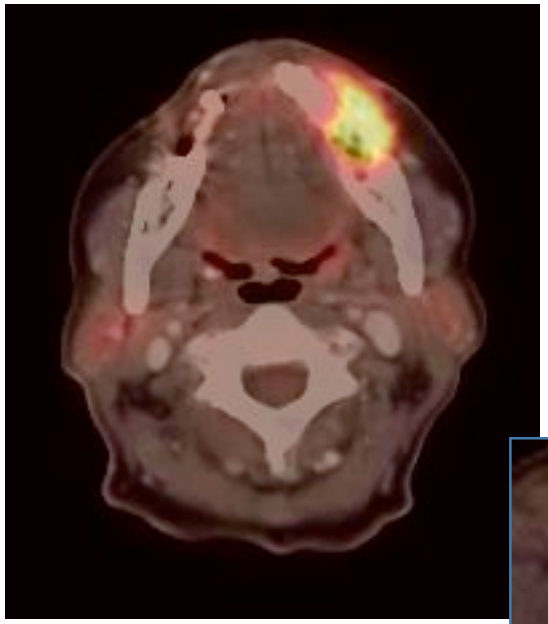
Principles of PET/CT

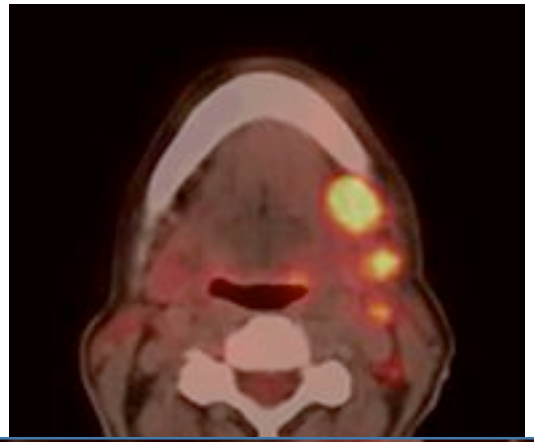
- principles of application

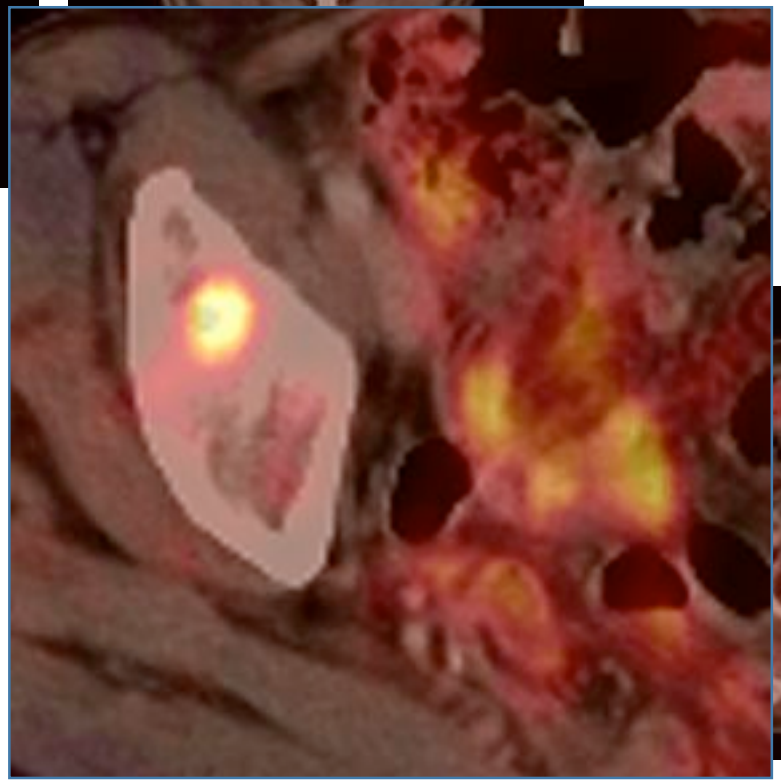
Mandibular cancer

biograph 16

Cancer Imaging an Tracer Developmer

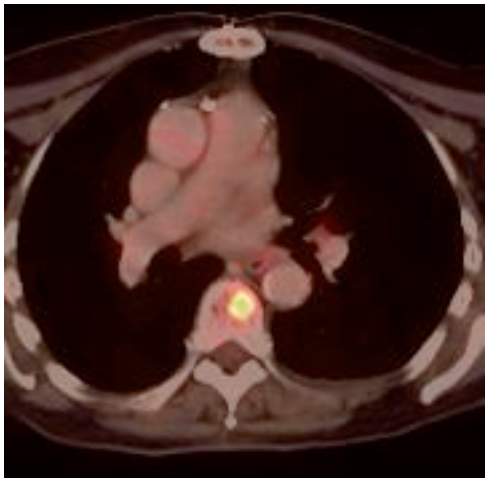




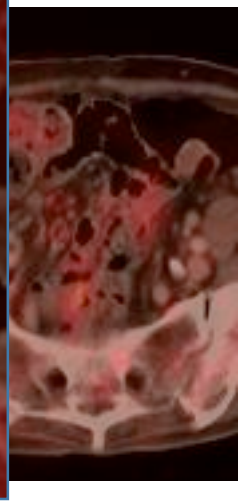


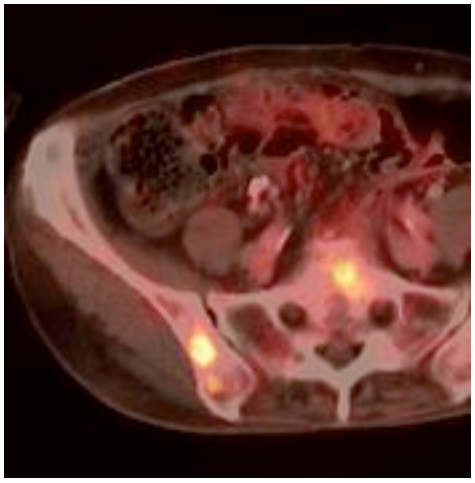
83 year-old female with mandibular cancer. PET/CT scan acquired pre-surgery identified 3 left-side positive nodes 5-12 mm in size with increased FDG uptake. Post surgery, pathology identified 35 nodes positive for cancer.

Primary (1.5 x 3.8 cm)



5 mm lytic spine lesion



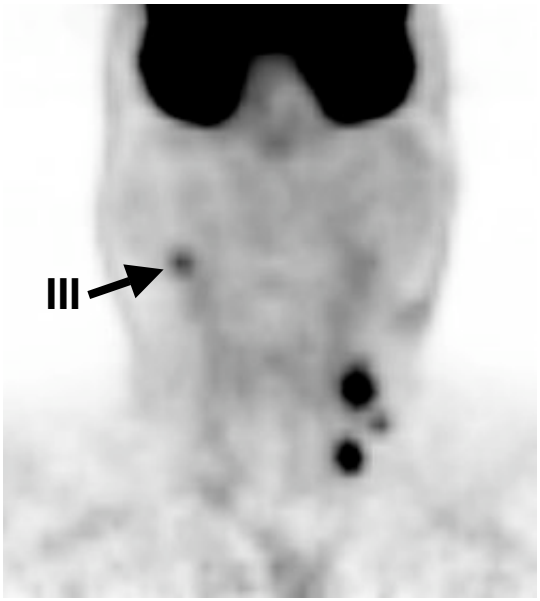


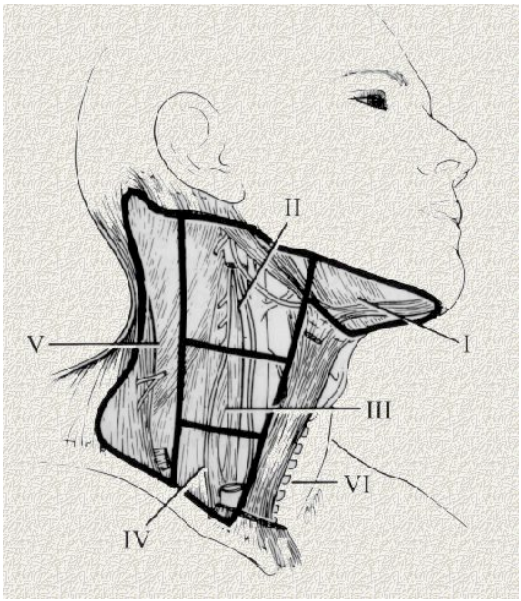
Bone lesions, 6-7 mm in diameter

Staging disease

biograph 16

Cancer Imaging an
Tracer Developmer

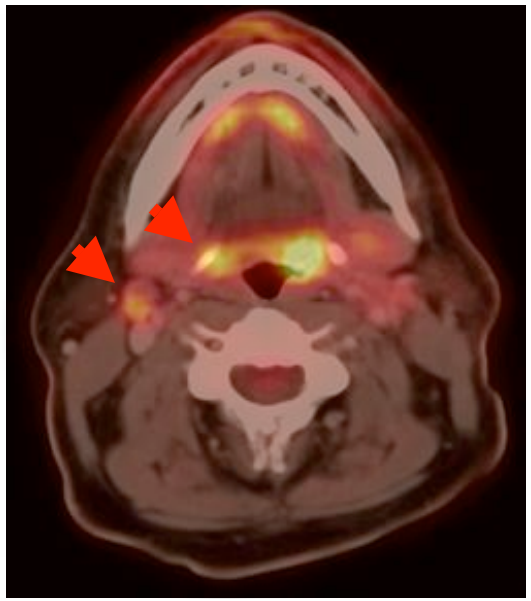


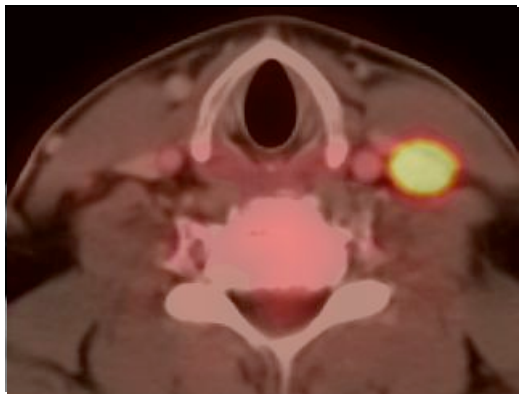


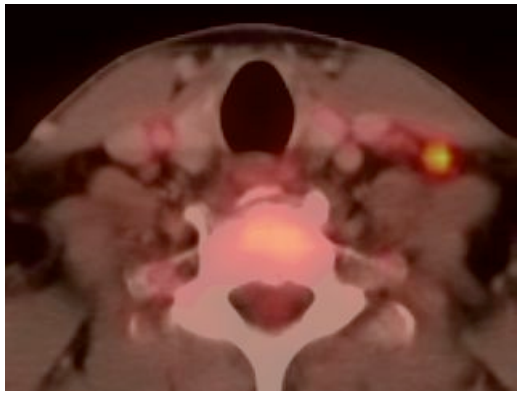
Left side: 9/30 nodes positive.
6/16 level IV; 3/5 level V (<1.5 cm)

Right side: 1/16 nodes positive.
1/12 level III (1.3 cm)

Primary cancer found in the right palatine tonsil





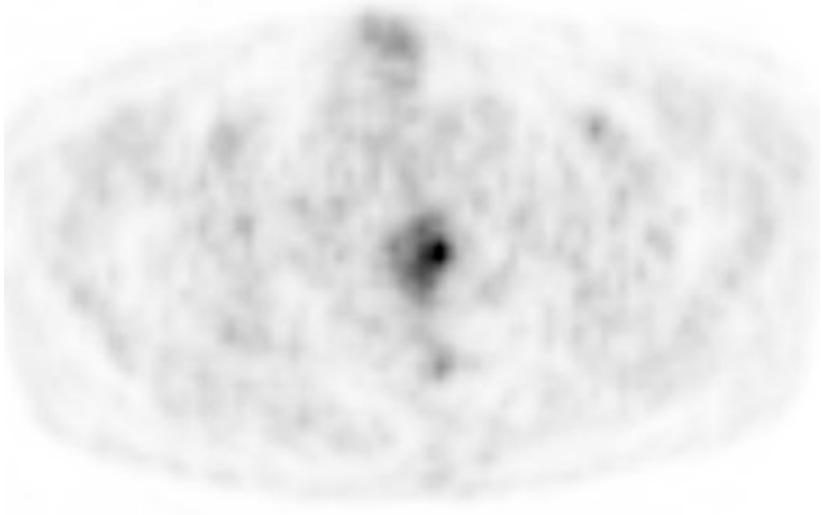


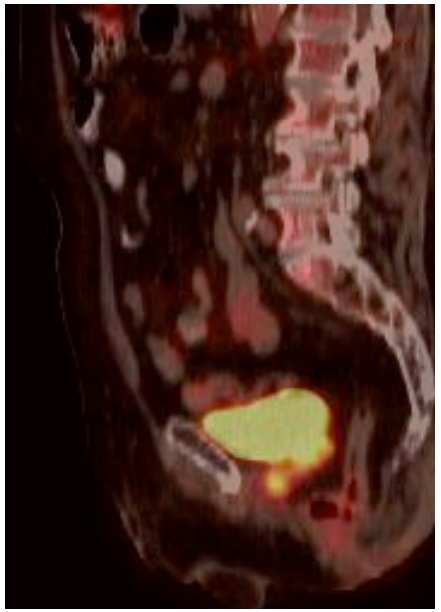
49 year-old male with mass in left neck. Unknown primary.

Prostate cancer

biograph 16

Cancer Imaging an Tracer Developmer





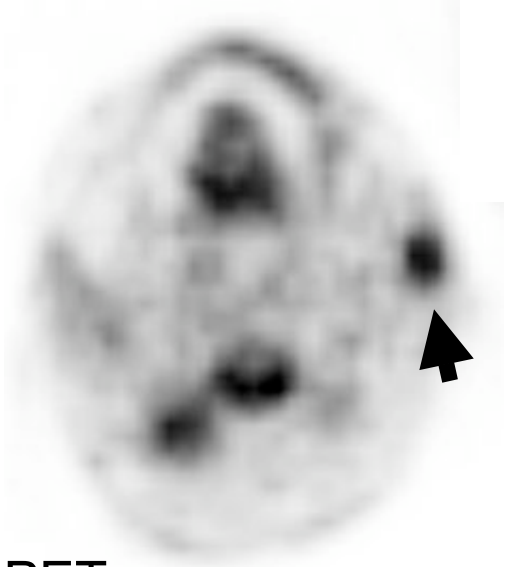
82 year-old male, 189 lbs, with 17 year history of prostate cancer, referred for PET/CT for staging following recent rise in PSA. Elevated uptake of FDG in left prostate bed (SUV=8.7) suspicious for recurrent disease. Metastatic uptake in L3, sacral and right proximal femur noted.

Scan protocol: **CT: 168 mAs, 120 kV, 5 mm slices at 0.75 mm**

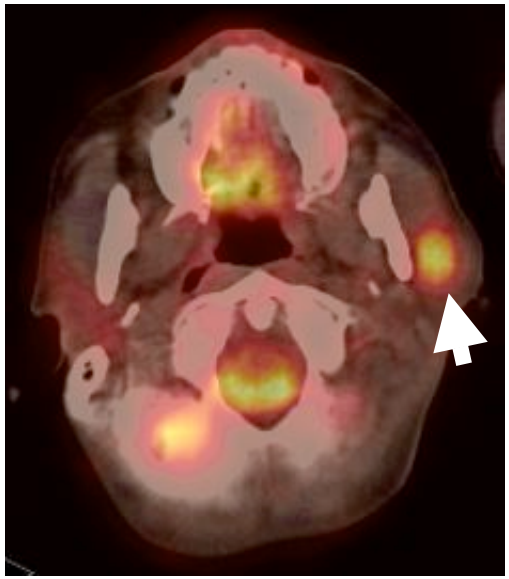
PET: 11.1 mCi FDG, 120 min pi, 3 min/bed, 8 beds; 4i/8s; 5F

Benign pleomorphic adenoma

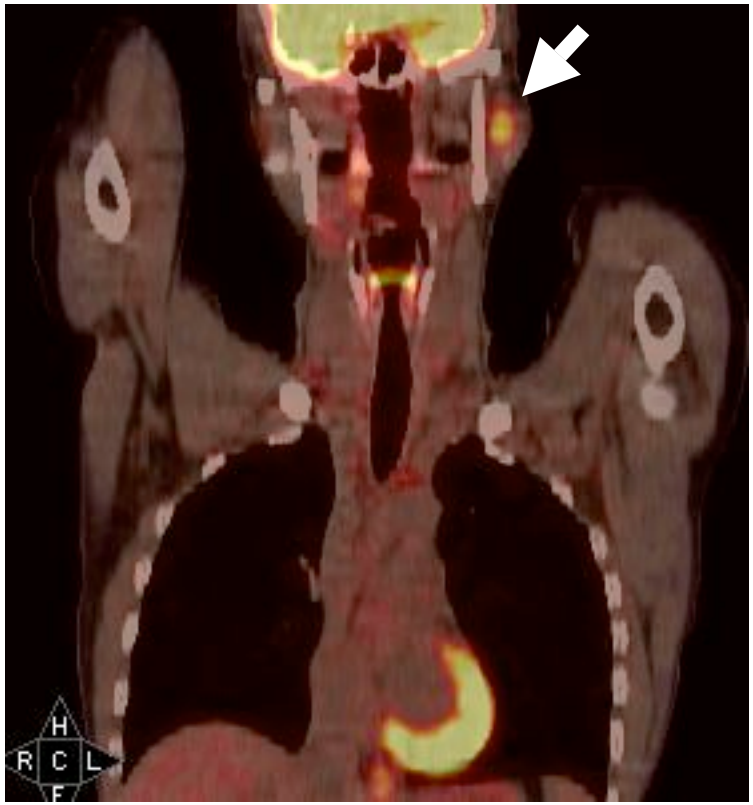
Cancer Imaging and Tracer Development

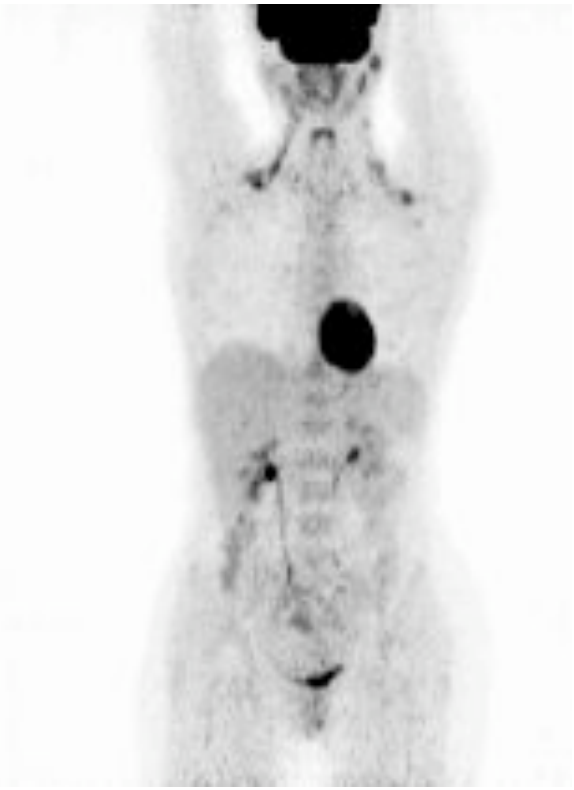


PET



PET/CT



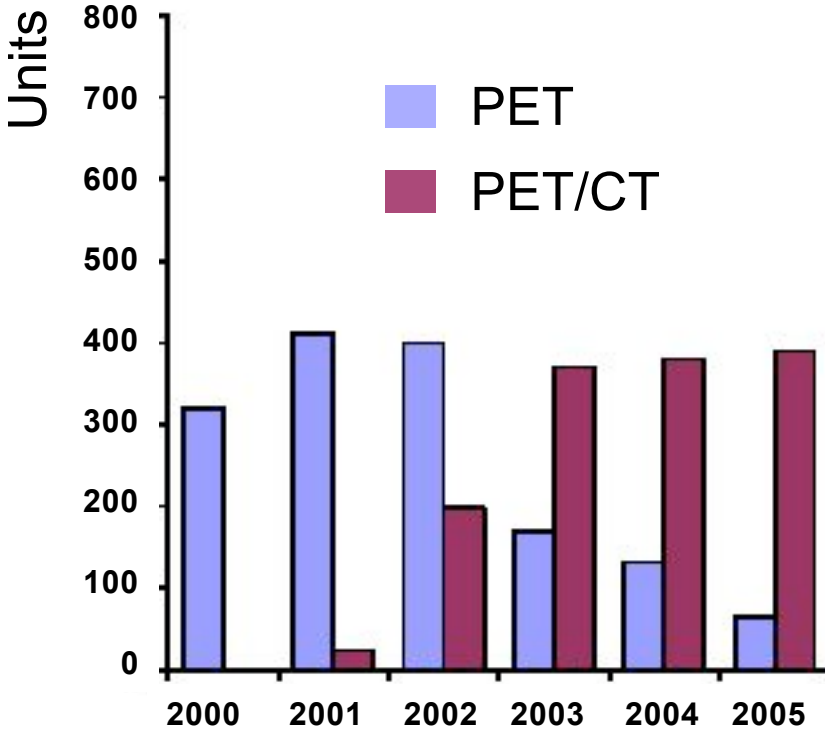


- 10.1 mCi injected; 133 lbs; 143 min post-injection;
- 7 bed positions; 2 min/bed position
- SUV (mean) = 6

Summary: the impact of FDG-PET/CT

- localize pathological FDG uptake
- distinguish normal uptake from pathology
- improve accuracy of interpretation
- improve confidence of clinical reading
- add value to *both* CT *and* PET for staging
- improve accuracy of therapy planning and biopsy
- accurately monitor therapeutic response
- *reduce scan duration and increase throughput*
- *simplify scheduling for patients and physicians*

The future for PET/CT



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PET/CT will likely replace PET even without extensive clinical validation of PET/CT compared to PET only.

- greater clinical flexibility
- yields better clinical results
- increased confidence
- CT can be used stand-alone

- 99% PET/CT by 2010
- 10% growth rate (units)
- PET/CT is 100% of growth