4D PET: promises and limitations

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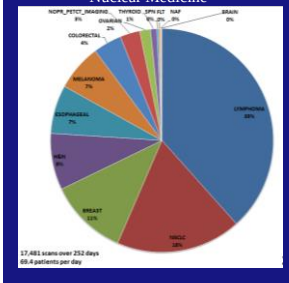
Outlines

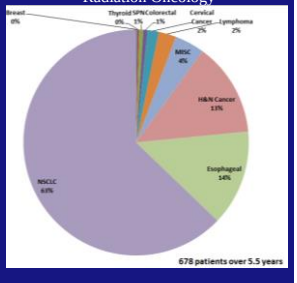
- Background
- Gating techniques:
  - Deep inspiration breath hold
  - 4D PET/CT
- Non-gating techniques
  - Average CT (0.87 mSv) to match the temporal resolution of PET
- Summary

PET/CT applications at M.D.Anderson

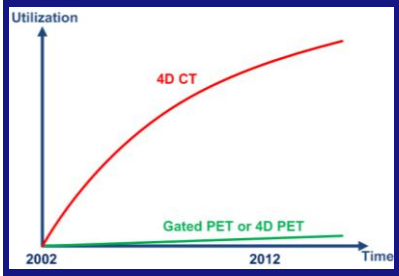
Nuclear Medicine



Radiation Oncology



Utilization of 4D-CT and 4D-PET

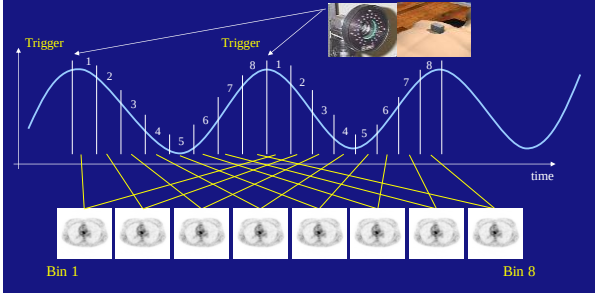


1 PET before treatment
Longer setup time (5 min)
Longer acq. time (10 min)
Longer proc. time (10 min)
Patient comfort
Effectiveness?

4D PET/CT

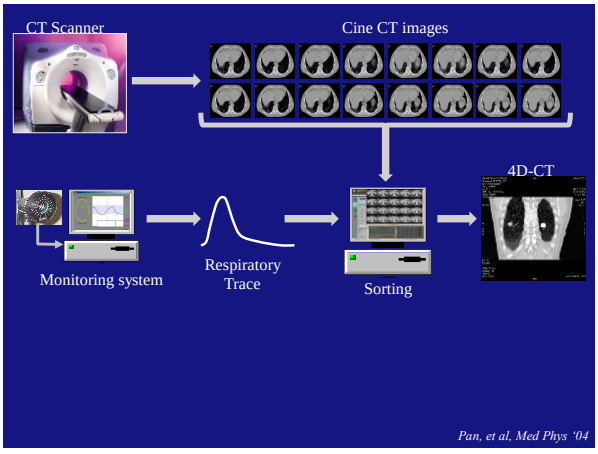
(challenging to perform in the clinic)

4D PET

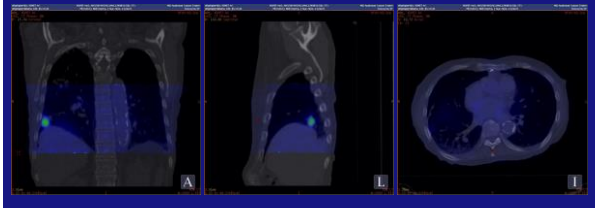


Longer acquisition time

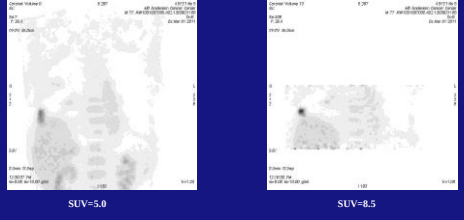
Generates complete image-set for each respiratory phase



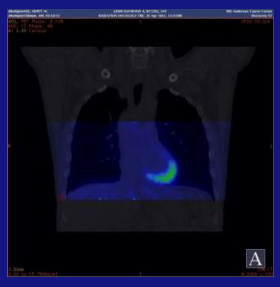
4D PET/CT patient study

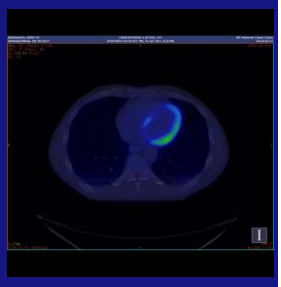


4D PET patient study



4D PET/CT of the heart





Which one is not a limitation of a 4D PET scan (relative to a regular PET scan)?

20% 1. Longer acquisition time

10% 2. Higher radiation exposure from F18-FDG

10% 3. More complex in set-up

3% 4. No reimbursement for 4D PET

13% 5. More complex in post-processing

Which one of the following is not a limitation of a 4D PET scan compared with a regular PET scan?

1. Longer acquisition time
2. Higher radiation exposure from F18-FDG
3. More complex in set-up and post-processing
4. No reimbursement for 4D PET
5. Need 4D CT for accurate quantitation

Ref: Nehmeh, SA, et al, Four-dimensional (4D) PET/CT imaging of the thorax. Med Phys 2004

Which CT data should be used for attenuation correction of the 4D PET data?

17%	1.	End-inspiration CT
17%	2.	End-expiration CT
3%	3.	Free-breathing CT
13%	4.	4D CT
13%	5.	Average CT

Which CT data should be used for attenuation correction of the 4D PET data?

1. End-inspiration CT
2. End-expiration CT
3. Free-breathing CT
4. 4D CT
5. Average CT

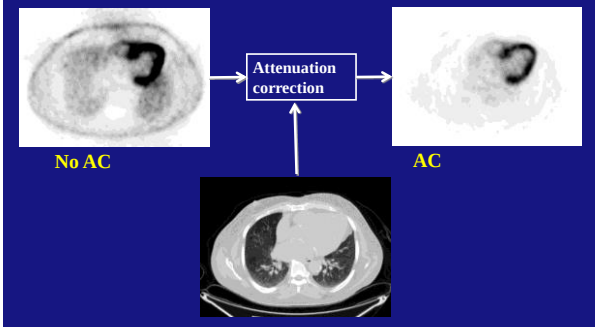
Ref: Nehmeh, SA, et al, Four-dimensional (4D) PET/CT imaging of the thorax. Med Phys 2004

Clinical impact

	Nuc Med (Osman, JNM 05)	Rad Onc (Liu IJORBP 06)	Rad Onc (Aristophanous, IJORBP 11)	Nuc Med (Chi IJORBP 08)	Cardiology (Gould JNM 07)
# Patients	300	152 (57% III & VI)	10	216	259
Study	PET/CT	4D-CT	4D-PET	PET/CT w/ACT	Cardiac PET/CT w/ACT
Misalignment Motion	2%	11% > 1cm	All < 1 cm	15% Δ SUV > 20%	40%
% Δ Volume			significant	8% ≥ 100% (17)	
Centroid shift				6% ≥ 5 mm (13)	

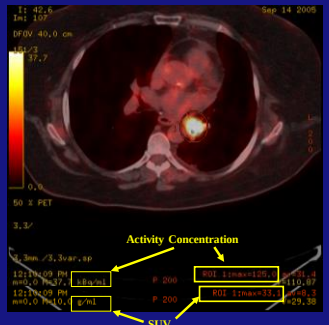
No evidence that 4D PET improves planning

Quantification of PET data



Quantitation of PET needs CT data

Activity concentration and SUV



$$SUV\ (g/ml) = \frac{\text{Measured activity (k Bq / ml)}}{\frac{\text{Injected dose(k Bq)}}{\text{Body weight (g)}}}$$

1 mCi = 3.7 x 10^7 dps = 3.7 x 10^7 bequerel (Bq)

Differences between PET and CT

PET

- scan of 15 cm for 2 to 5 mins,
- spatial resolution ~ 5-10 mm
- temporal resolution ~ breathing cycle

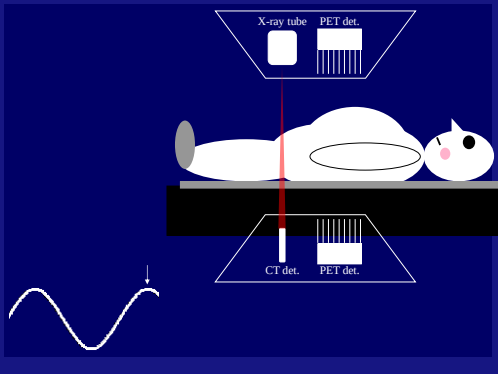
CT – 0.5 sec rotation

- scan of 90 cm < 20 sec
- spatial resolution < 1 mm
- temporal resolution < 1 sec

Potential misalignment between PET and CT images

Free-breathing or breath-hold CT ?

Helical CT data acquisition

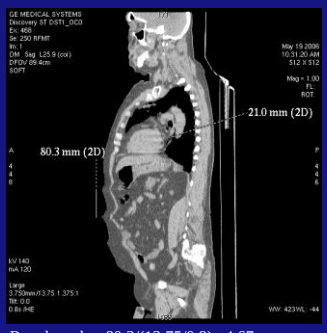


Breathing Artifacts

Protocol: 16x0.625 mm, 0.8 s gantry rotation, pitch 1.375:1

Speed: 13.75 mm/0.8 s or 17.2 mm/s

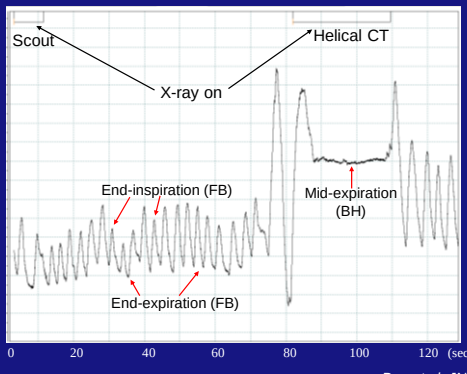
Breathing artifacts to physiological info



Breath cycle= 80.3/(13.75/0.8)= 4.67 s

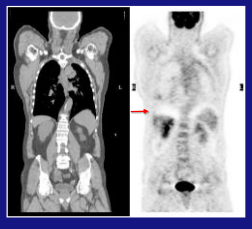
Heart rate= (21/(13.75/0.8)) $^{-1}$*60= 49 bpm

Misalignment in breathing states



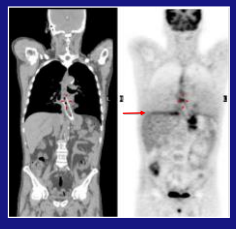
Pan et al, JNM, 2005

Mis-matched PET-CT data sets



Mismatch 1:

CT diaphragm position lower than PET



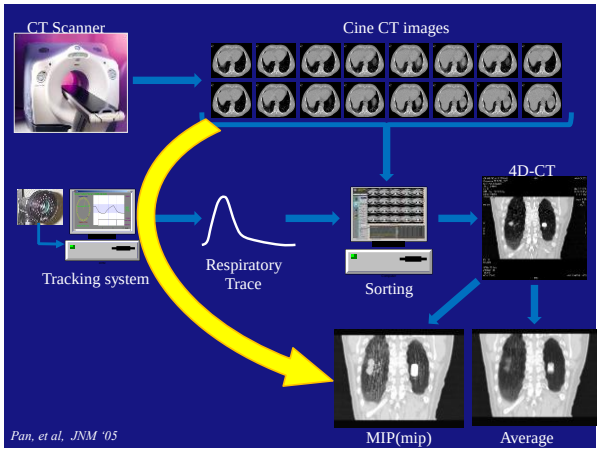
Mismatch 2:

CT diaphragm position higher than PET

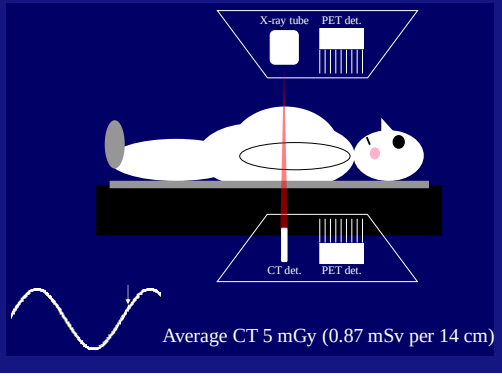
Average CT (ACT)

Data acquired at high temporal resolution and averaged over one breath cycle

Attenuation correction, RT dose calculation, IGRT

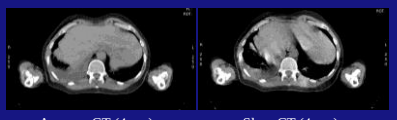


Cine CT Data Acquisition



Average CT and slow CT

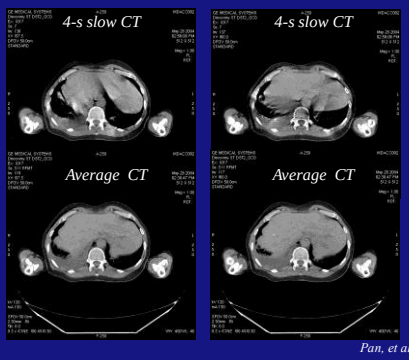
0.5 sec rotation 4 sec rotation



Average CT (4 sec) Slow CT (4 sec)

Average CT is better than slow CT

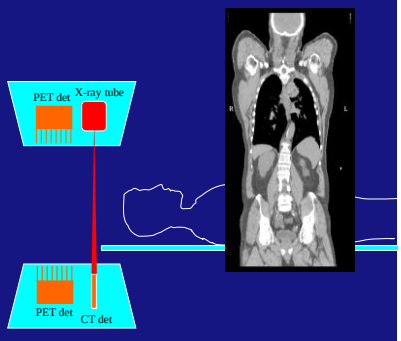
(2 adjacent CT slices of 2.5 mm apart)



Pan, et al, Med Phys '06

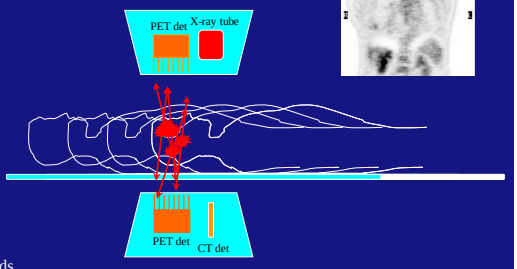
PET/CT protocol with ACT

Acquire helical CT



PET/CT protocol with ACT

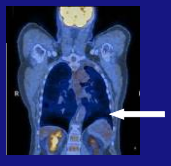
Acquire helical CT ➡ Acquire PET



7-9 beds
2-5 min/bed

PET/CT protocol with ACT

Acquire helical CT ➡ Acquire PET

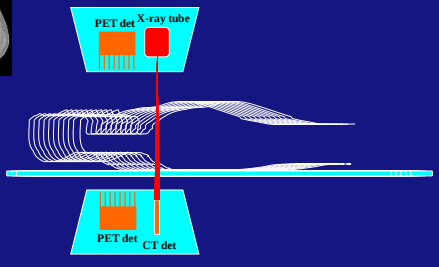


Misalignment between PET and CT data?

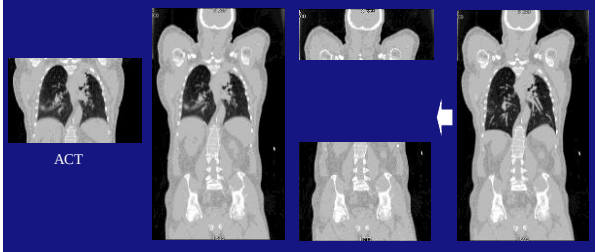
PET/CT protocol with ACT

Acquire helical CT ➡ Acquire PET ➡ Acquire cine CT

cine duration ~ 5 s



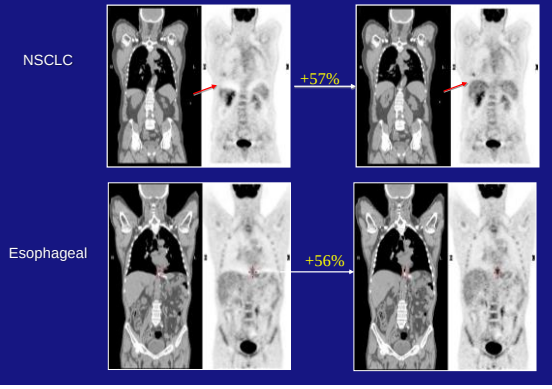
Combined CT



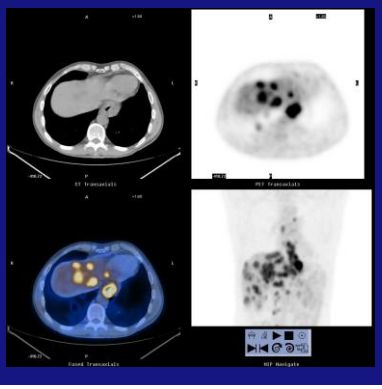
Pan, et al, Med Phys '06

Clinical Data

Clinical Studies

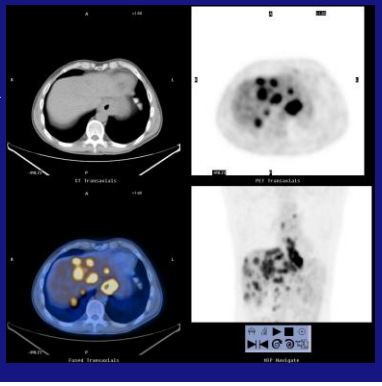


Lung or liver lesion?

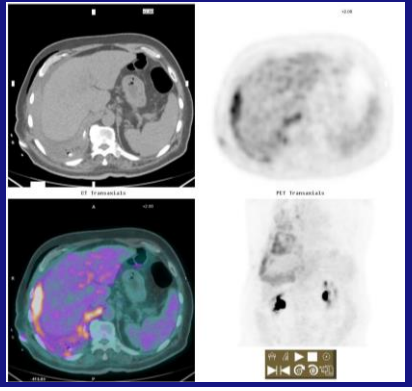


Lung lesion or liver lesion?

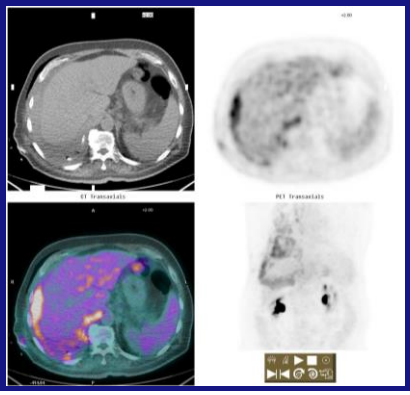
Average CT



Colorectal cancer

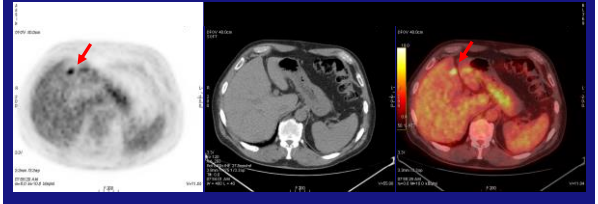


Colorectal cancer

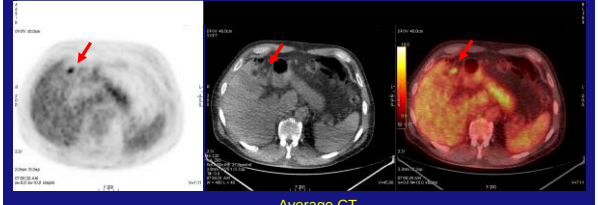


Average CT

Inside the liver?

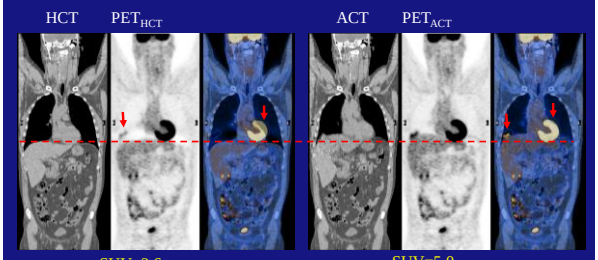


Outside the liver

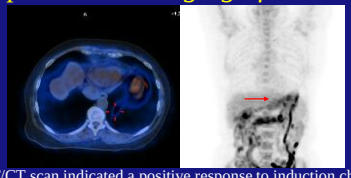


Average CT

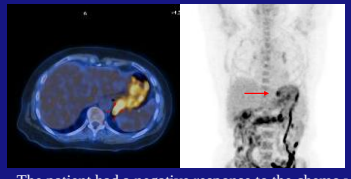
Tumor and cardiac imaging



Improve the restaging after chemo



PET/CT scan indicated a positive response to induction chemo with HCT.

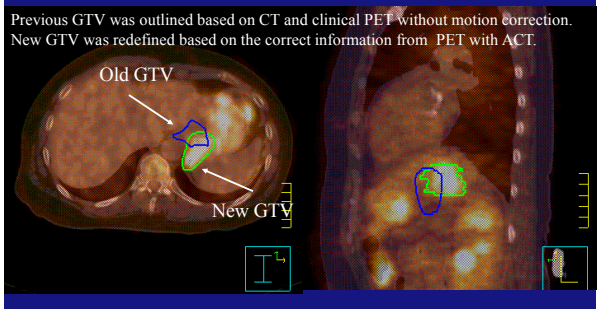


The patient had a negative response to the chemo with ACT.

Pan, et al, Med Phys '08

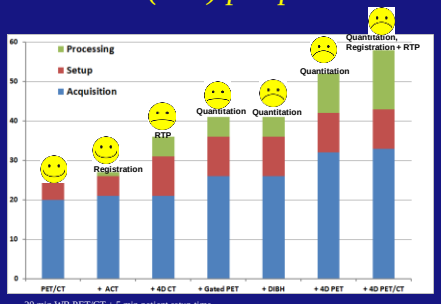
Impact on treatment planning

Previous GTV was outlined based on CT and clinical PET without motion correction.
New GTV was redefined based on the correct information from PET with ACT.



Pan, et al, Med Phys '08

Total time (min) per procedure

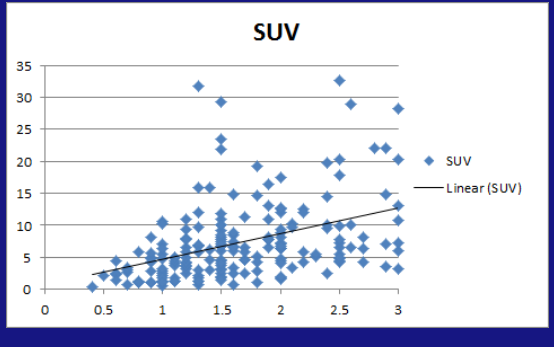


1. 20 min WB PET/CT + 5 min patient setup time
2. Patient comfort threshold is about 30 min maximum with arms up
3. ACT: Average CT
4. DIBH: Deep inspiration BH
5. RTP: Radiation Therapy Planning
6. Gated PET: end expiration phase PET

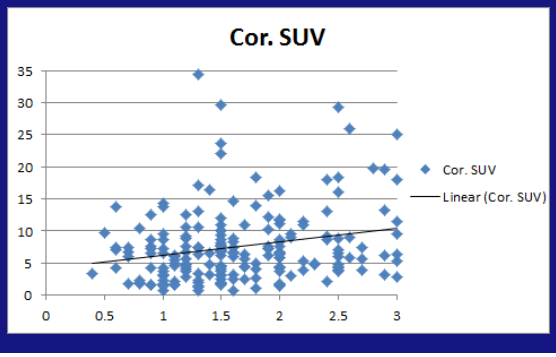
Summary

- Respiratory gating PET can improve quantification, yet is challenging to implement in the clinic
- Respiratory gated or 4D-CT is routine in RT
- Average CT can improve registration of CT and PET

193 SBRT lesions (37<1 cm<112<2 cm<44<3 cm)

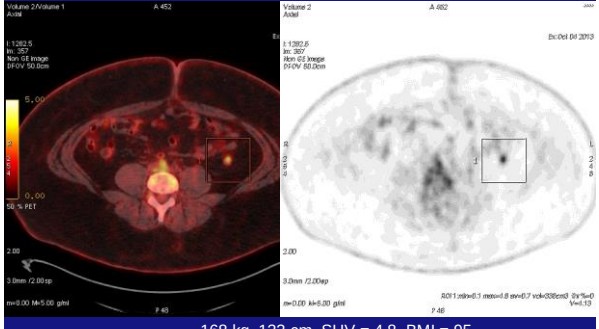


193 SBRT lesions (37<1cm, 112<2cm and 44<3cm)



Some factors other than respiratory motion affecting quantification

Incorrect patient info

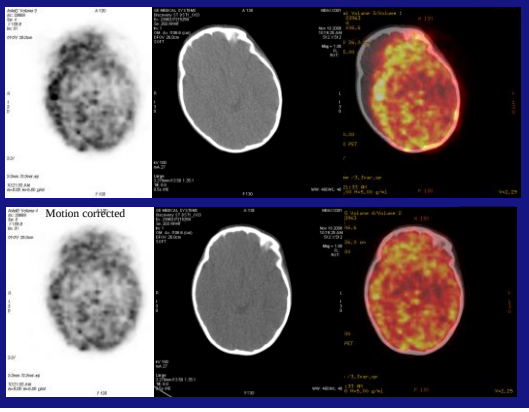


168 kg, 133 cm, SUV = 4.8, BMI = 95

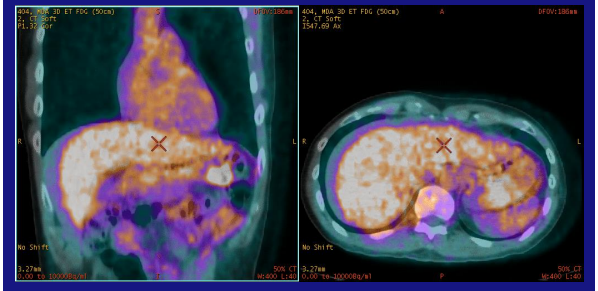
Correct patient info

133 kg, 168 cm, SUV = 3.8, BMI = 47

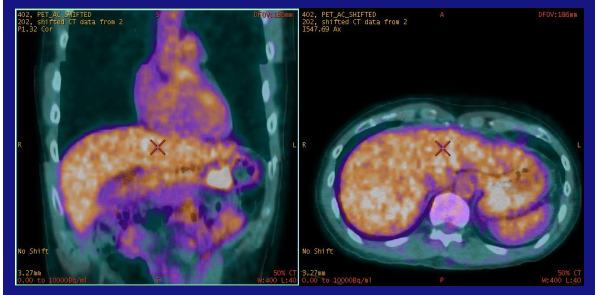
Patient head motion



Patient motion during the scan

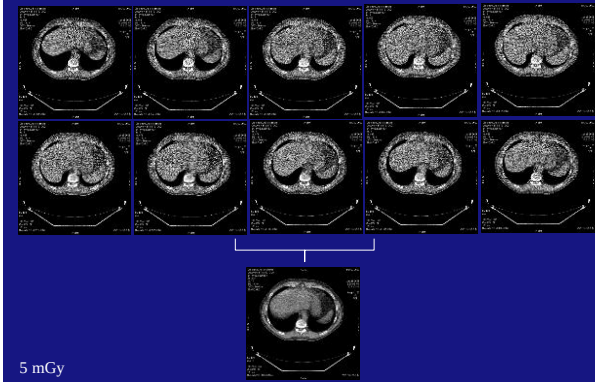


Correction of patient motion



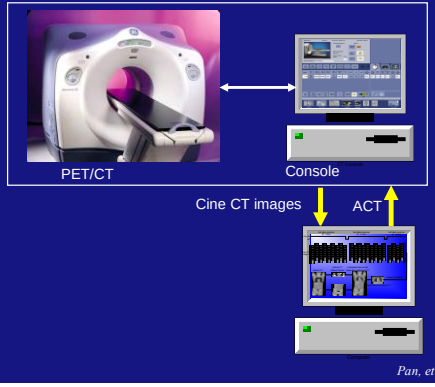
Cine acquisition for average CT

(120 kV, 8 X 2.5 mm, 10 mA, 5 s duration)



5 mGy

PET/CT with ACT



Pan, et al, Med Phys '07

Which one is not correct for average CT ?

10% 1. It has a temporal resolution of about one breath cycle

10% 2. It can be used for dose calculation in RT

10% 3. It can be used in registration with CBCT in IGRT

10% 4. It can be derived from 4DCT

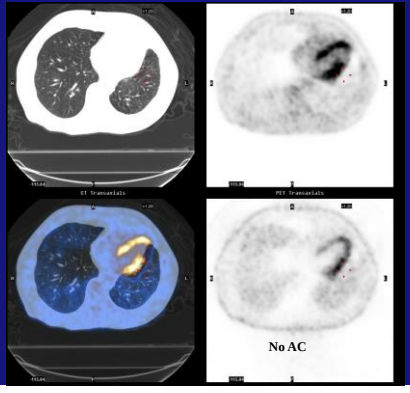
3% 5. It has a well-defined boundary for a moving object

Which one of the following is not correct for average CT ?

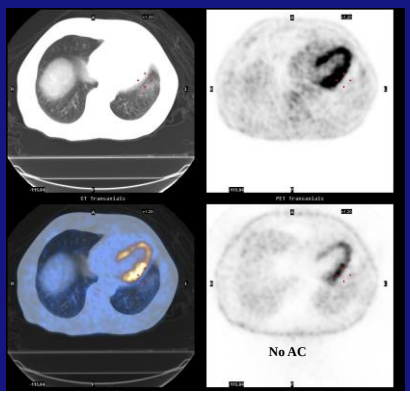
1. It has a temporal resolution of one breath cycle
2. It can be used for dose calculation
3. It can be used in registration with CBCT for IGRT
4. It can be derived from 4DCT
5. It has a well-defined boundary for the diaphragm

Ref: Pan T, et al, Attenuation correction of PET images with respiration-averaged CT in PET/CT. JNM, 2005. 46(9): p.1481-7

Cardiac imaging



Cardiac imaging



Average CT

Oncology PET/CT dose estimate

Injection dose: 10 mCi per patient

1 mCi = 3.7 x 10^7 dps = 3.7 x 10^7 bequerel (Bq)

Radiation dose: 7 mSv from PET
5 to 10 mSv from CT
< 0.5 to 1 mSv from ACT

Radiation dose: 3.6 mSv from the environment

The standardized update value measured in PET is <u>not</u> dependent on

37% 1. Patient height
20% 2. Patient weight
13% 3. Injected activity (Bq)
17% 4. Measured activity concentration (kBq/ml)
13% 5. Calibration of the PET system

The standardized update value measured in PET is <u>not</u> dependent on

1. Patient height
2. Patient weight
3. Injected activity (Bq)
4. Measured activity concentration (kBq/ml)
5. Calibration of the PET system

Ref: Huang, SC, Anatomy of SUV. Standardized uptake value. Nucl Med Biol, 2000. 27(7): p.643-6