Pitfalls and Remedies in PET/CT imaging for RT planning

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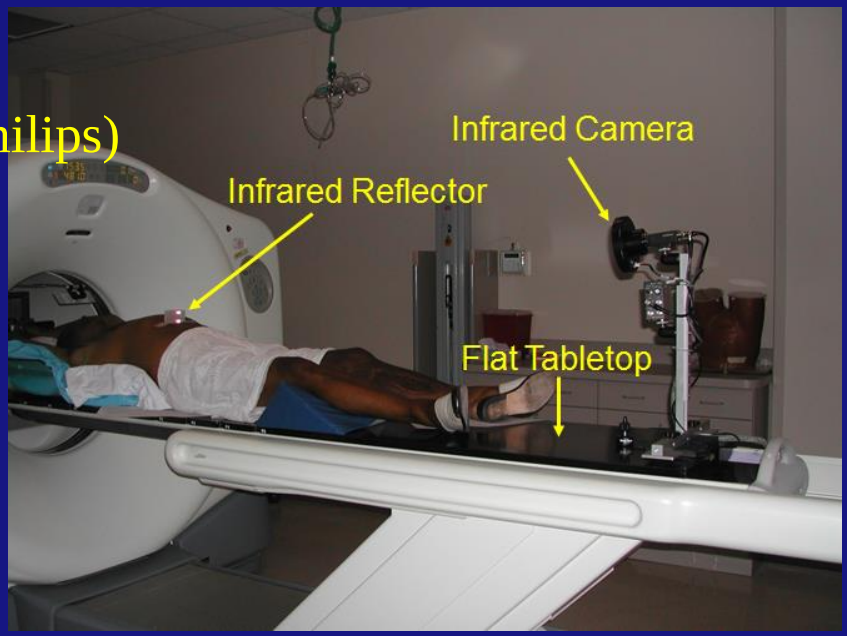
Outlines

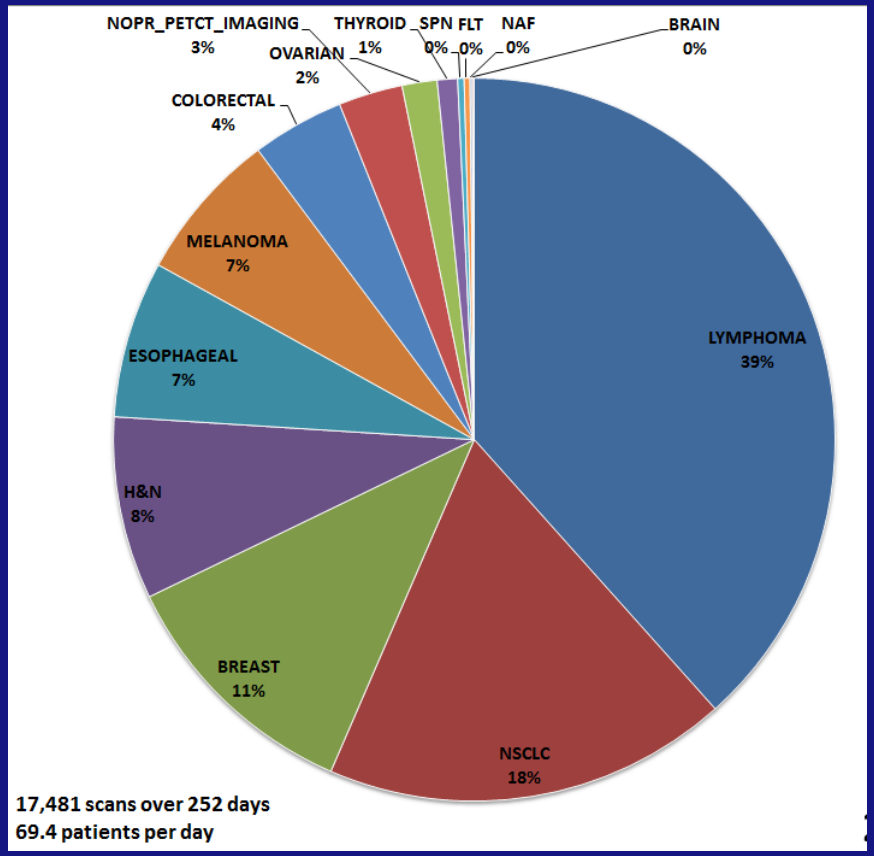
- Background
- Average CT (< 1 mSv) to reduce mis-alignment of PET and CT
  - Automatic processing without operator interaction
- Two different implementations
  - Average CT w/o gating (this talk)
  - Average CT w/ gating (GE/Siemens/Philips)
- Summary



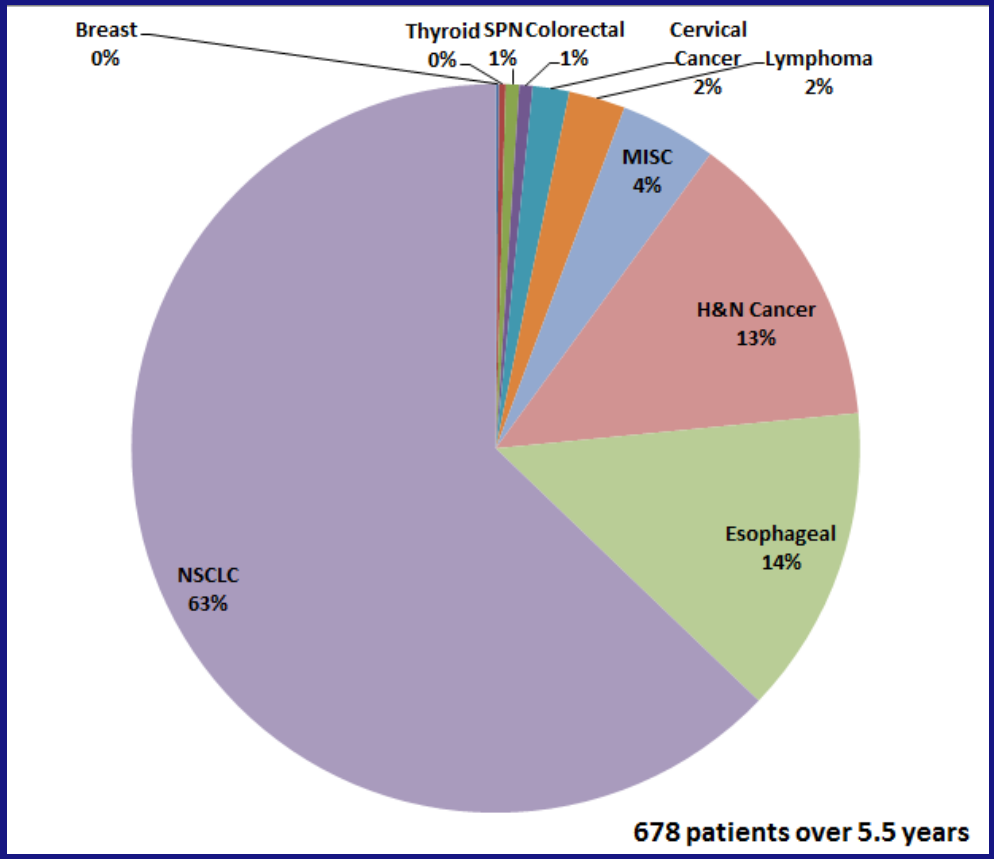
PET/CT applications at M.D.Anderson

- Majority for diagnosis and staging of cancer
- One PET/CT scan per patient prior to treatment

Diagnostic Imaging

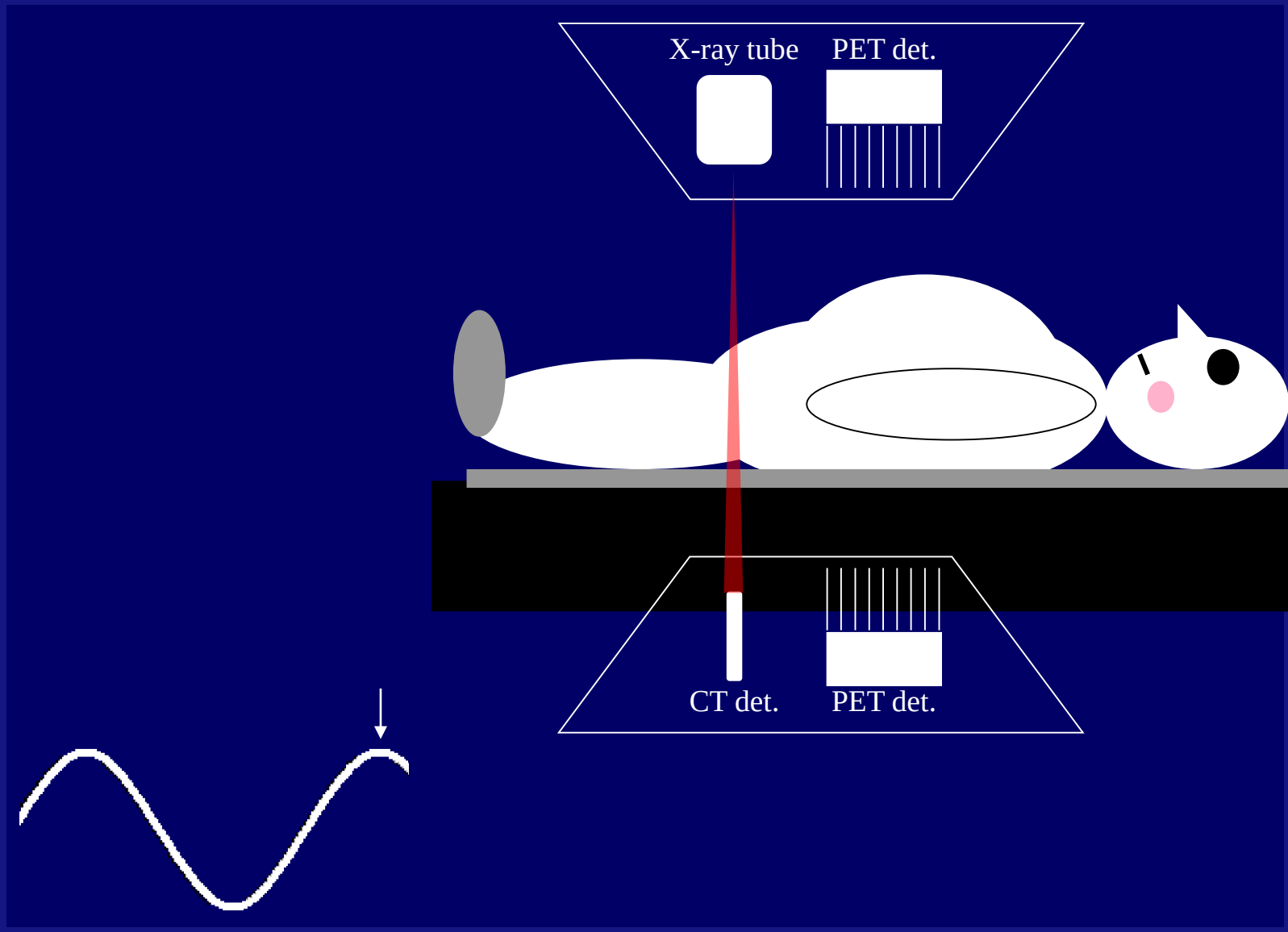


Radiation Oncology

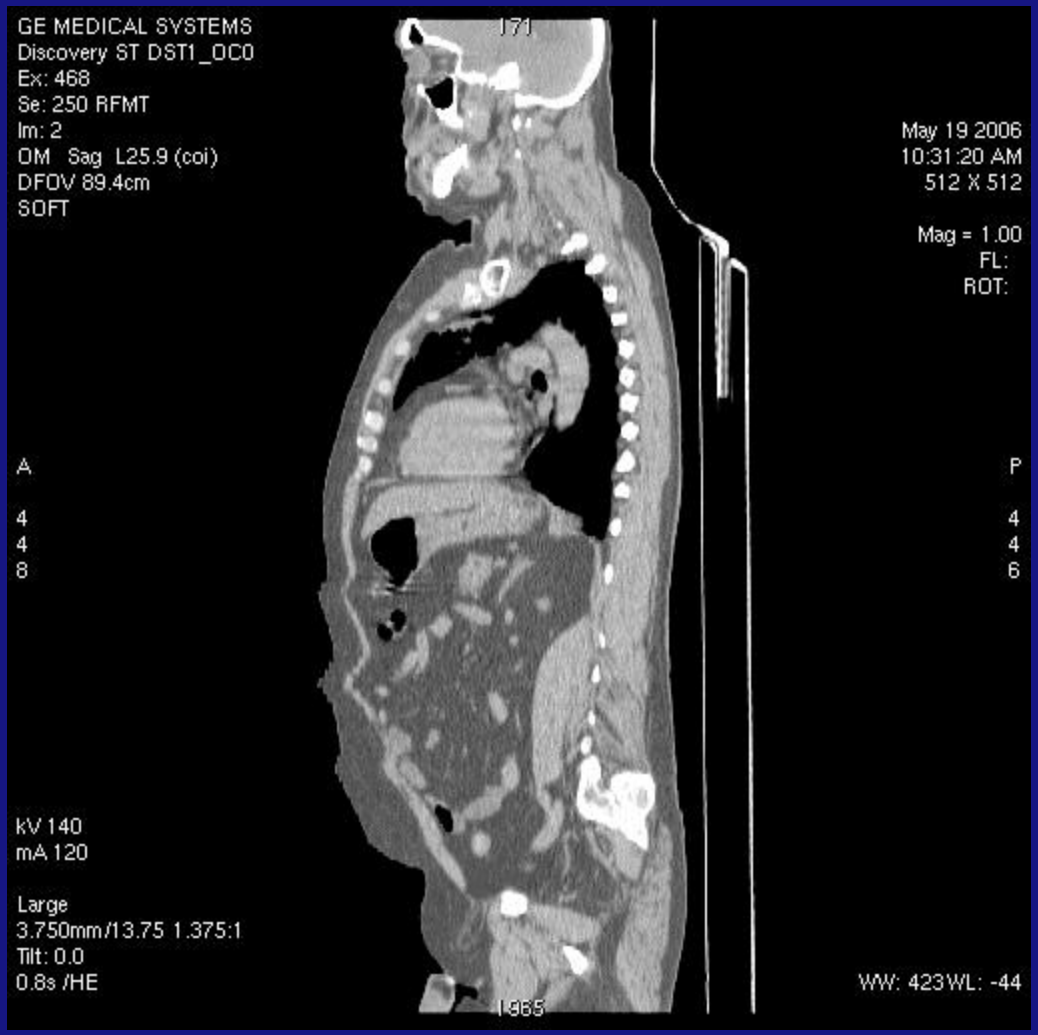


Free-breathing or breath-hold in CT of PET/CT ?

Helical CT data acquisition



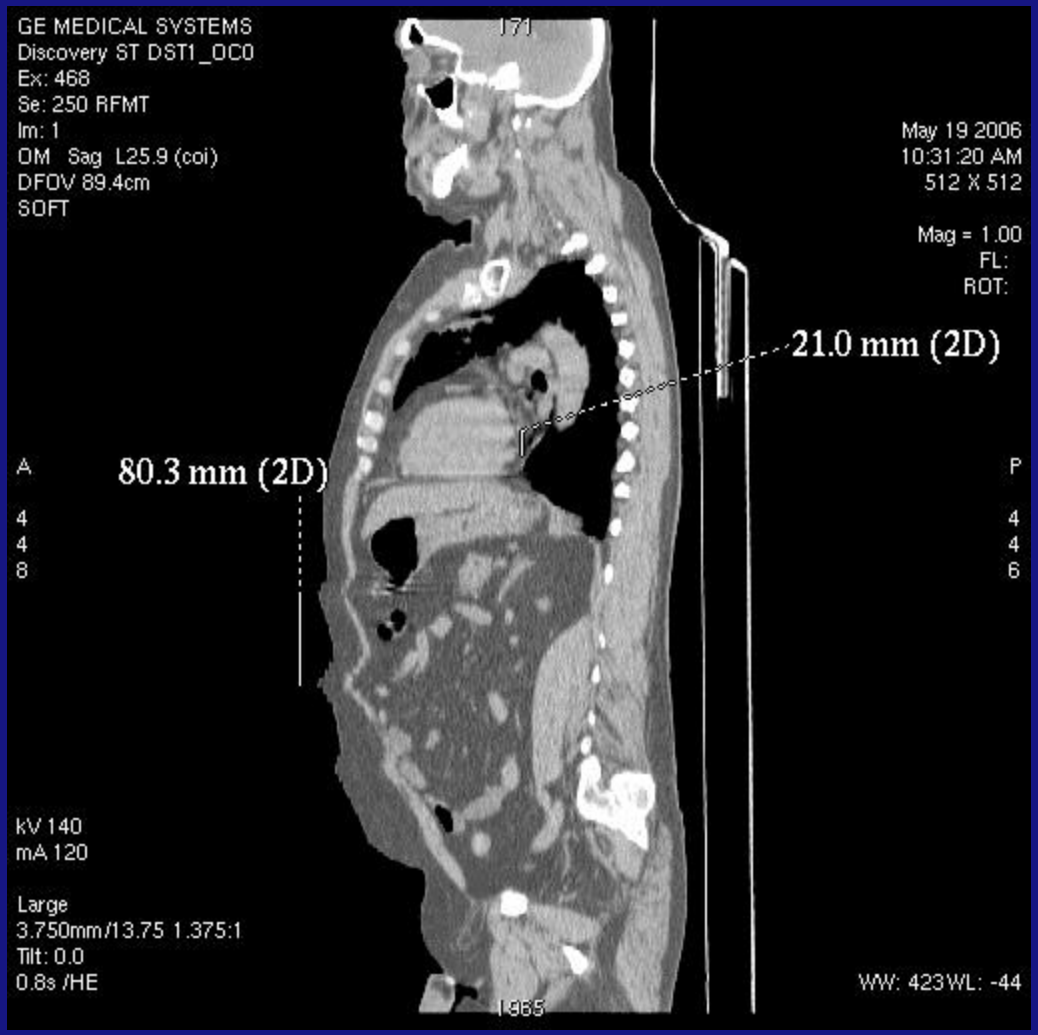
Breathing Artifacts



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

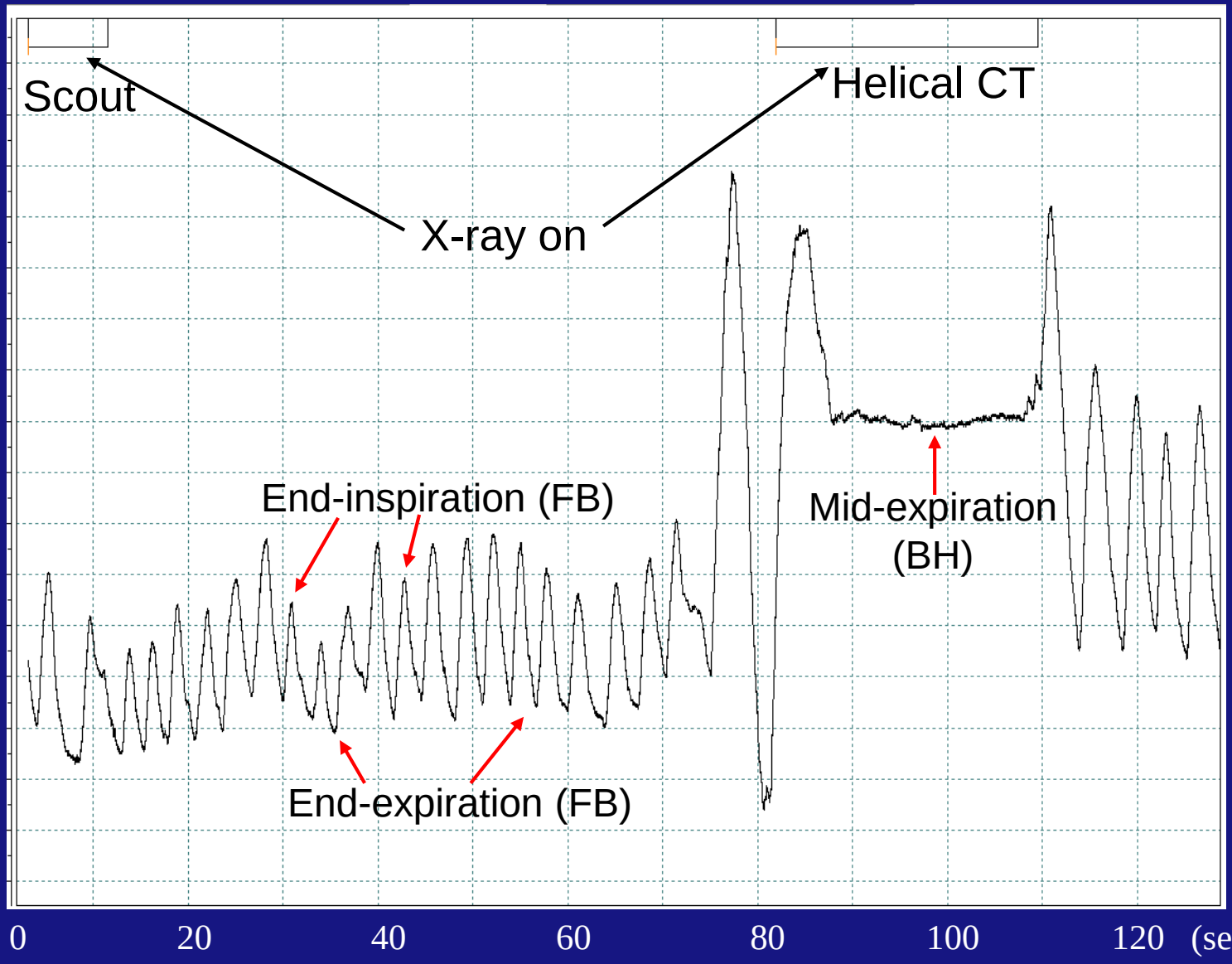


Breath cycle= 80.3/(13.75/0.8)= 4.67 s

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

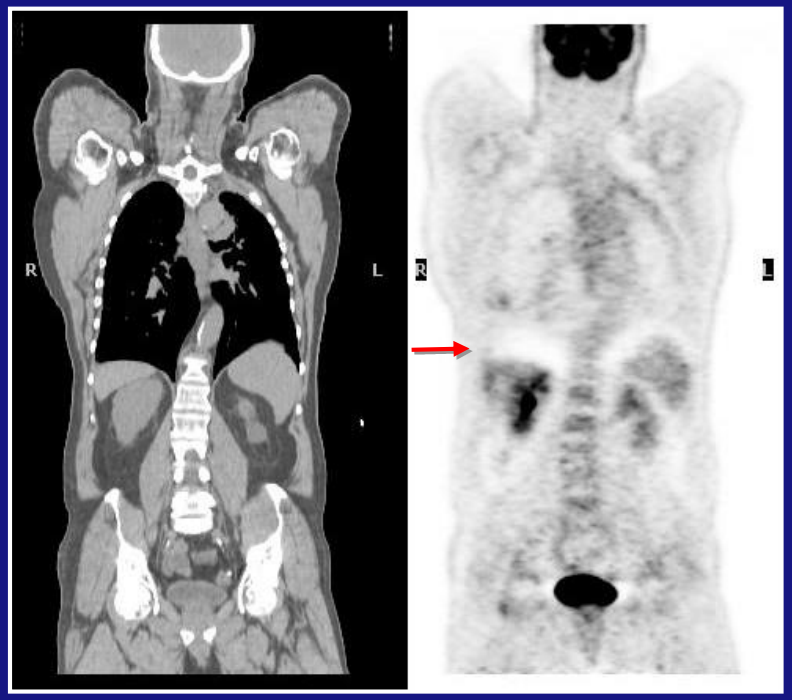
Registration of Free-Breathing CT and PET maybe like

Misalignment in breathing states



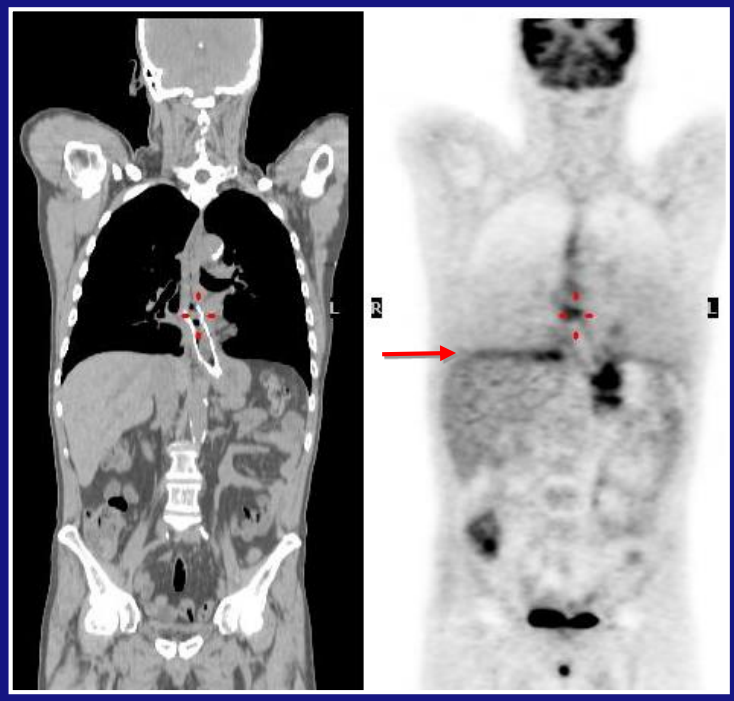
Pan et al, JNM, 2005

Mis-matched PET-CT data sets



Mismatch 1:

CT diaphragm position lower than PET



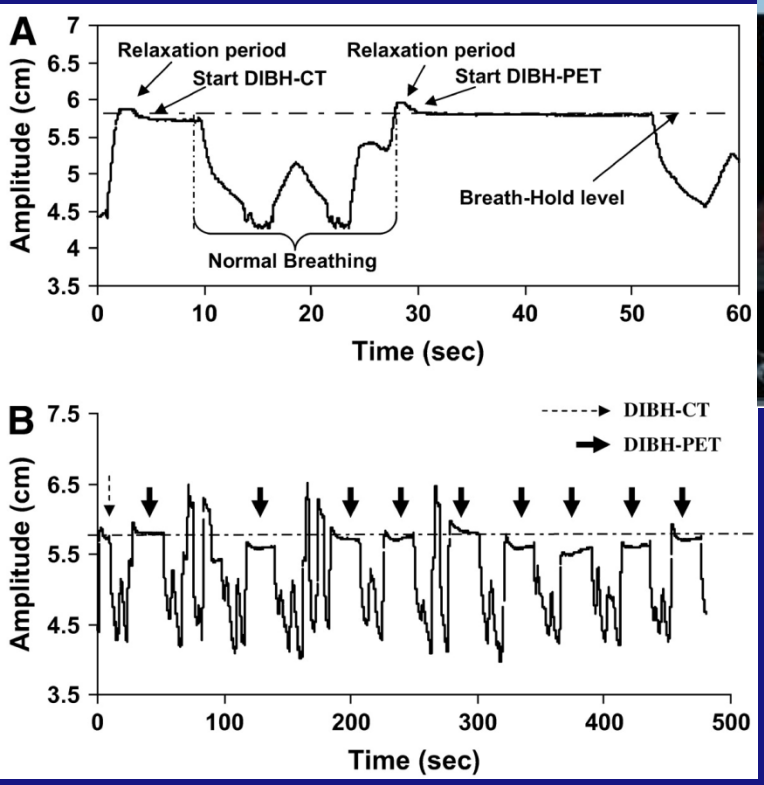
Mismatch 2:

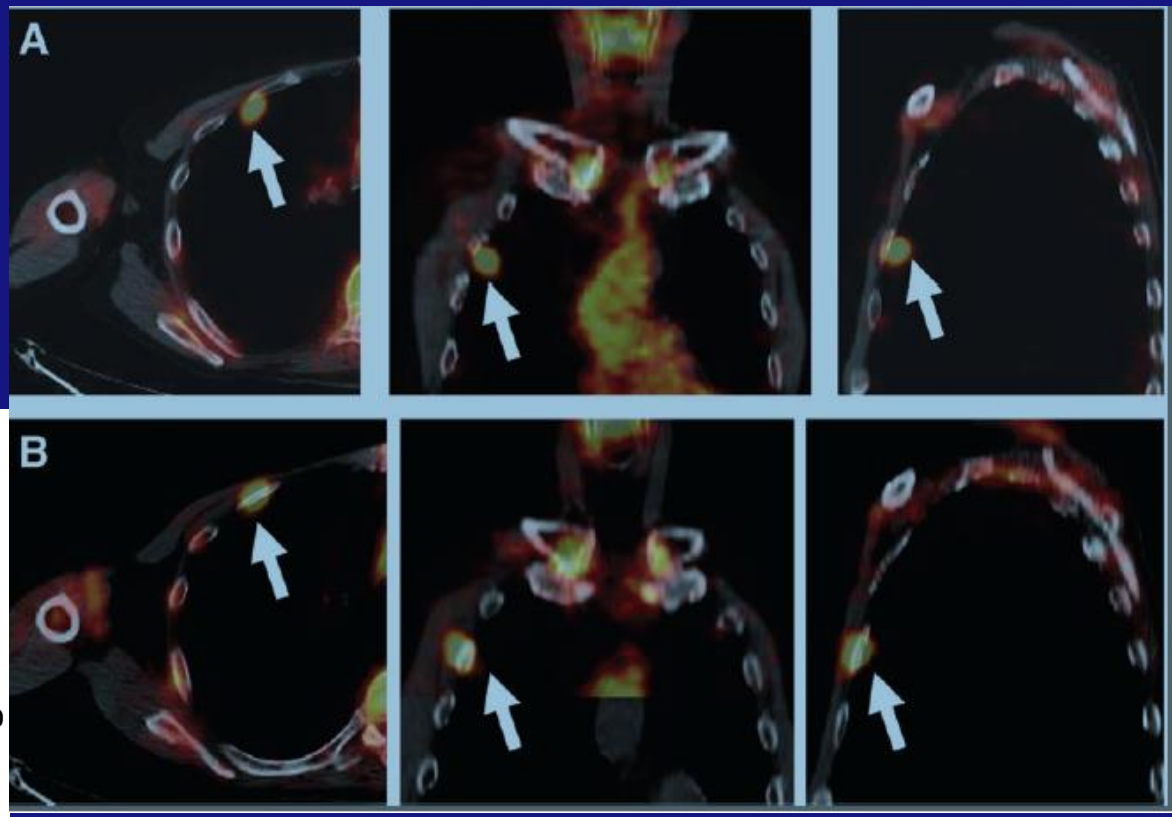
CT diaphragm position higher than PET

Deep inspiration breath-hold PET/CT

Deep inspiration breath-hold (3 min)

FB PET/CT





DIBH PET/CT

5 sec DBH CT

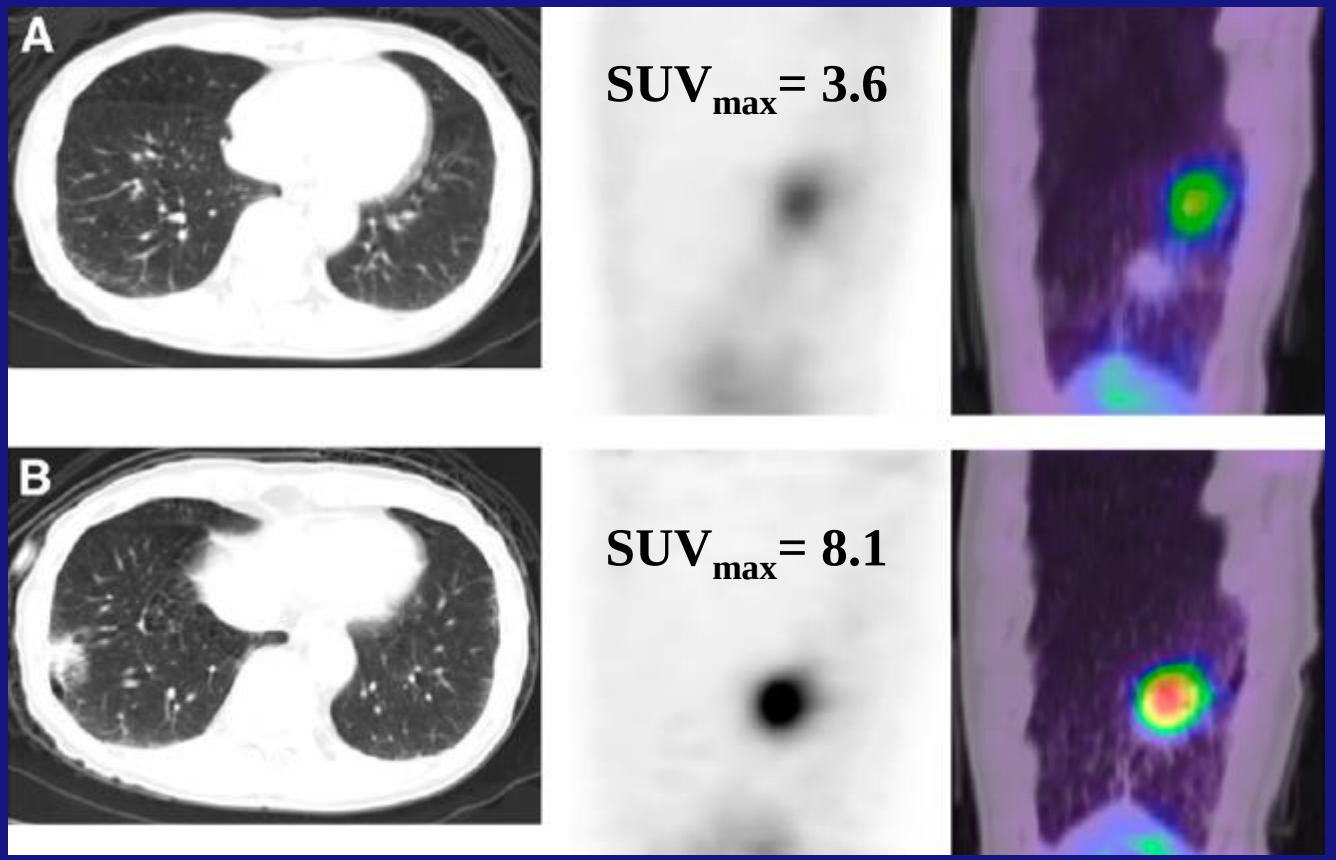
9 x 20 sec DIBH PET

Nehmeh et al, JNM, 07

Deep inspiration breath-hold (20 s)

FB PET/CT

DIBH PET/CT



Torizuka et al, JNM, 09

4D PET/CT

(better with list-mode, and challenging to perform in the clinic)

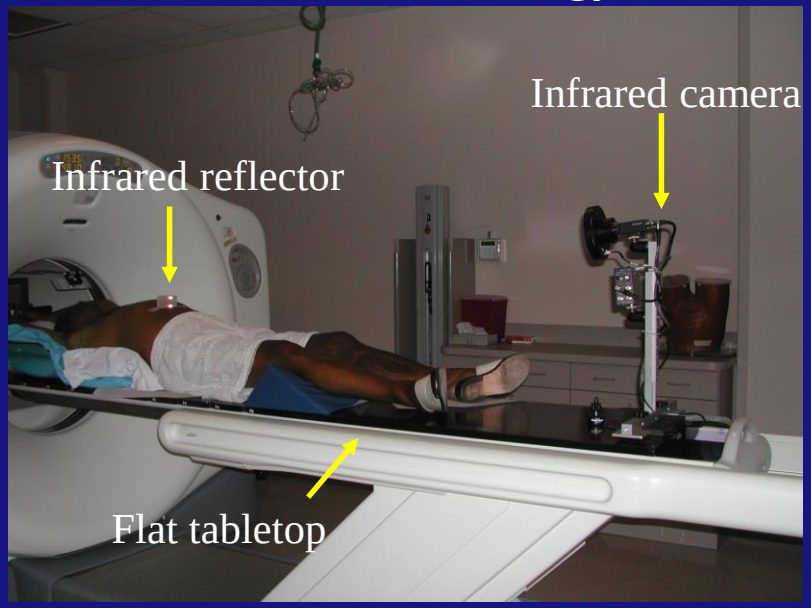
Respiratory gating devices

Varian (Optical)

Anzai (Pressure)

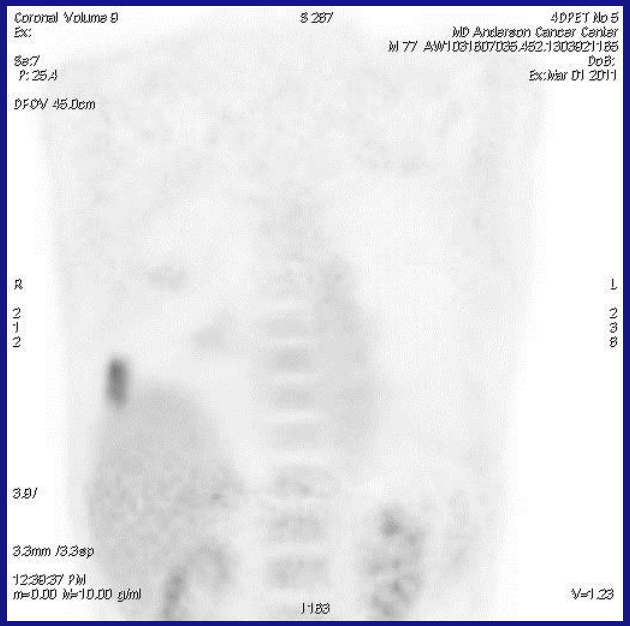
Philips (air bellows)

Radiation Oncology

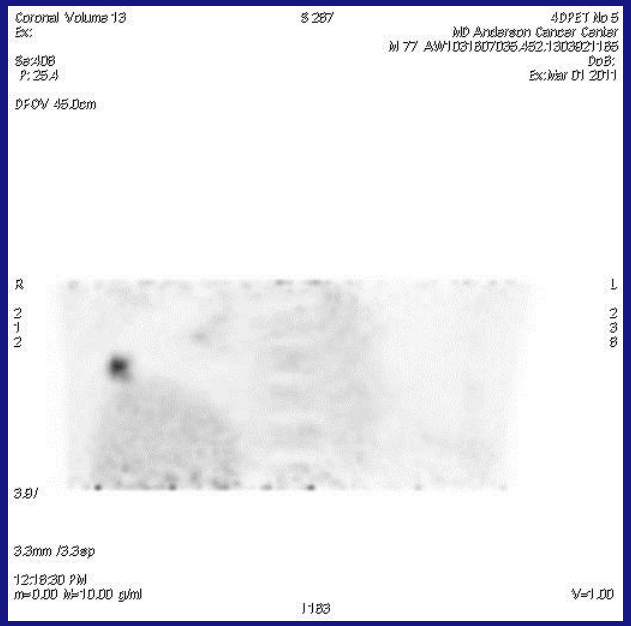


Diagnostic Imaging

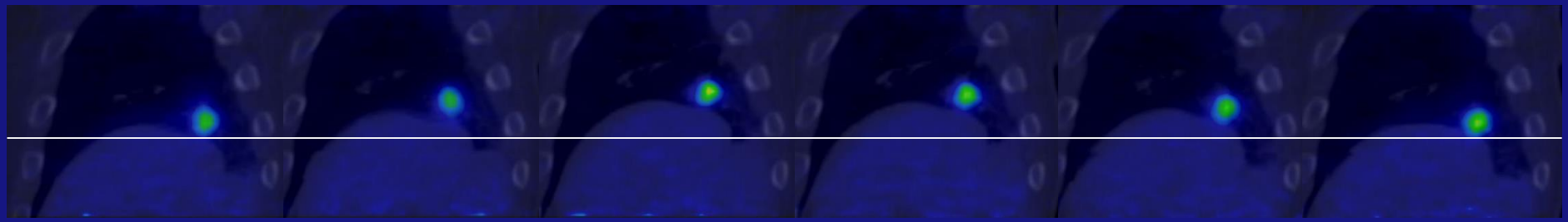
4D PET patient study



SUV=5.0

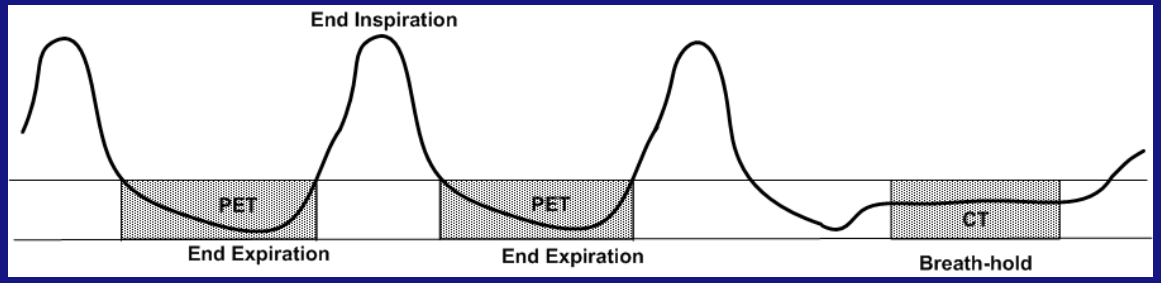


SUV=8.5



Near end-expiration PET/CT

Near end-expiration PET



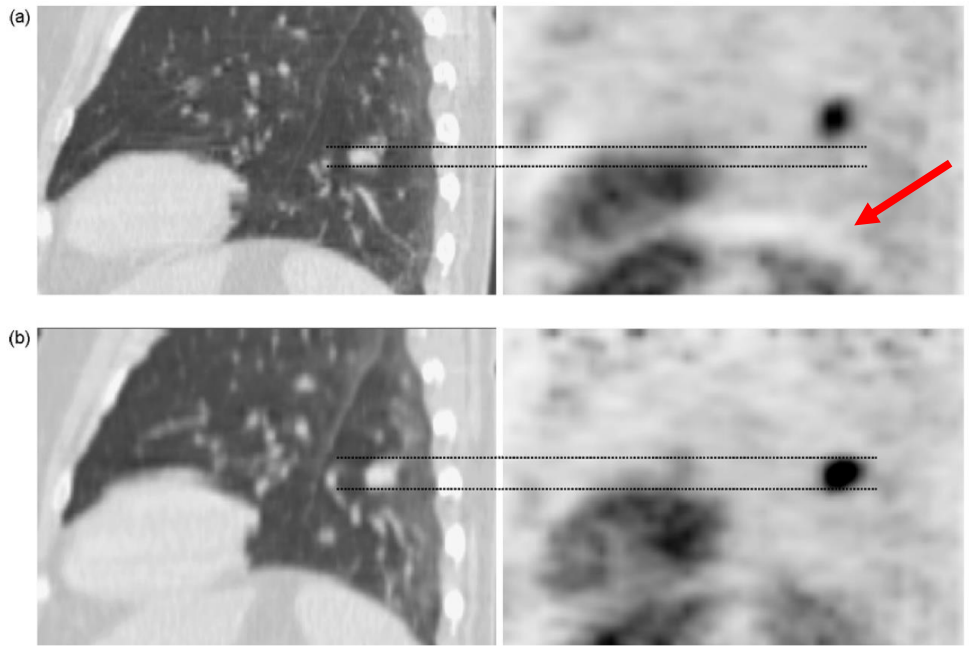


Fig. 4 – Sagittal cross-sections of images from Patient 1 for (a) CT-std (left) and Ungated PET (right) images and (b) BH-CT (left) and BH-CT-based PET (right) images. Dotted lines are placed on the upper and lower boundaries of the lesion on the CT images and carried over onto the corresponding PET image. Cardiac motion artifacts are visible on both CT images because no cardiac gating was performed.

Daouk, et al, '08

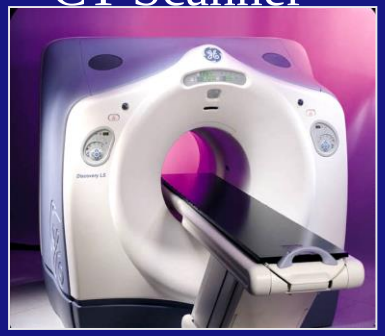
Average CT (ACT) < 1 mSv

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

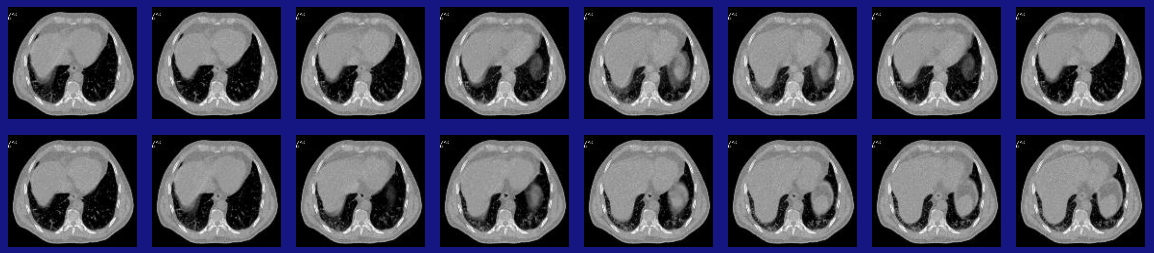
Attenuation correction, RT dose calculation, IGRT

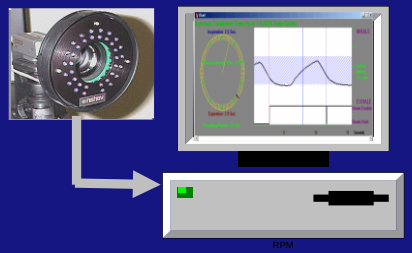
4D-CT

CT Scanner

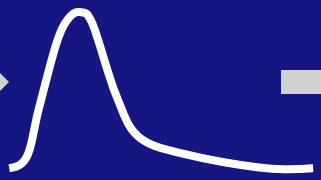


Cine CT images





Monitoring system



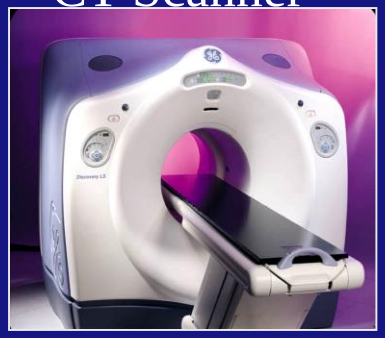
Respiratory Trace

Sorting

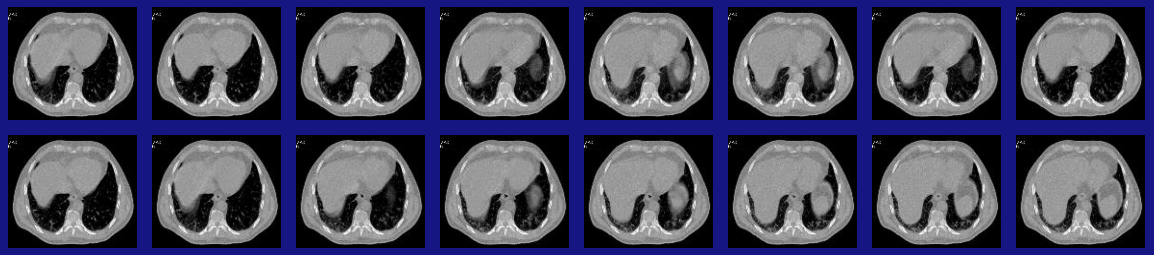
4D-CT

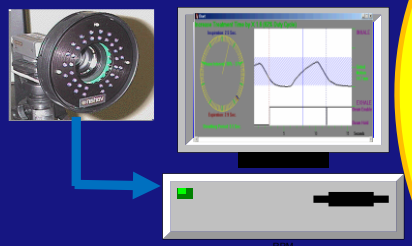
Pan, et al, Med Phys '04

CT Scanner

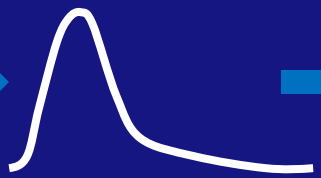


Cine CT images





Tracking system

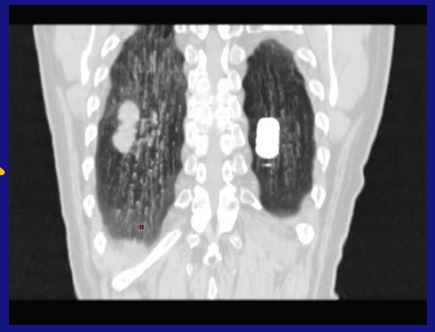


Respiratory Trace

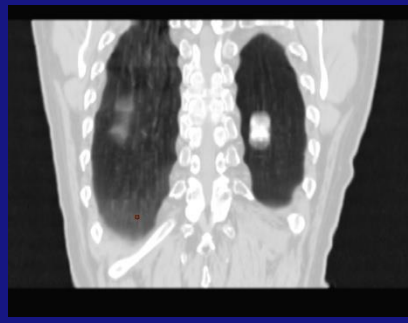
Sorting

4D-CT

Average CT (ACT) < 1 mSv



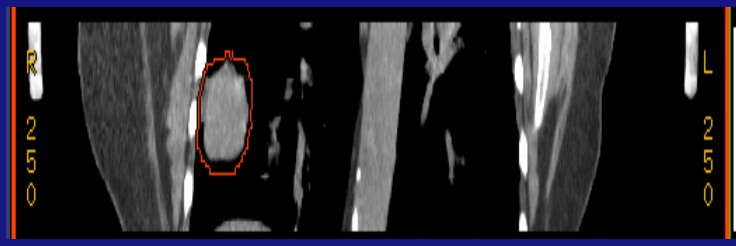
MIP(mip)



Average

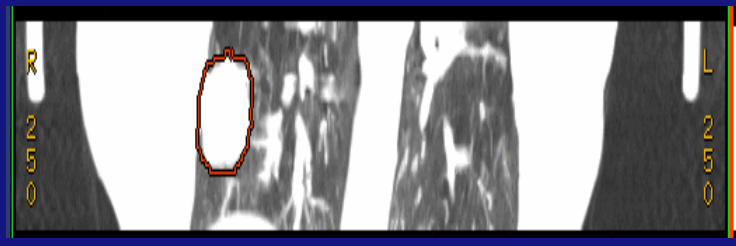
Pan, et al, JNM '05

Tumor contouring with MIP CT



Soft tissue (400,40)

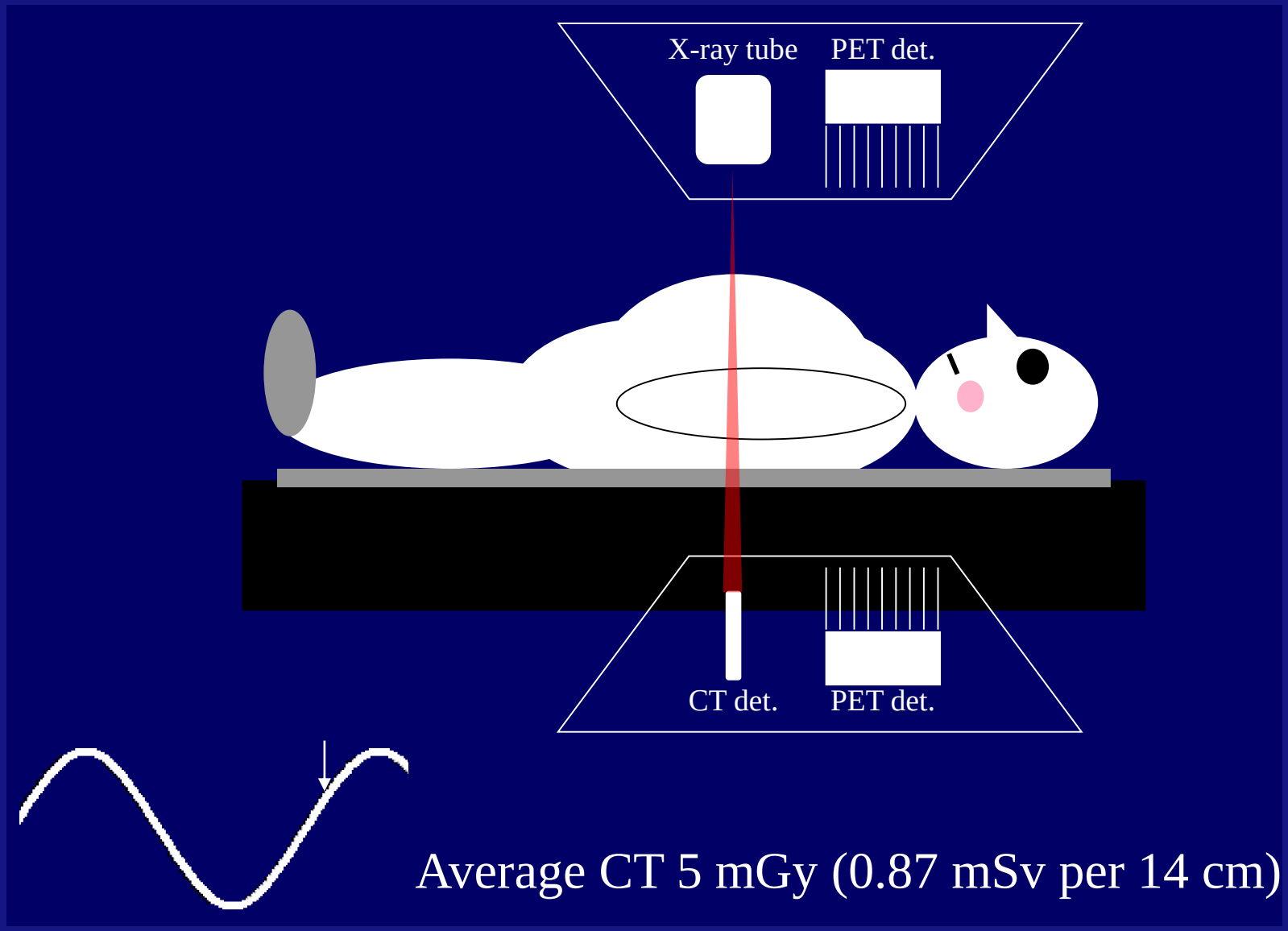
40% SUV_{max}



Lung (1000,-700)

20% SUV_{max}

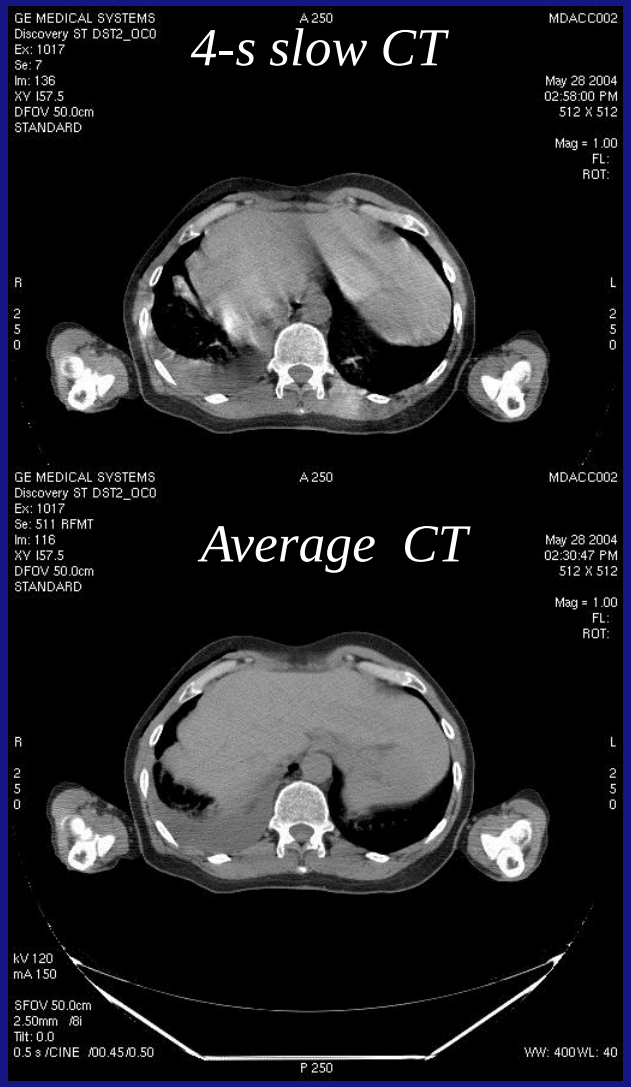
Cine CT Data Acquisition

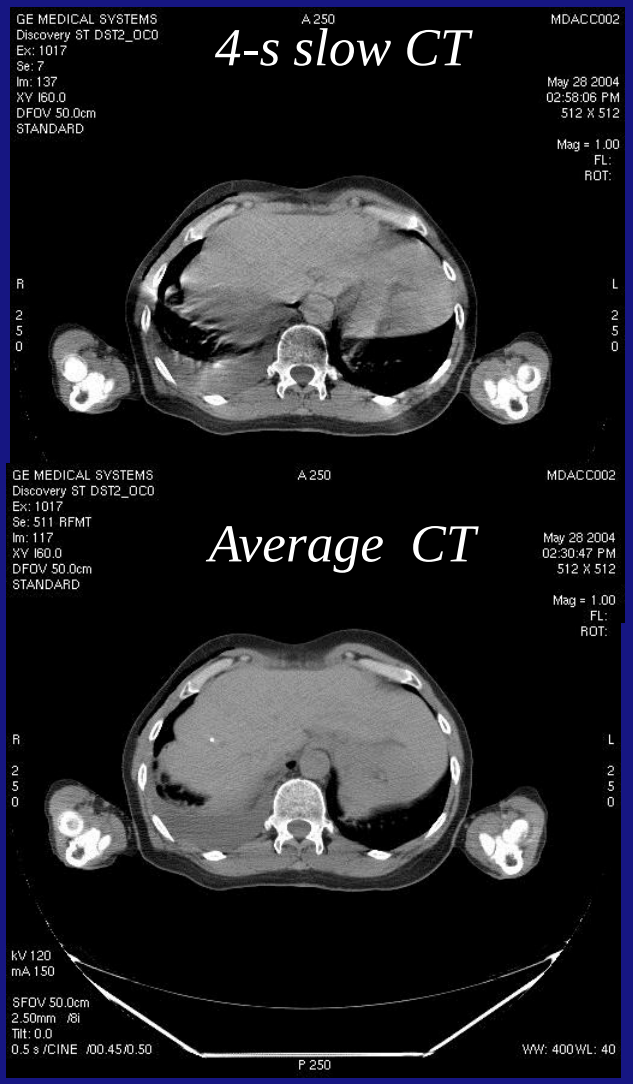


Average CT 5 mGy (0.87 mSv per 14 cm)

Average CT is better than slow CT

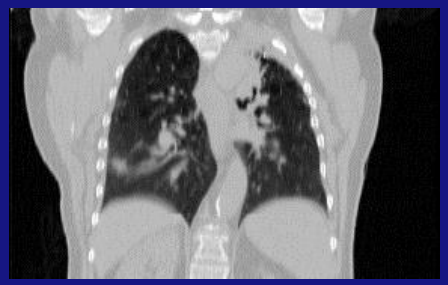
(2 adjacent CT slices of 2.5 mm apart)



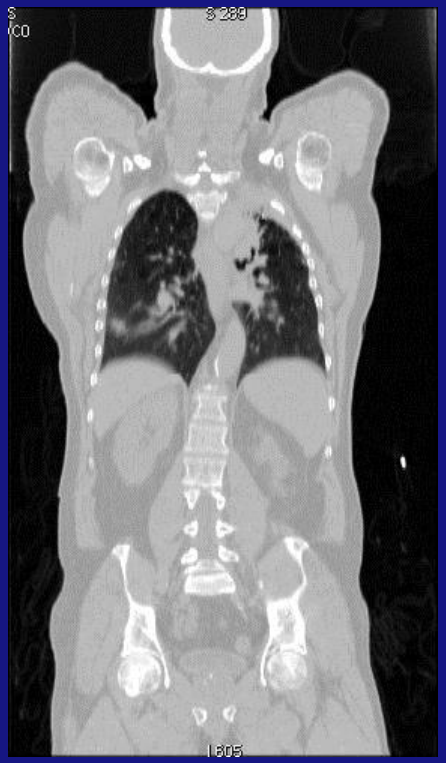


Pan, et al, Med Phys '06

Creating combined CT

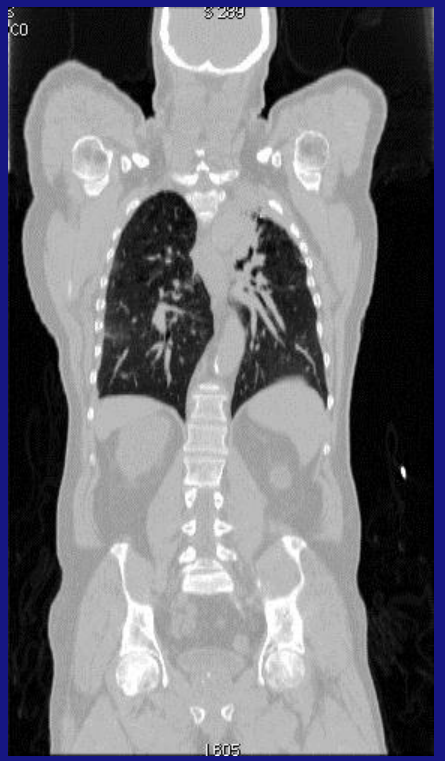


ACT



Helical CT w ACT

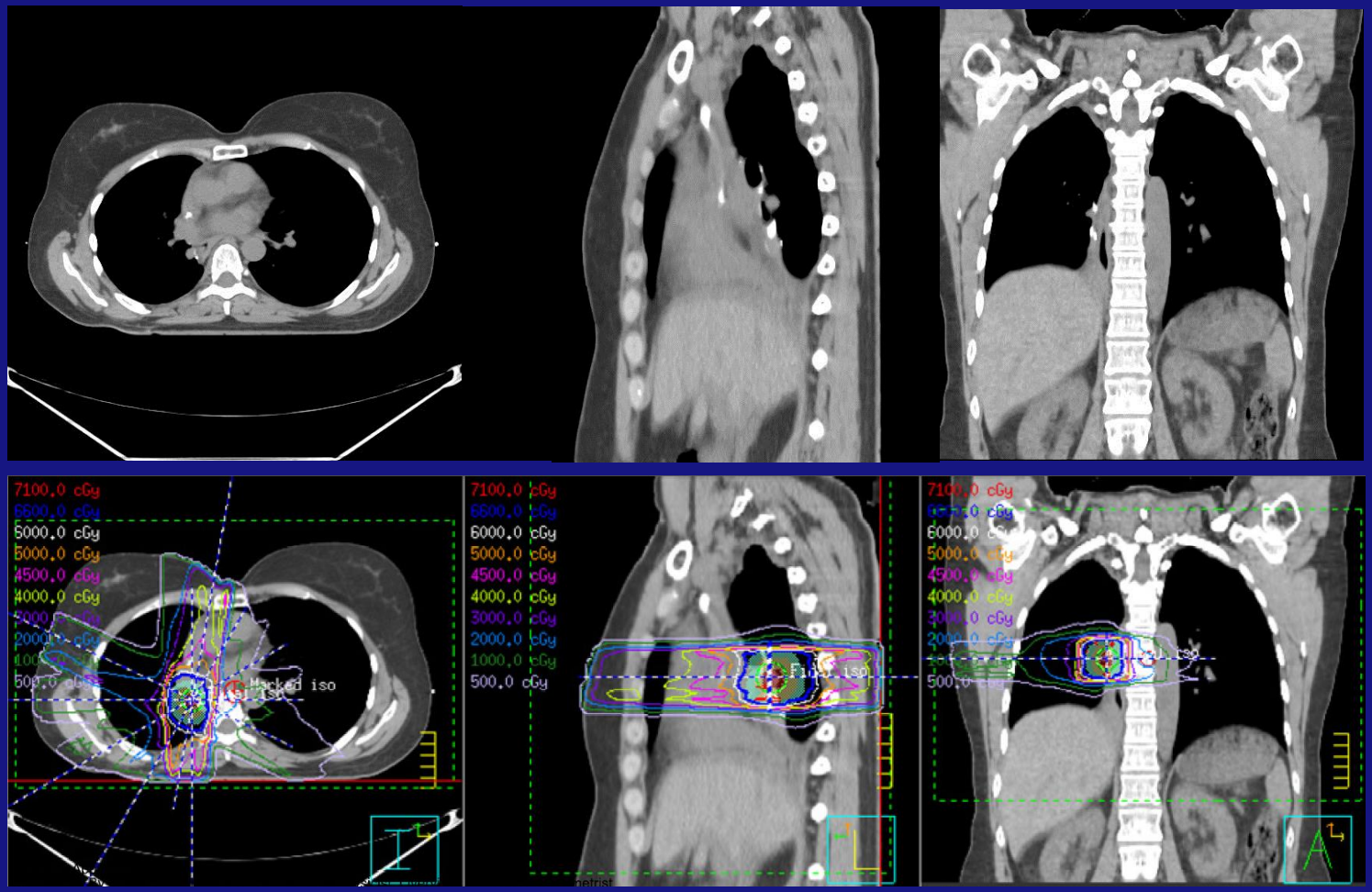
Helical CT w/o thorax



Helical CT

Pan, et al, Med Phys '06

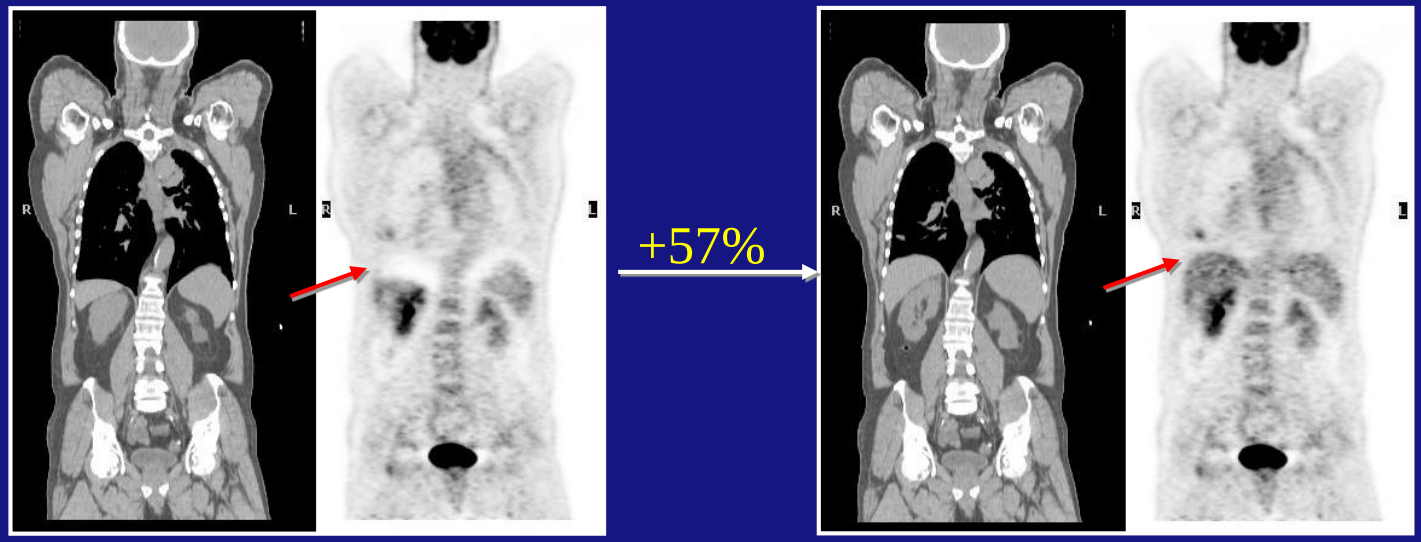
Average CT for RT dose calculation



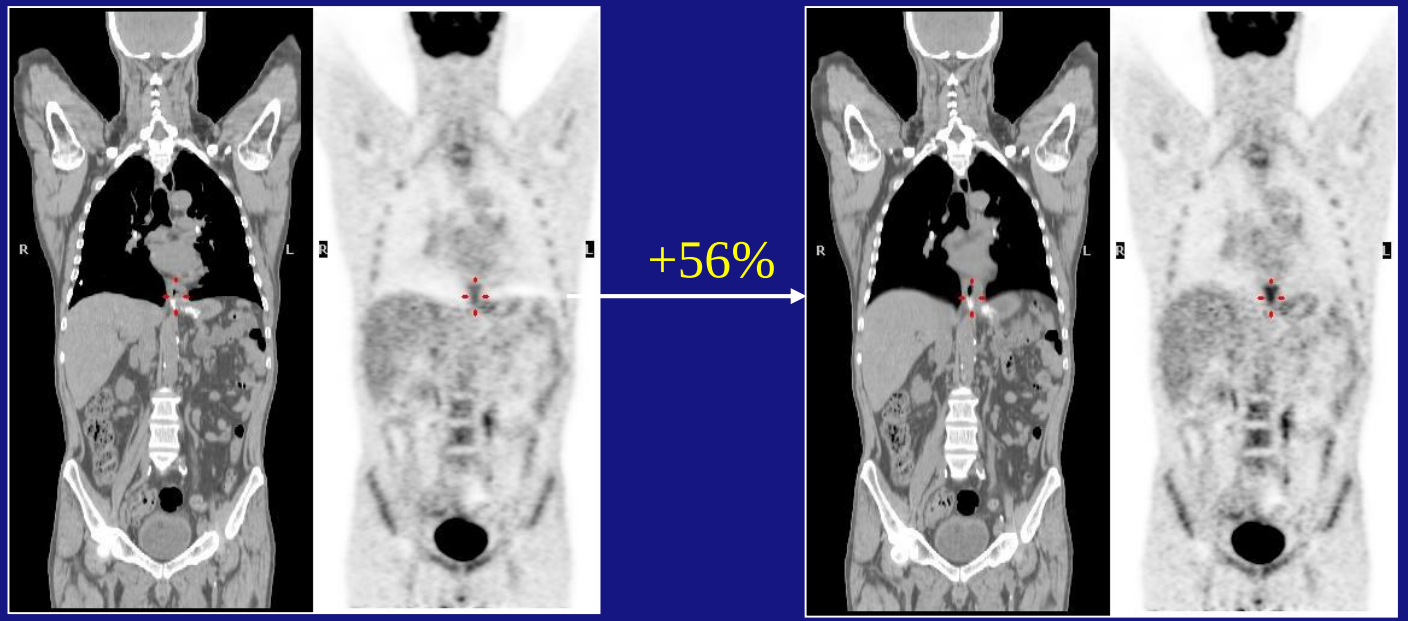
Clinical examples of average CT

Clinical Studies

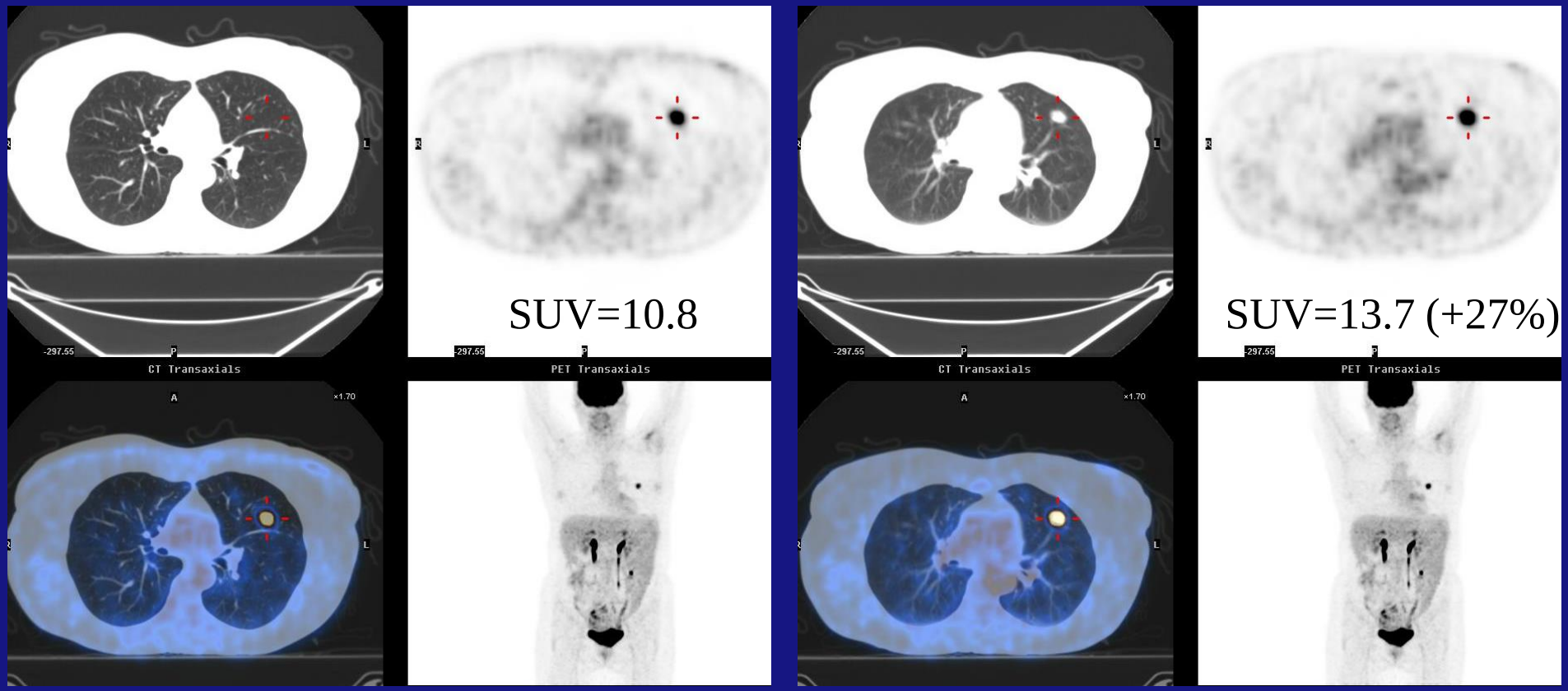
NSCLC



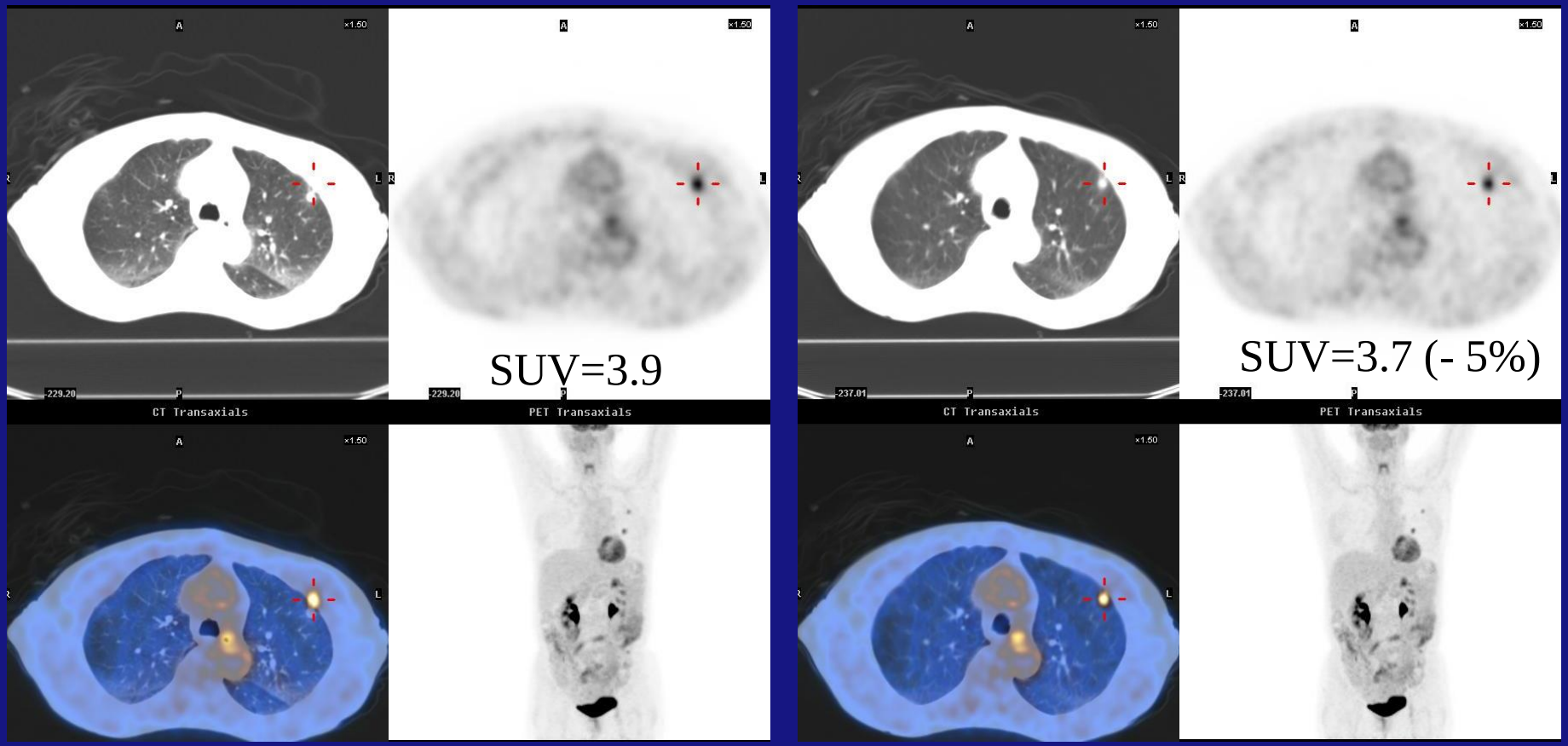
Esophageal



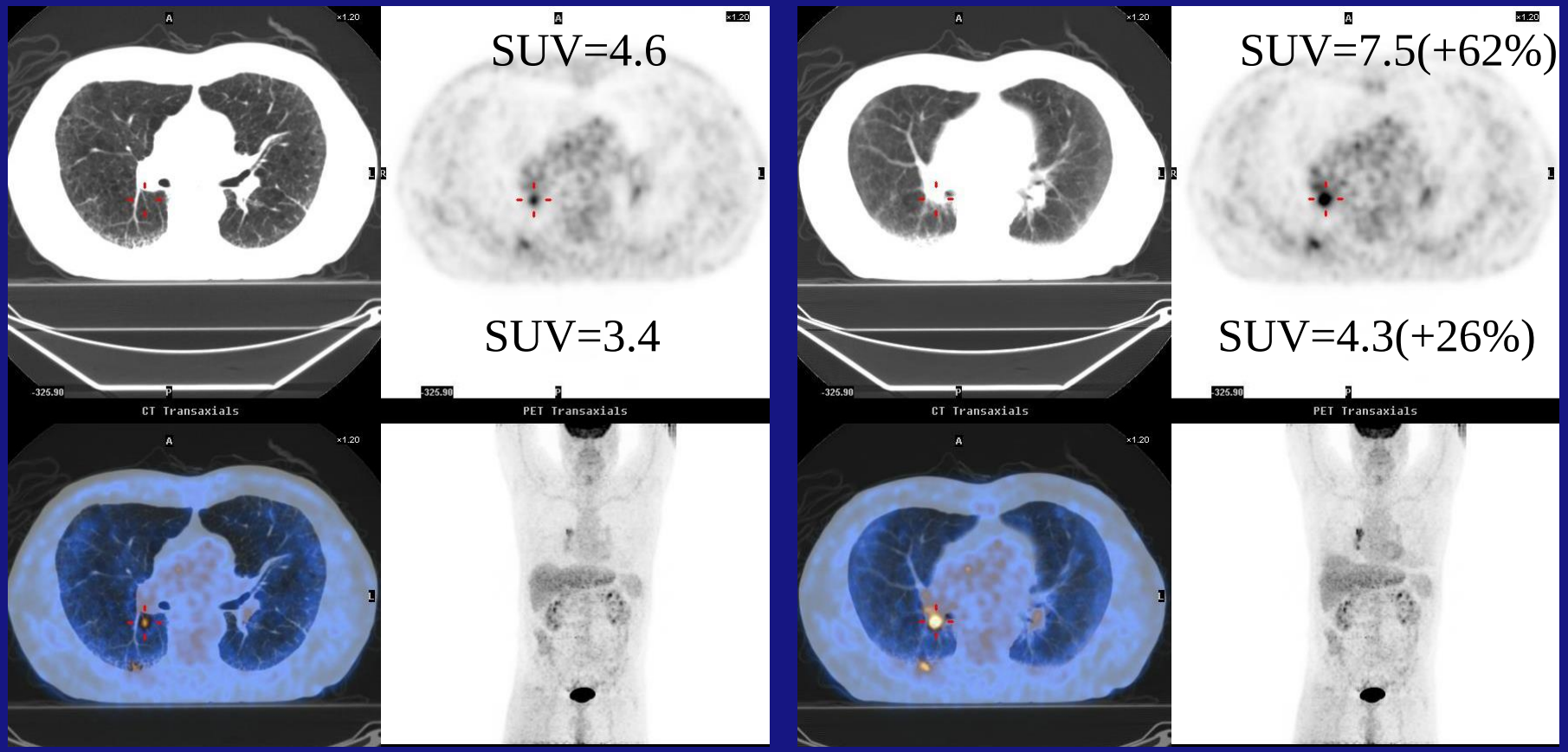
Lung tumor 1


SUV=10.8
SUV=13.7 (+27%)
CT Transaxials
PET Transaxials
CT Transaxials
PET Transaxials

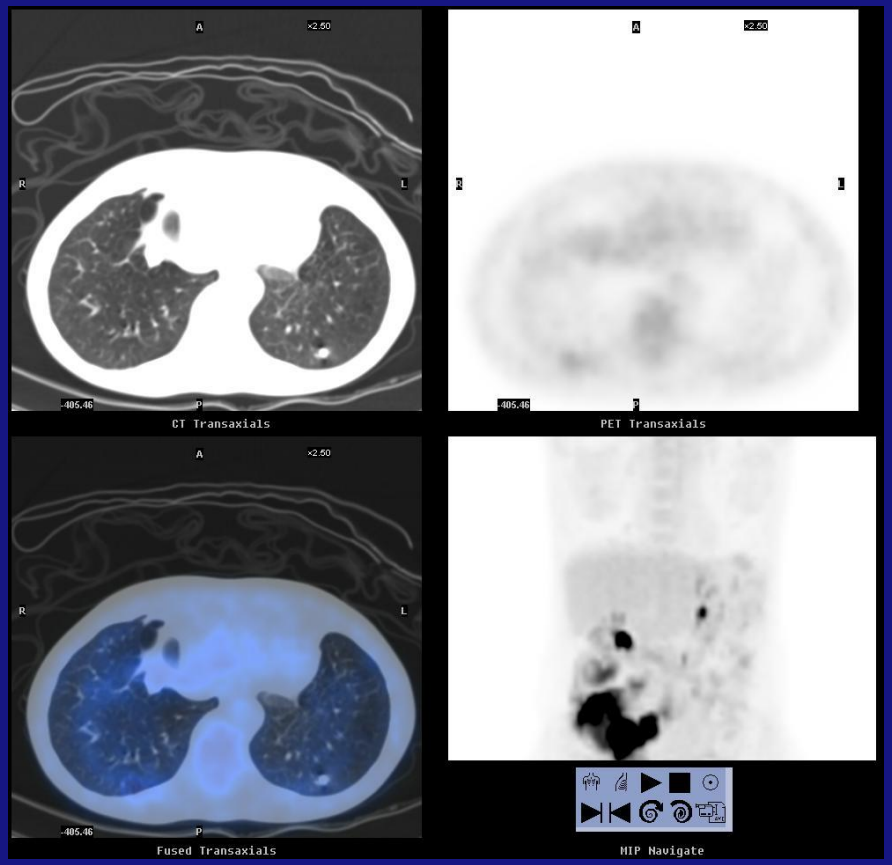
Lung tumor 2

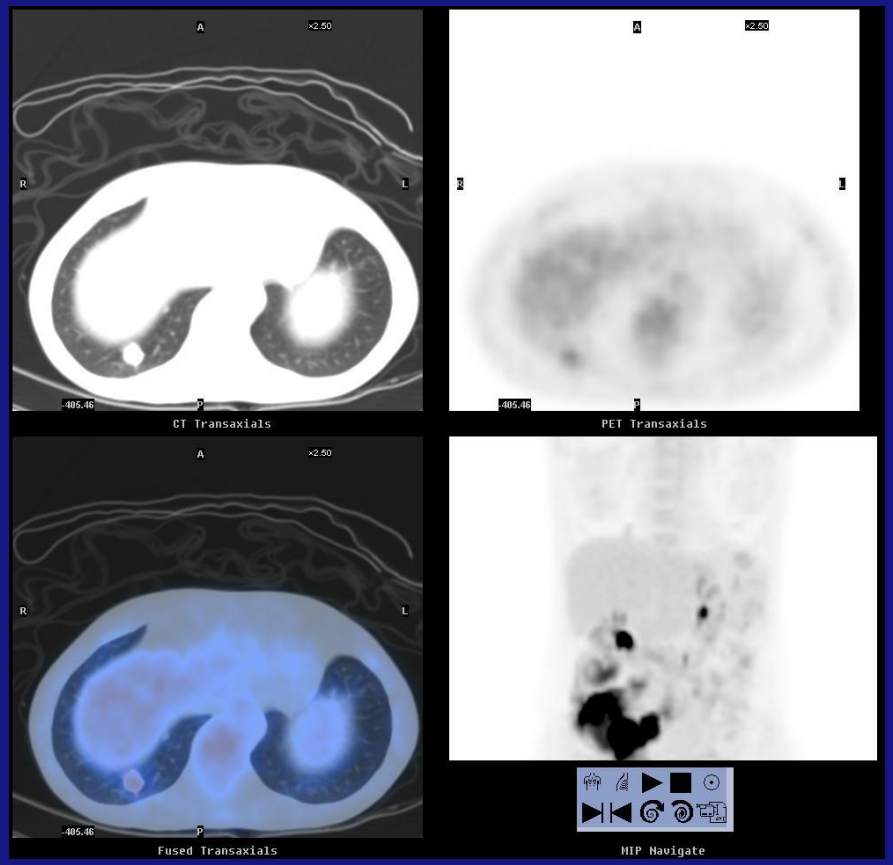

SUV=3.9
SUV=3.7 (- 5%)
CT Transaxials
PET Transaxials
CT Transaxials
PET Transaxials

Lung tumor or lymph node

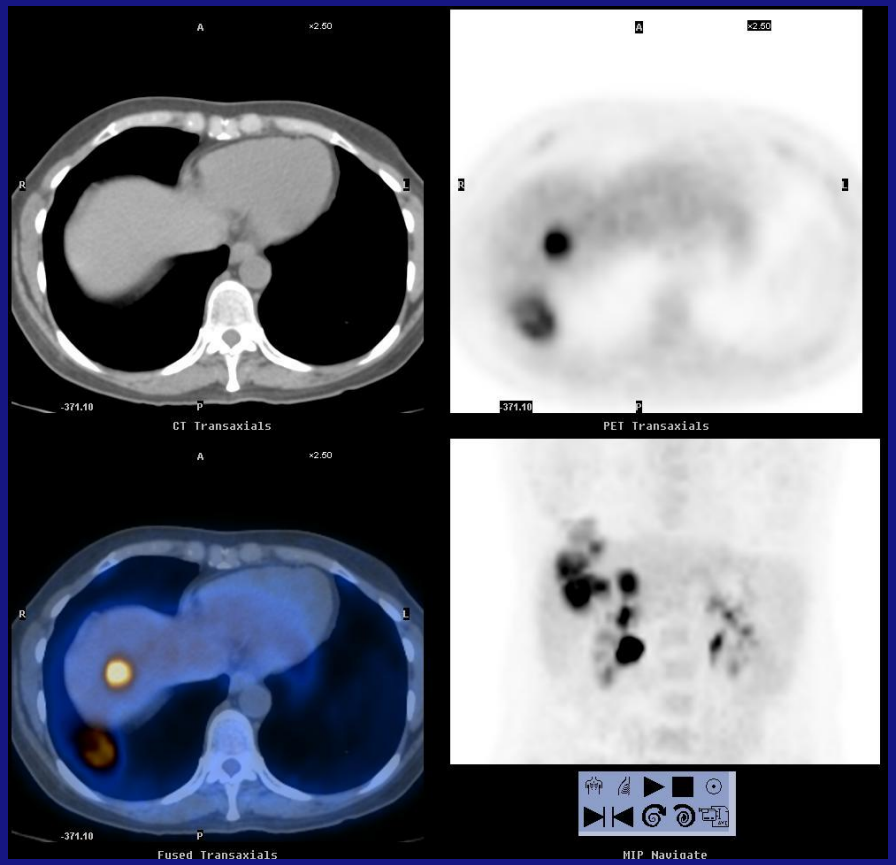


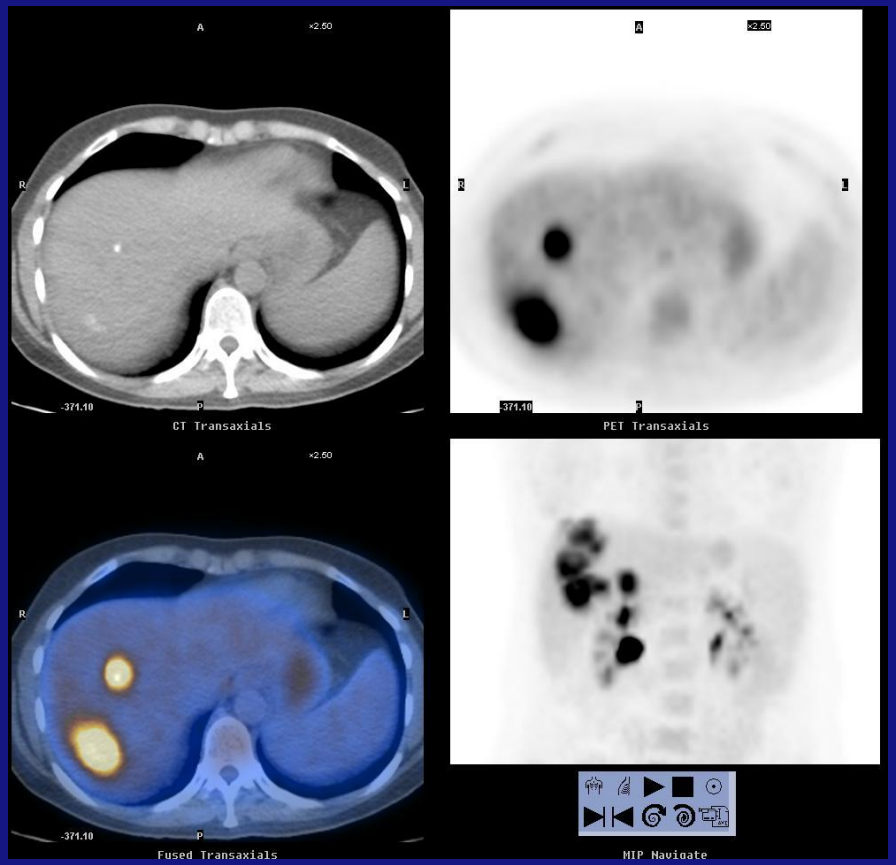
Lung tumor


CT Transaxials
PET Transaxials
Fused Transaxials
MIP Navigate

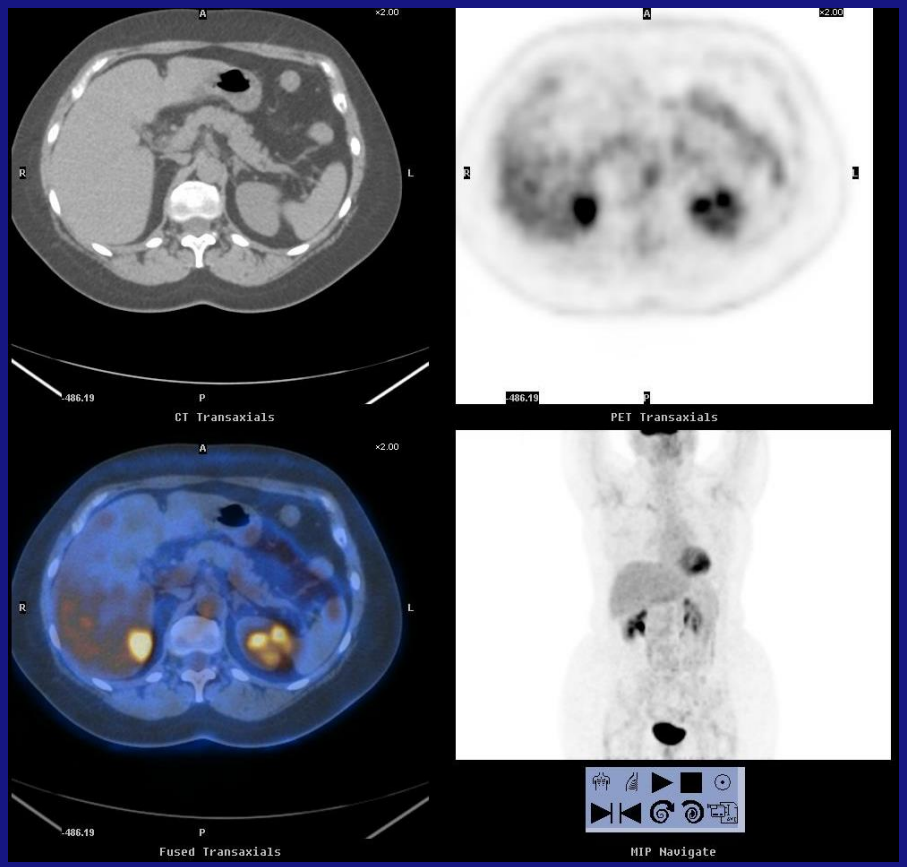

CT Transaxials
PET Transaxials
Fused Transaxials
MIP Navigate

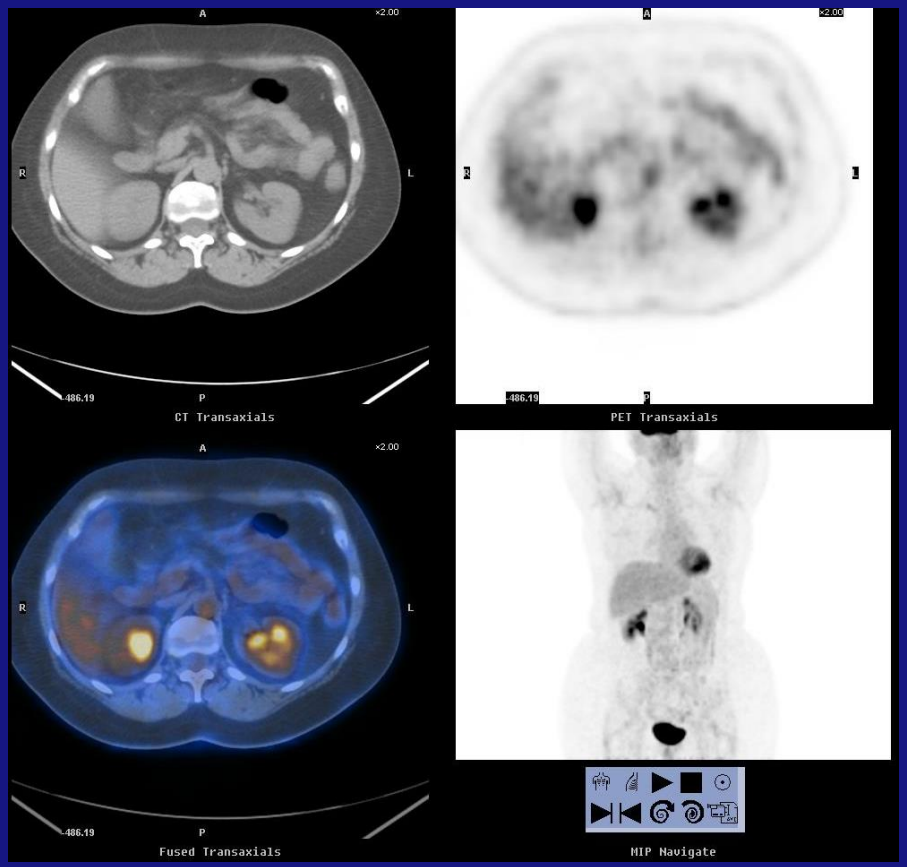
Liver lesion



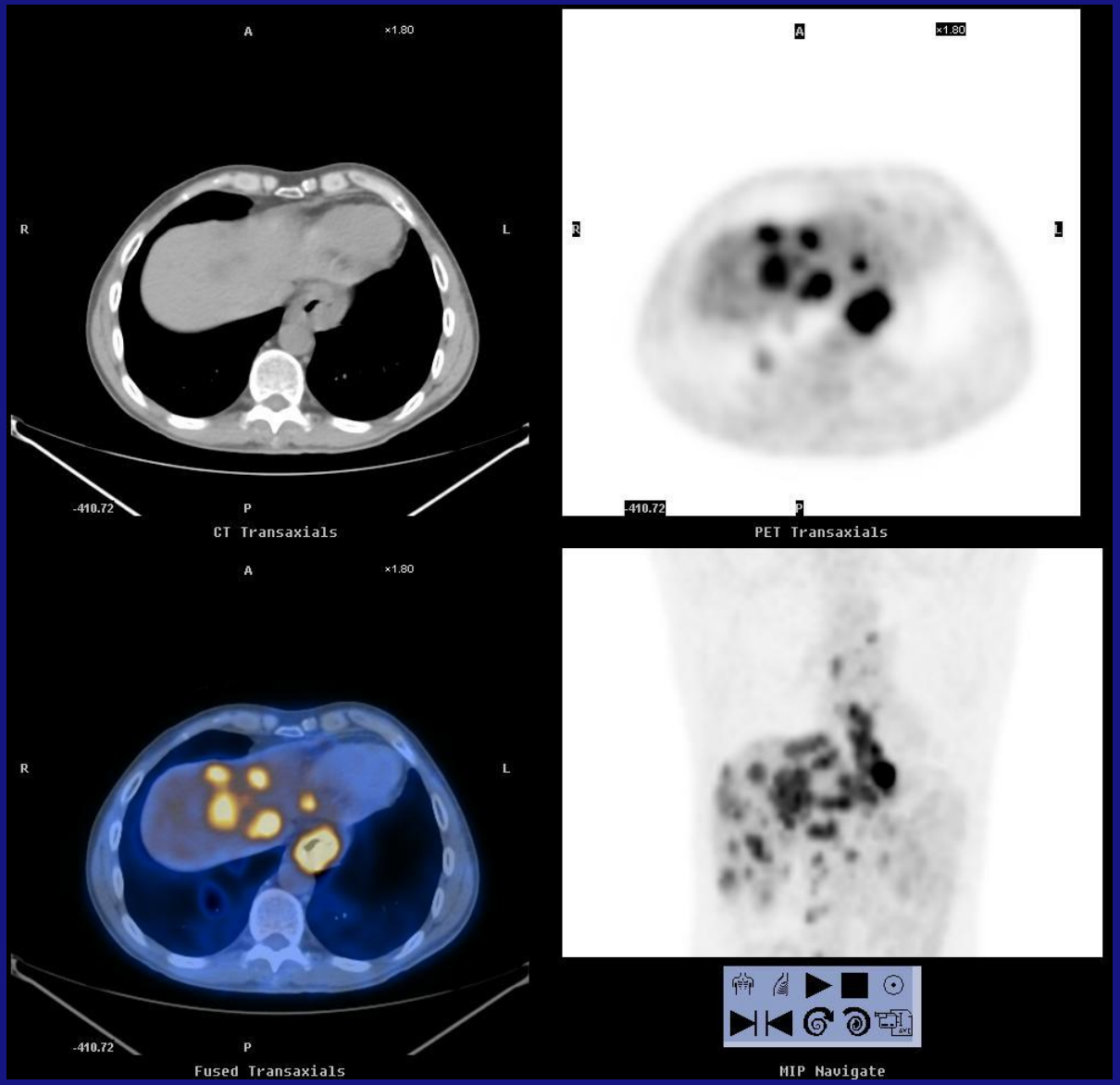


Kidney or liver uptake



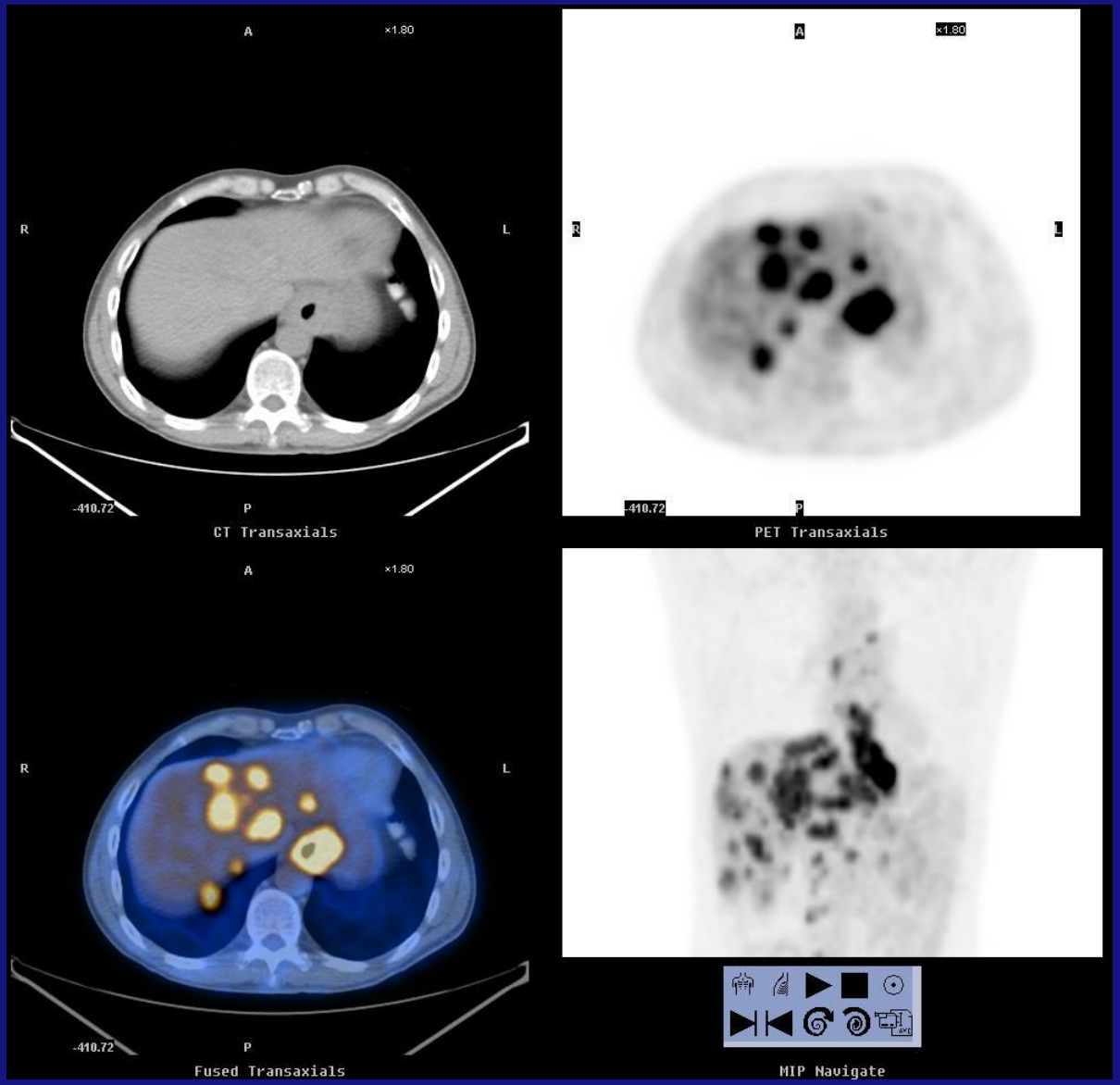


Lung or liver lesion?

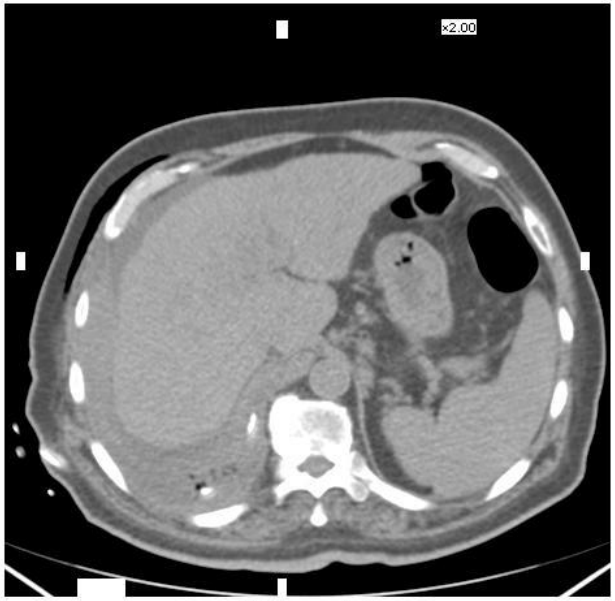


Lung lesion or liver lesion?

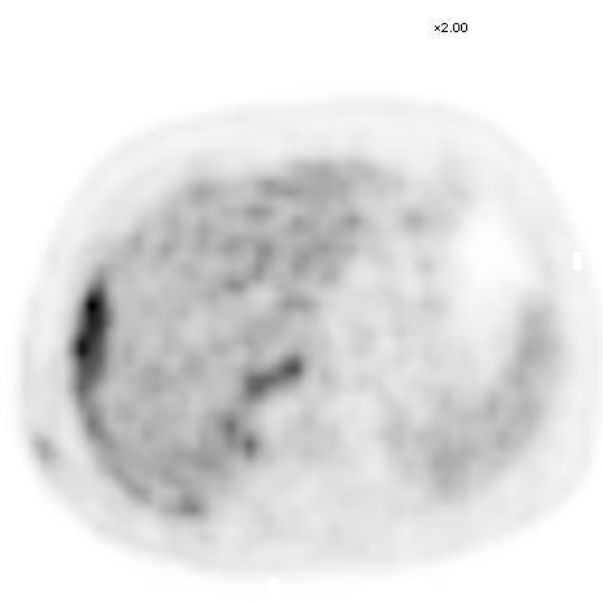
Average CT



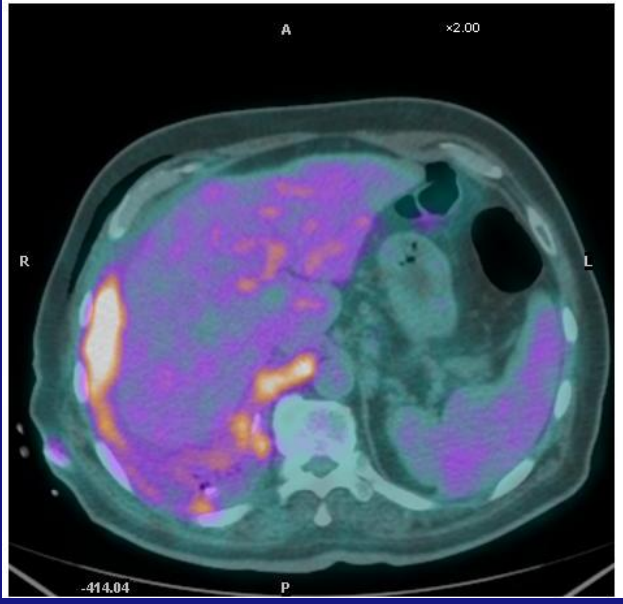
Colorectal cancer

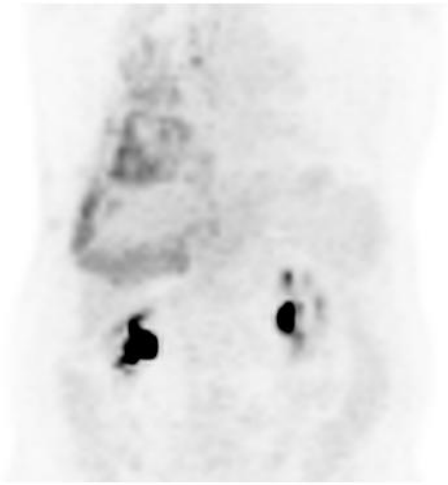


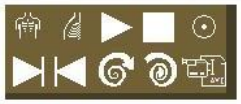
CT Transaxials



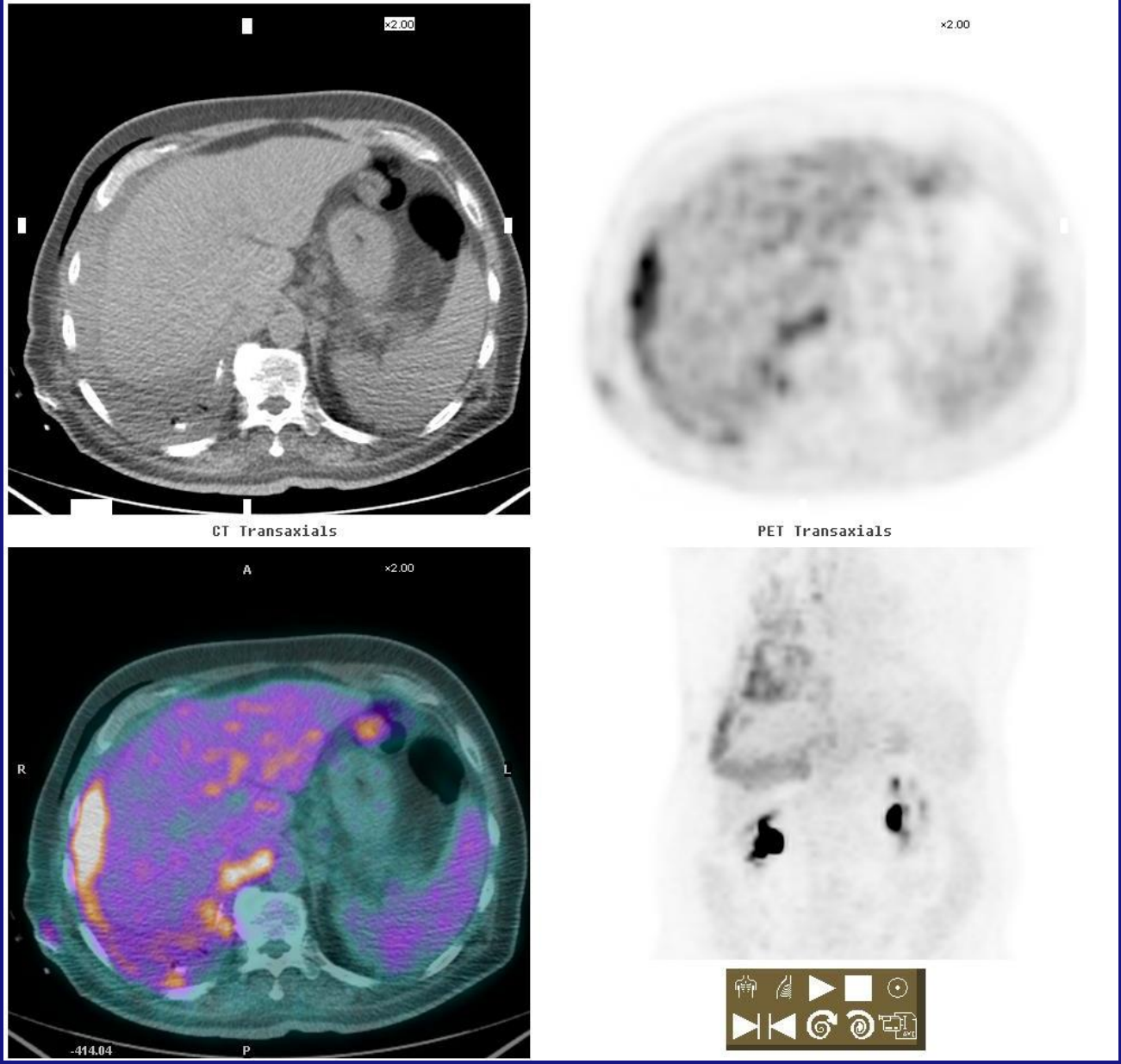
PET Transaxials





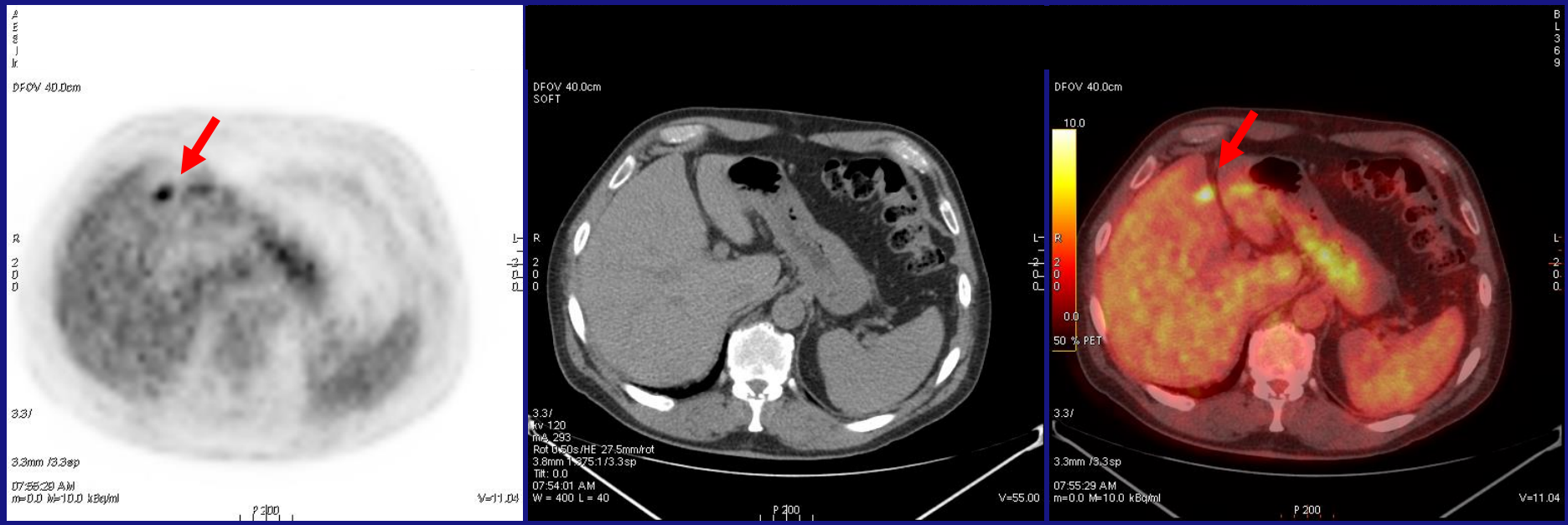


Colorectal cancer

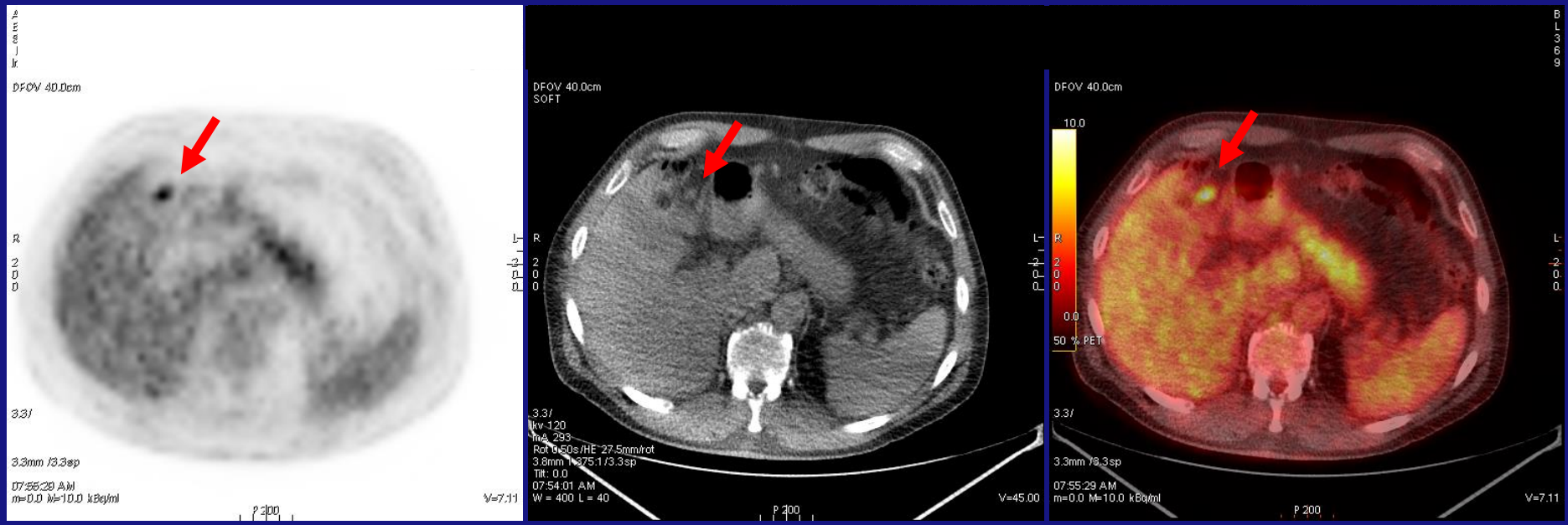


Average CT

Inside the liver?



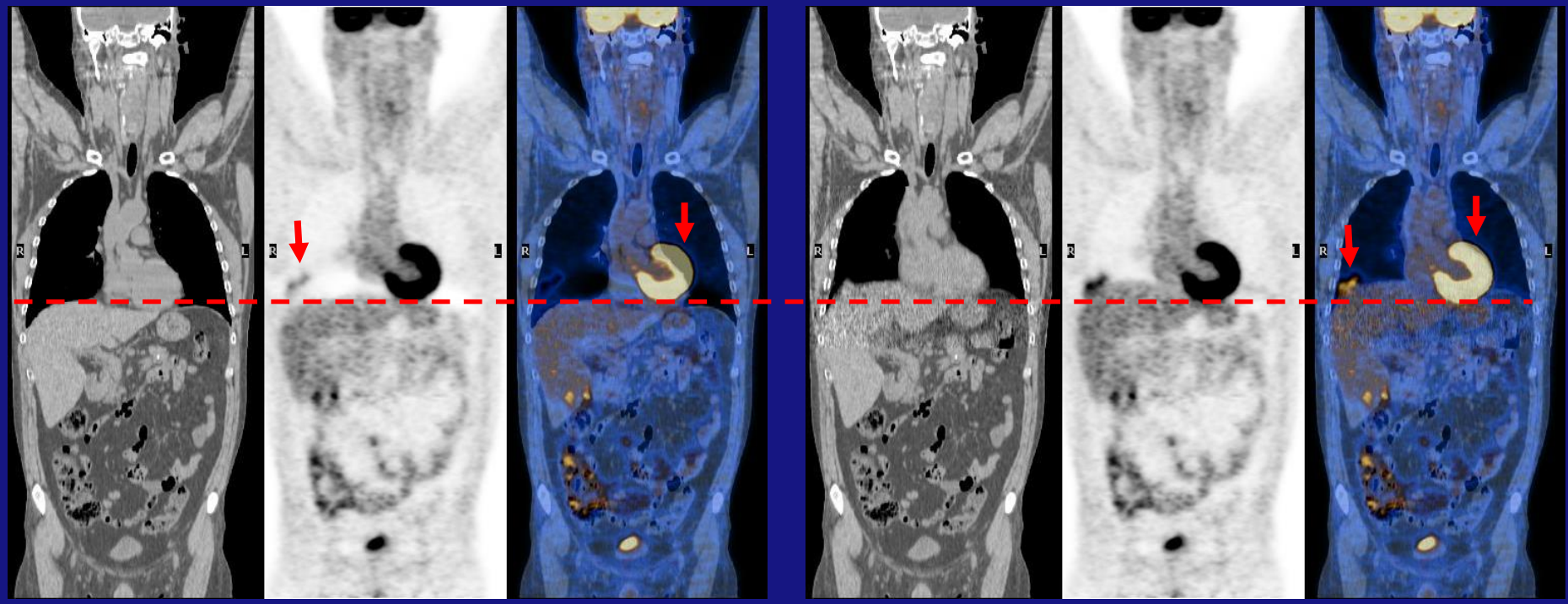
Outside the liver



Average CT

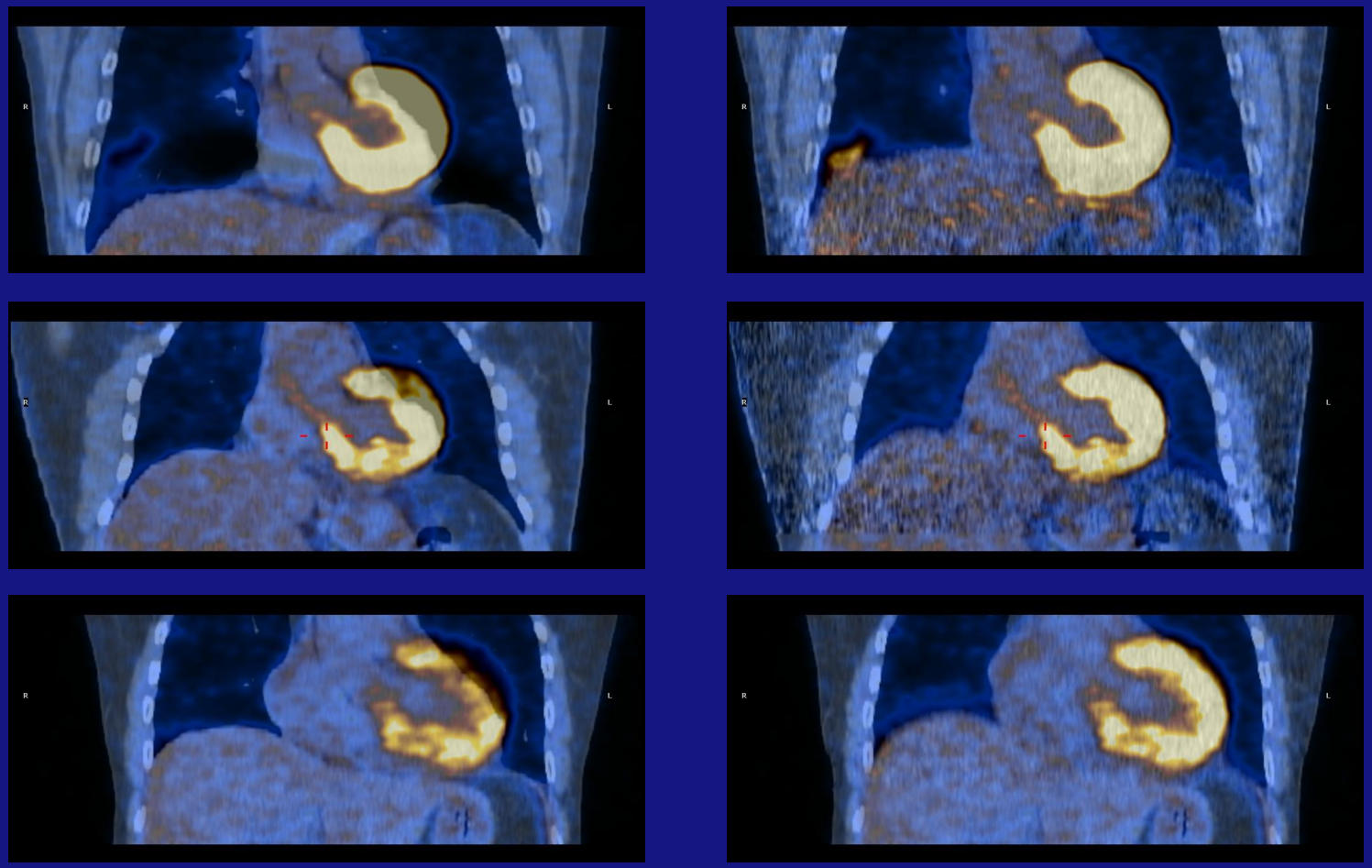
Tumor and cardiac imaging

HCT PET_{HCT} PET_{ACT} ACT



SUV=2.6 SUV=5.0

Average CT in cardiac PET

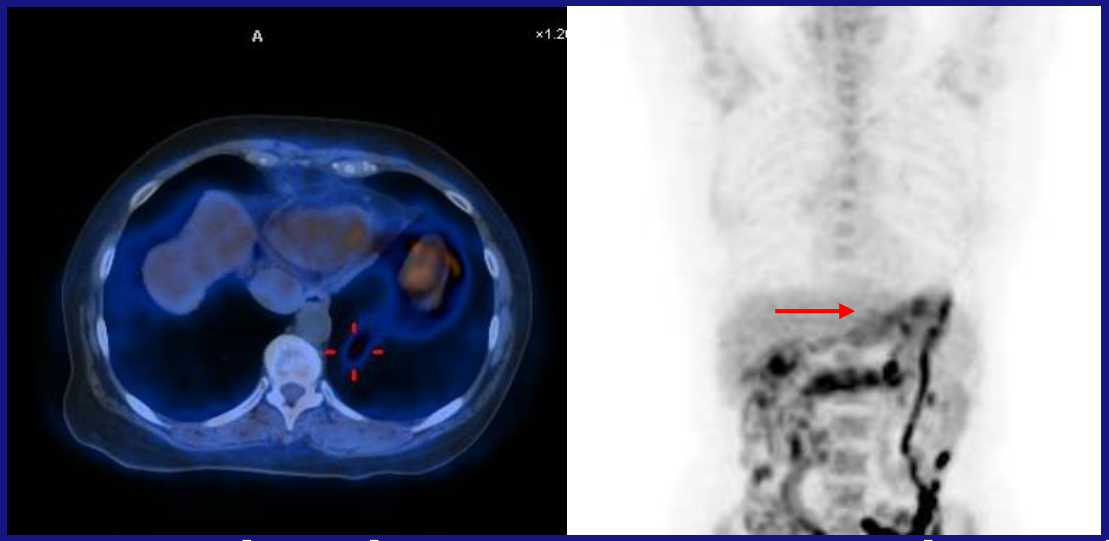


HCT- misregistration

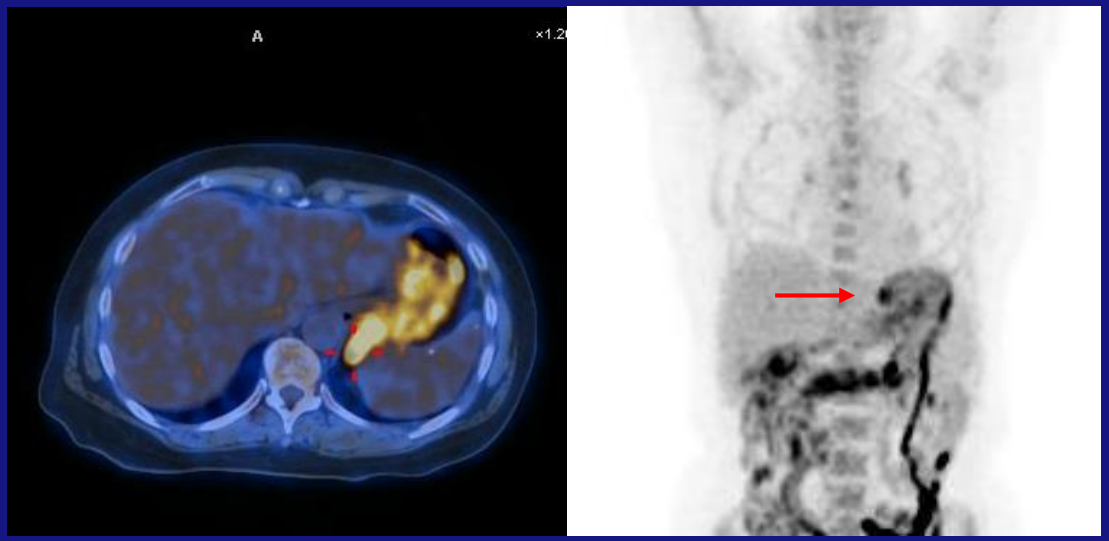
ACT

Pan et al, Med. Phys. 2006

Improve the restaging after chemo



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

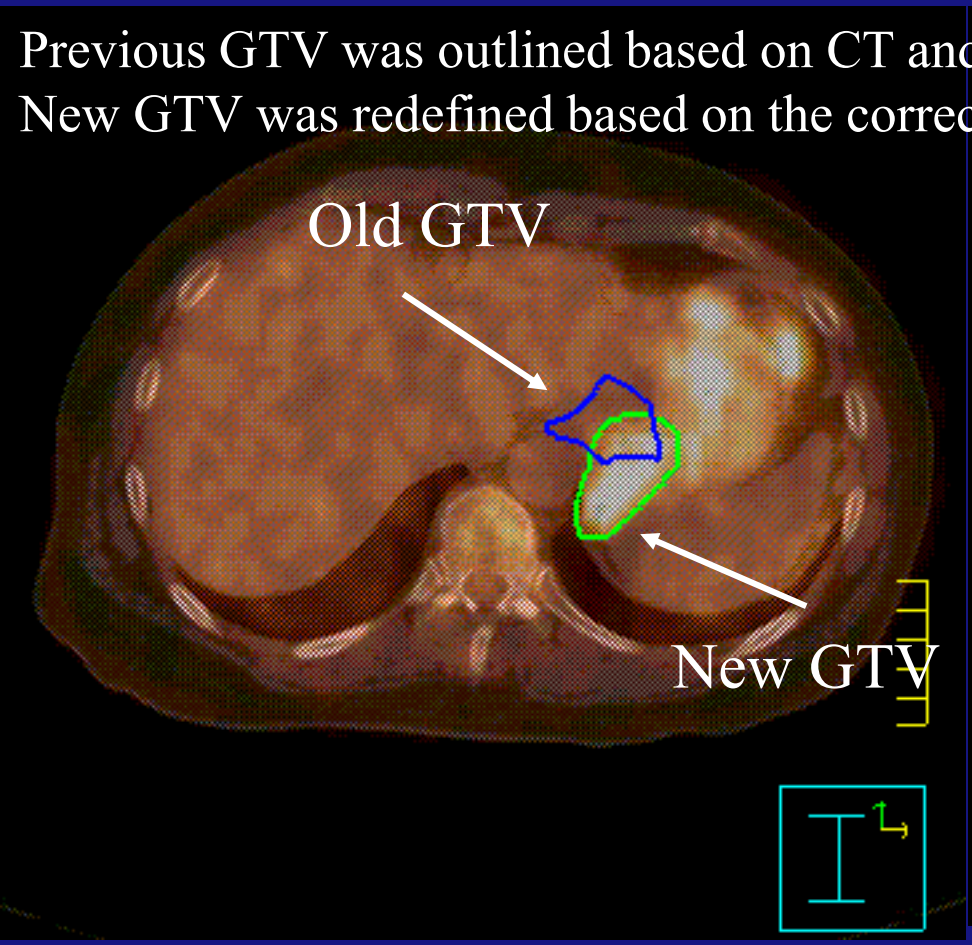


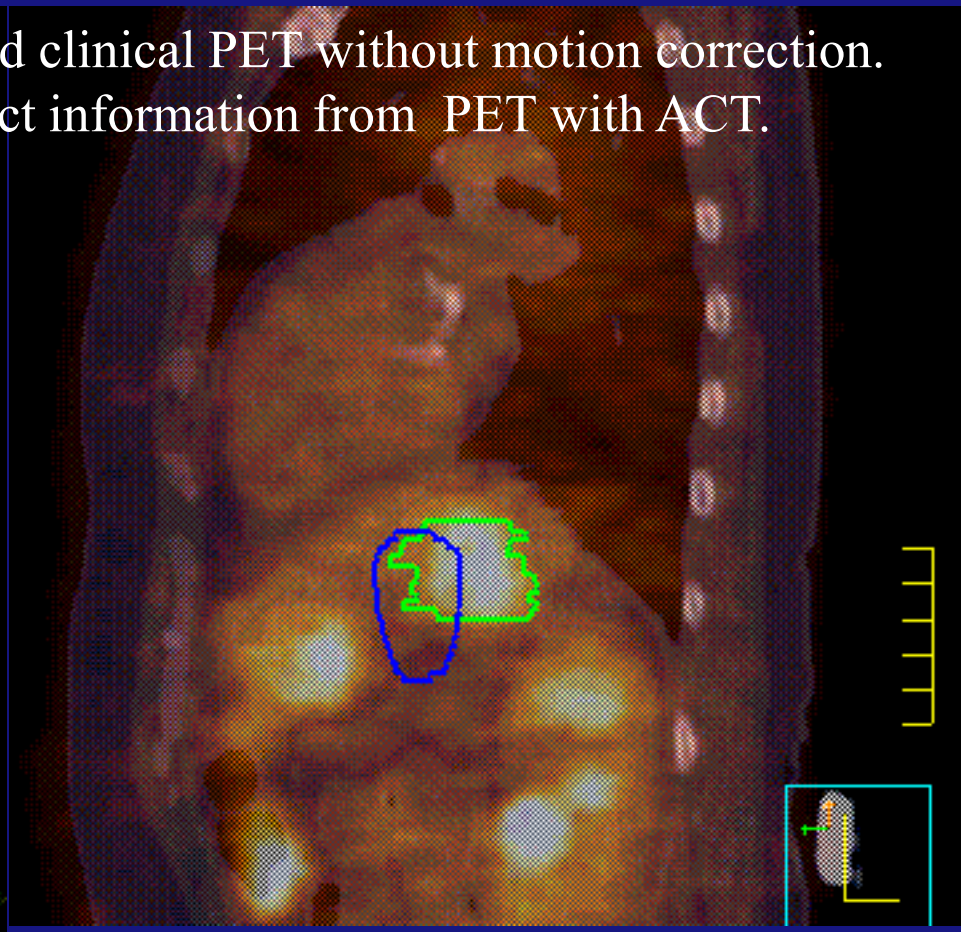
The patient had a negative response to the chemo with ACT.

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

Oncology PET/CT dose estimate

Injection dose: 10 mCi per patient

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

Radiation dose: 7 mSv from PET

5 to 10 mSv from CT

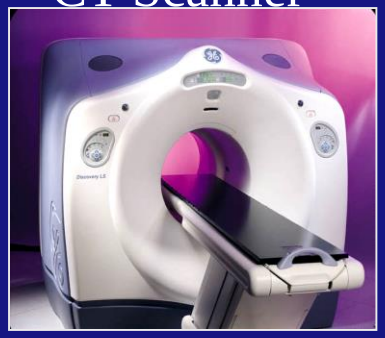
< 0.5 to 1 mSv from ACT

Radiation dose: 3.6 mSv from the environment

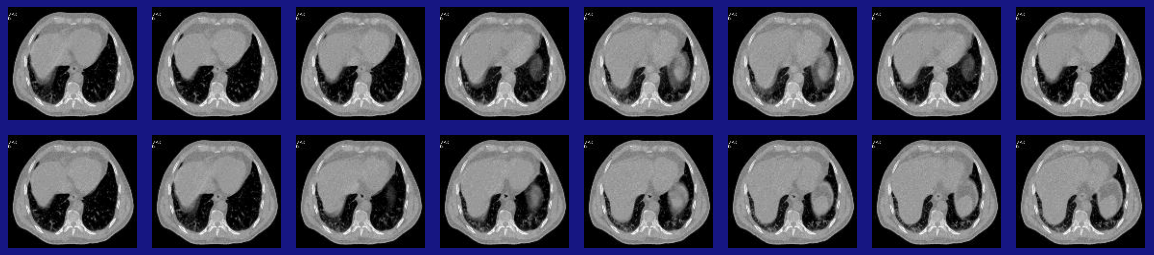
Why are we not using average CT?

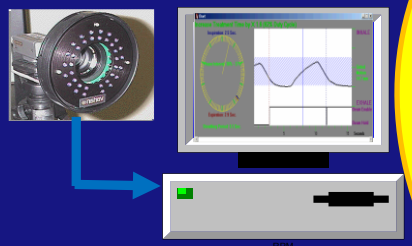
Complexity, Workflow and Cost

CT Scanner

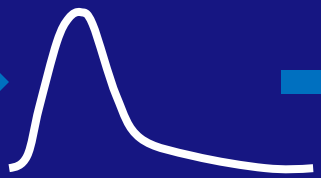


Cine CT images





Tracking system

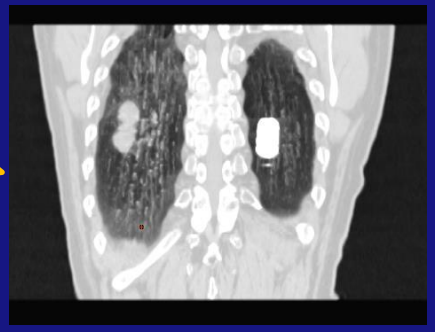


Respiratory Trace

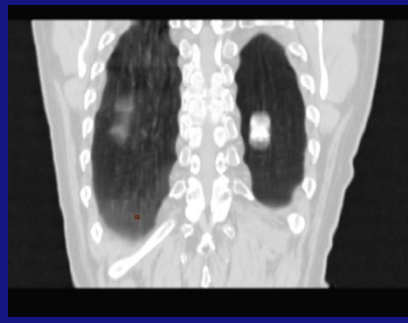
Sorting

4D-CT

Average CT (ACT) < 1 mSv



MIP(mip)

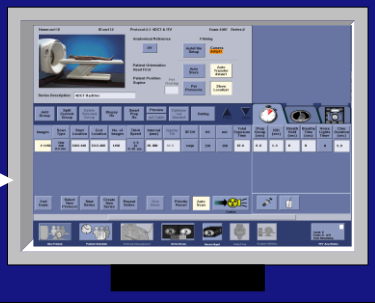


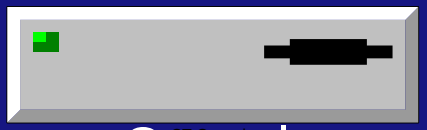
Average

Pan, et al, JNM '05

4D-CT Workflow

CT or PET/CT





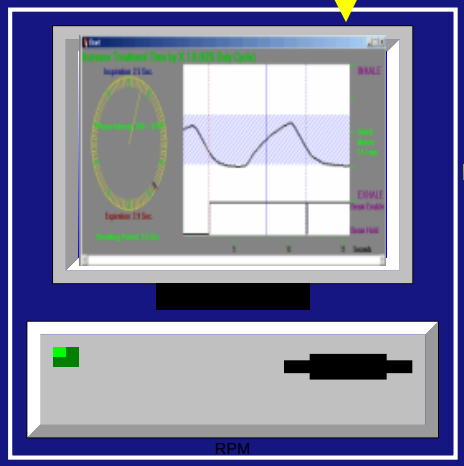
Console

PET & CT

Controls

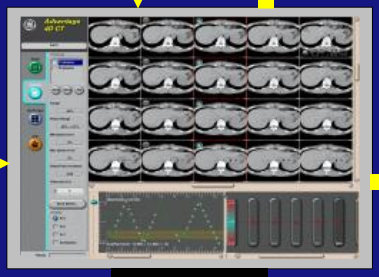
Cine CT images

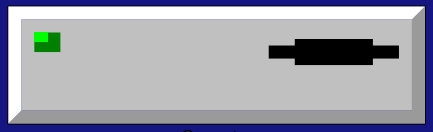
Average CT (ACT)



RPM

Respiratory Signal





Computer

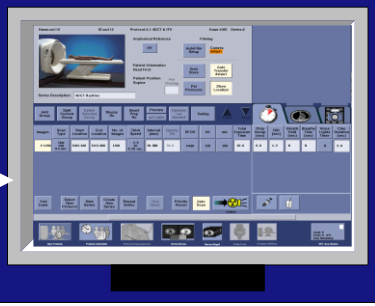
4D-CT

Treatment Planning System

AW and Advantage 4D-CT

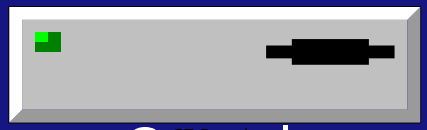
Cine CT Workflow without Gating

CT or PET/CT



PET & CT

Treatment Planning System



Console

Cine CT images

Average CT (ACT)

MIP

Transparent to the user

February 4 18:51

512: 114713 256: 458854

PET Partial Ready

Idle

Removed Series 999/812

Sent: 10328/3/... (dstaw1)

**** Film Composer started ****

Prescribed slice(s) are not visible over localizer window.

Autovoice Volume

Check Security

Unix Shell

Turn Off Extend HU

Quick Snap

Application Selection Remove Sort Network Archive PPS Queue Utilities Messages

Examinations :

Exam	Name	Date	Description	Mod	Fmt	PPS	A
10017	zzdst2_1203200	Dec 03 08		CT	DICO	-	N
10016	zzzgetest	Dec 02 08		CT	DICO	-	N
10015	ZZZGETEST	Dec 02 08		CT	DICO	-	N
10008	zzpetct	Dec 02 08		CT	DICO	-	N
9991/DST2	ZZPETCT zzmont	Nov 24 08		CT	DICO	-	N
9990/DST2	ZZPETCT zzmont	Nov 24 08		CT	DICO	-	N
9979/DST2	zzdst2_112408	Nov 24 08		CT	DICO	-	N
9973/DST2	zzdst2_112108	Nov 21 08		CT	DICO	-	N
9965/DST2	zzdst2_112008	Nov 20 08		CT	DICO	-	N
9957/DST2	zzdst2_111908	Nov 19 08		CT	DICO	-	N
9947/DST2	zzdst2_111808	Nov 18 08		CT	DICO	-	N
9939/DST2	ZZDST2_111708	Nov 17 08		CT	DICO	-	N
9936/DST2	zzdst2_111408	Nov 14 08		CT	DICO	-	N
9927/DST2	ZZDST2_111308	Nov 13 08		CT	DICO	-	N
9920/DST2	zzdst2_111208	Nov 12 08		CT	DICO	-	N
9919/DST2	zzzgetestdst2	Nov 11 08		CT	DICO	-	N
999/DST2	Anonymous999	May 25 04	PET,NSCLC IN	CT	DICO	-	N

164 examinations

Exam no 999, May 25 04, Anonymous999

Ser	Type	Imgs	Description	Mod	PPS
1	PROSP	992		CT	-

one series

Add / Sub

Edit Patient

Film

Mini Viewer

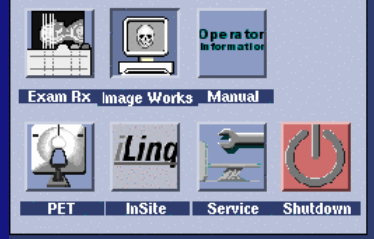
Reformat

Viewer

Series no 1 - PROSP

Img	Im Ctr S-I (mm)	Thick (mm)	Gntry (deg)	Im Ctr R-L	Im Ctr A-P	SFOV (cm)	DFOV (cm)	Alg	Matrix	Midscan (sec)	Ph %R	Archive
1	I255.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
2	I257.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
3	I260.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
4	I262.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
5	I265.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
6	I267.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
7	I270.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
8	I272.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
9	I255.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
10	I257.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
11	I260.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
12	I262.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
13	I265.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No

992 images



Autovoice Volume
Check Security
Unix Shell
Turn Off Extend HU
Quick Snap

Application Selection Remove Sort Network Archive PPS Queue Utilities Messages

Examinations :

Exam	Name	Date	Description	Mod	Fmt	PPS	A
10017	zzdst2_1203200	Dec 03 08		CT	DICO	-	N
10016	zzzgetest	Dec 02 08		CT	DICO	-	N
10015	ZZZGETEST	Dec 02 08		CT	DICO	-	N
10008	zzpetct	Dec 02 08		CT	DICO	-	N
9991/DST2	ZZPETCT zzmont	Nov 24 08		CT	DICO	-	N
9990/DST2	ZZPETCT zzmont	Nov 24 08		CT	DICO	-	N
9979/DST2	zzdst2_112408	Nov 24 08		CT	DICO	-	N
9973/DST2	zzdst2_112108	Nov 21 08		CT	DICO	-	N
9965/DST2	zzdst2_112008	Nov 20 08		CT	DICO	-	N
9957/DST2	zzdst2_111908	Nov 19 08		CT	DICO	-	N
9947/DST2	zzdst2_111808	Nov 18 08		CT	DICO	-	N
9939/DST2	ZZDST2_111708	Nov 17 08		CT	DICO	-	N
9936/DST2	zzdst2_111408	Nov 14 08		CT	DICO	-	N
9927/DST2	ZZDST2_111308	Nov 13 08		CT	DICO	-	N
9920/DST2	zzdst2_111208	Nov 12 08		CT	DICO	-	N
9919/DST2	zzzgetestdst2	Nov 11 08		CT	DICO	-	N
999/DST2	Anonymous999	May 25 04	PET.NSCLC IN	CT	DICO	-	N

164 examinations

Exam no 999, May 25 04, Anonymous999

Ser	Type	Imgs	Description	Mod	PPS
1	PROSP	992		CT	-
810	PROSP	32	P_AVG	CT	-
811	PROSP	32	P_mip	CT	-
812	PROSP	32	P_MIP	CT	-

Automatically generated

4 series

Add / Sub
Edit Patient
Film
Mini Viewer
Reformat
Viewer

Series no 1 - PROSP

Img	Im Ctr S-I (mm)	Thick (mm)	Gntry (deg)	Im Ctr R-L	Im Ctr A-P	SFOV (cm)	DFOV (cm)	Alg	Matrix	Midscan (sec)	Ph %R	Archive
1	I255.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
2	I257.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
3	I260.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
4	I262.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
5	I265.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
6	I267.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
7	I270.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
8	I272.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.250		No
9	I255.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
10	I257.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
11	I260.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
12	I262.50	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No
13	I265.00	2.500	0.0	R 0.0	A 0.0	50.0	50.0	STND	512	0.401		No

992 images

Summary

- Respiratory gating PET can improve quantification, but is challenging to be performed in the clinic
- Average CT can improve registration of CT and PET, is used for dose calculation and IGRT in radiation therapy
- MIP CT can assist tumor contouring
- Workflow and efficiency can be improved, and cost can be reduced