Mitigation of mis-registration and tumor motion in PET/CT

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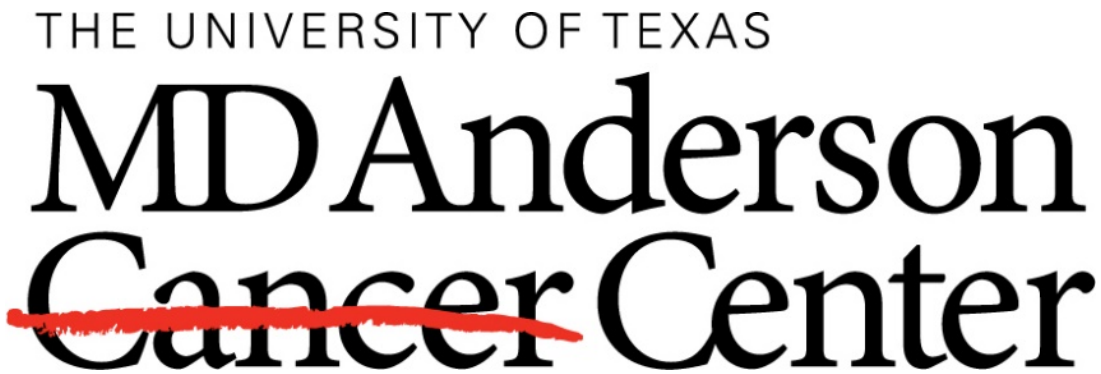
Imaging Physics and Radiation Physics

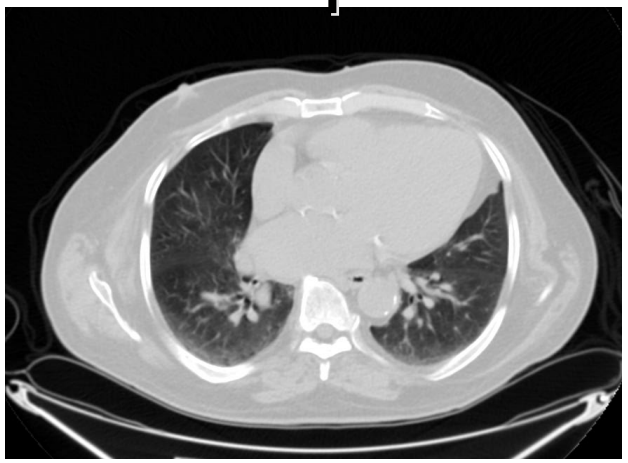
July 11, 2022

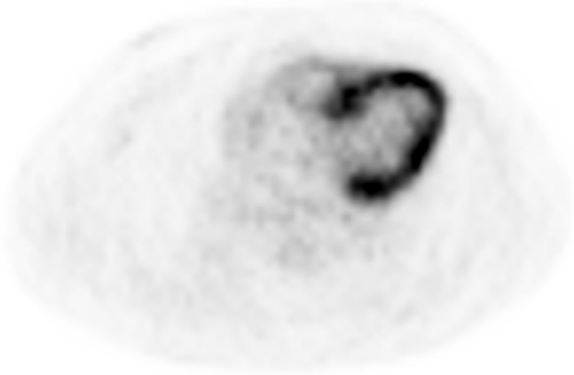


Quantification of PET data

Before AC

Attenuation correction (AC)

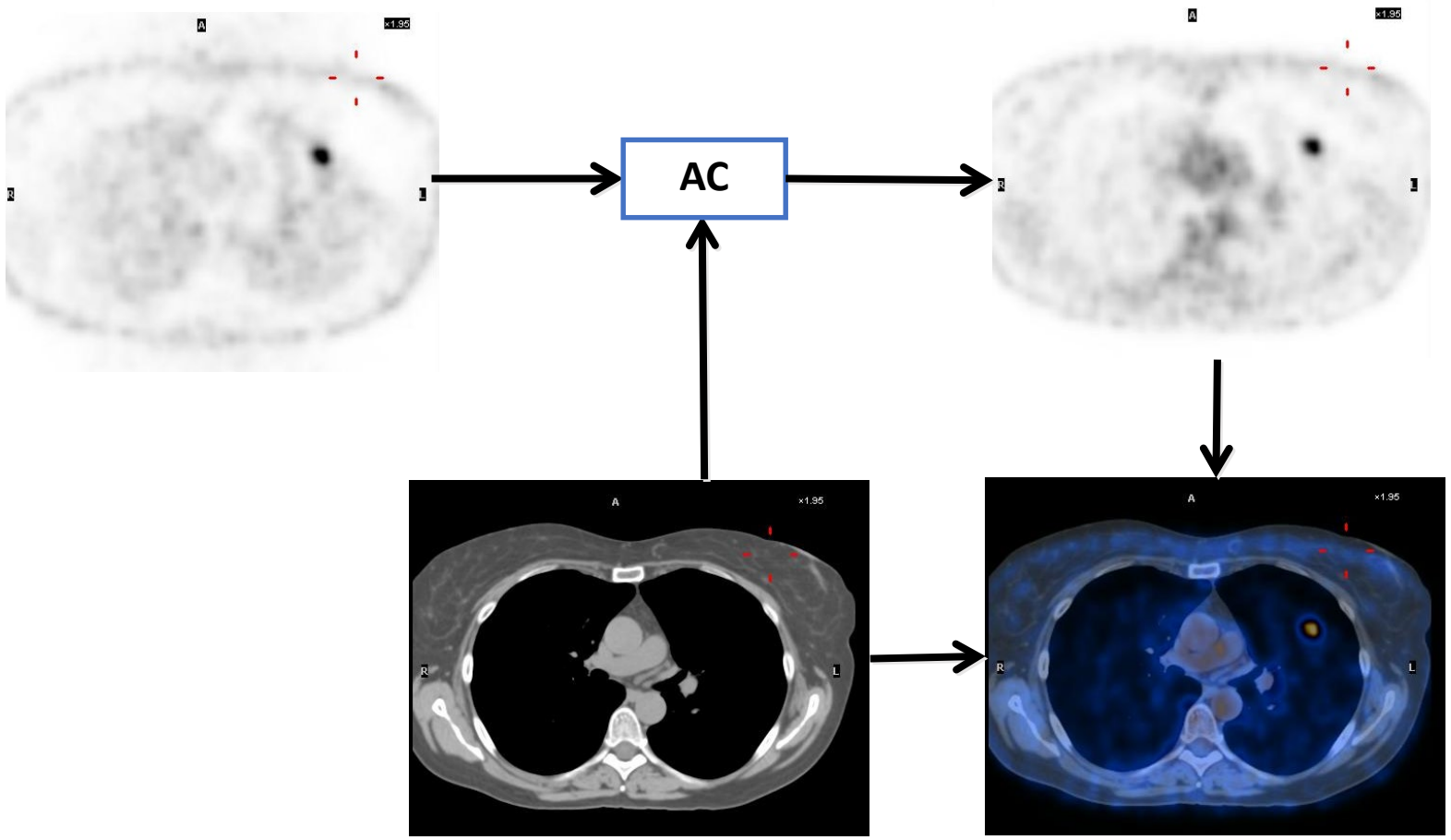




After AC

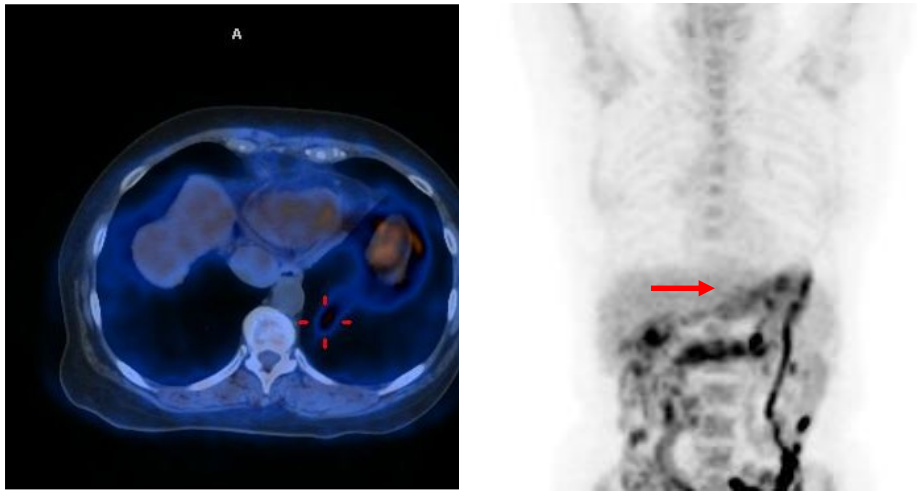
Photon Energy	H_2O - 1.0	Pb - 11.34
511 keV	7.22 cm	0.4021 cm

Verification of PET data

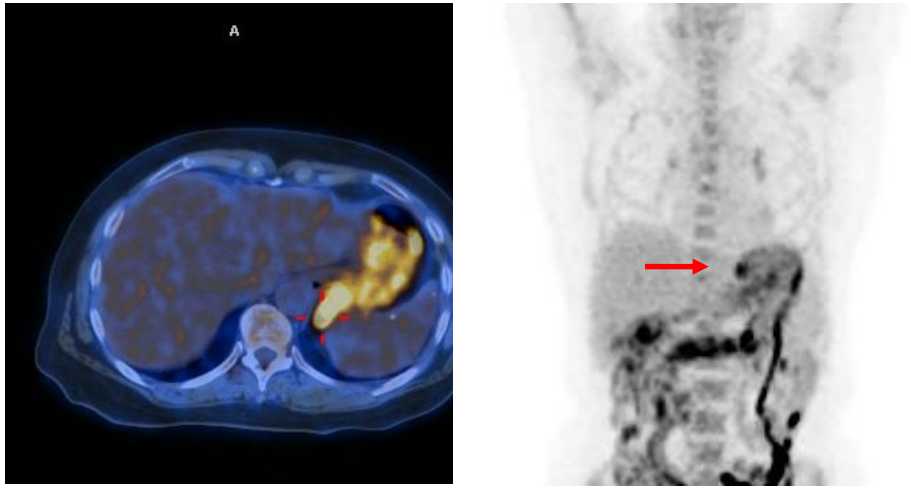


Suspicion arises when CT and PET are not consistent

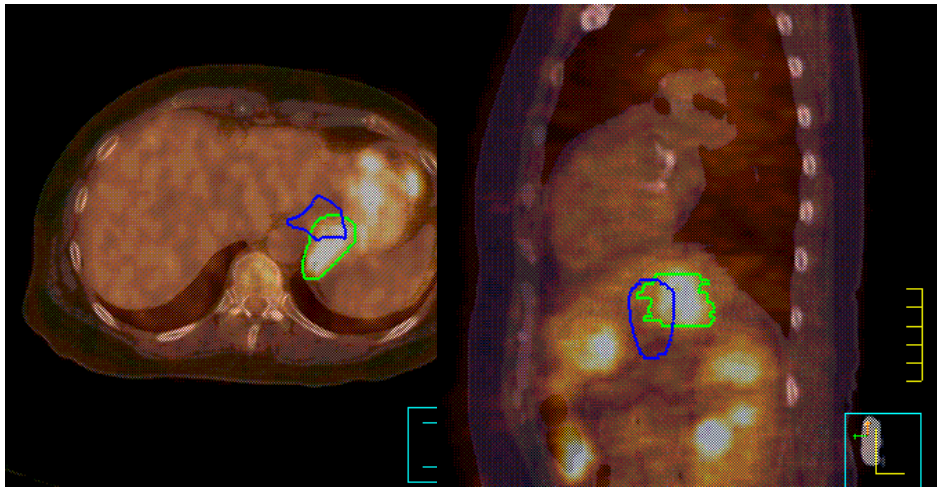
Mis-registration can lead to mis-treatment



False negative with misregistration after induction chemo



True positive w/o misregistration

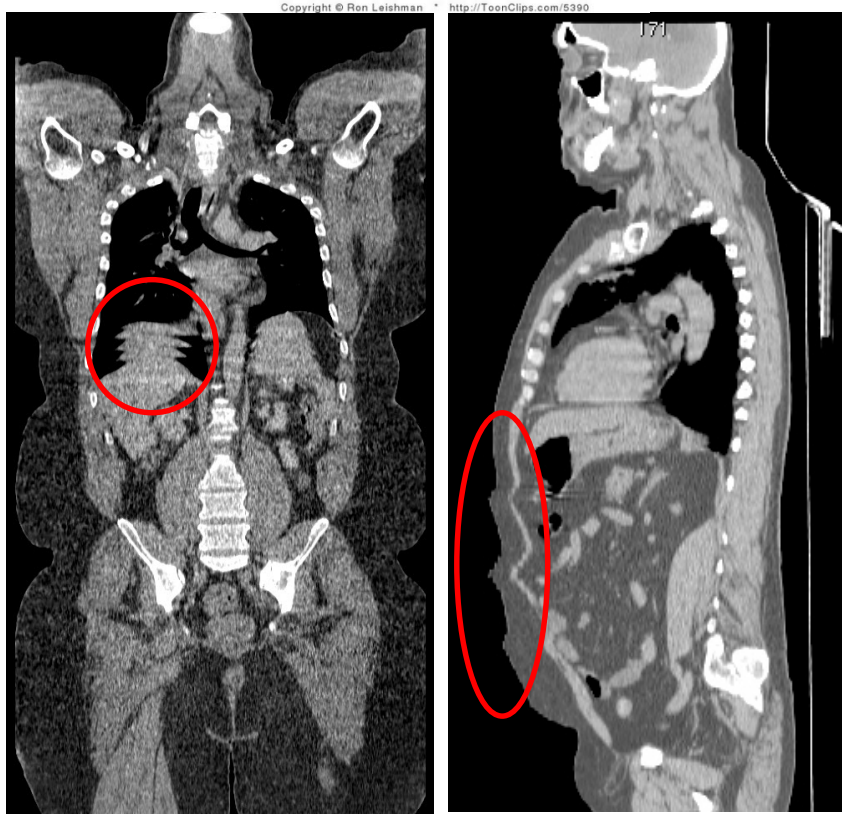


False negative **blue** & true positive in **green**

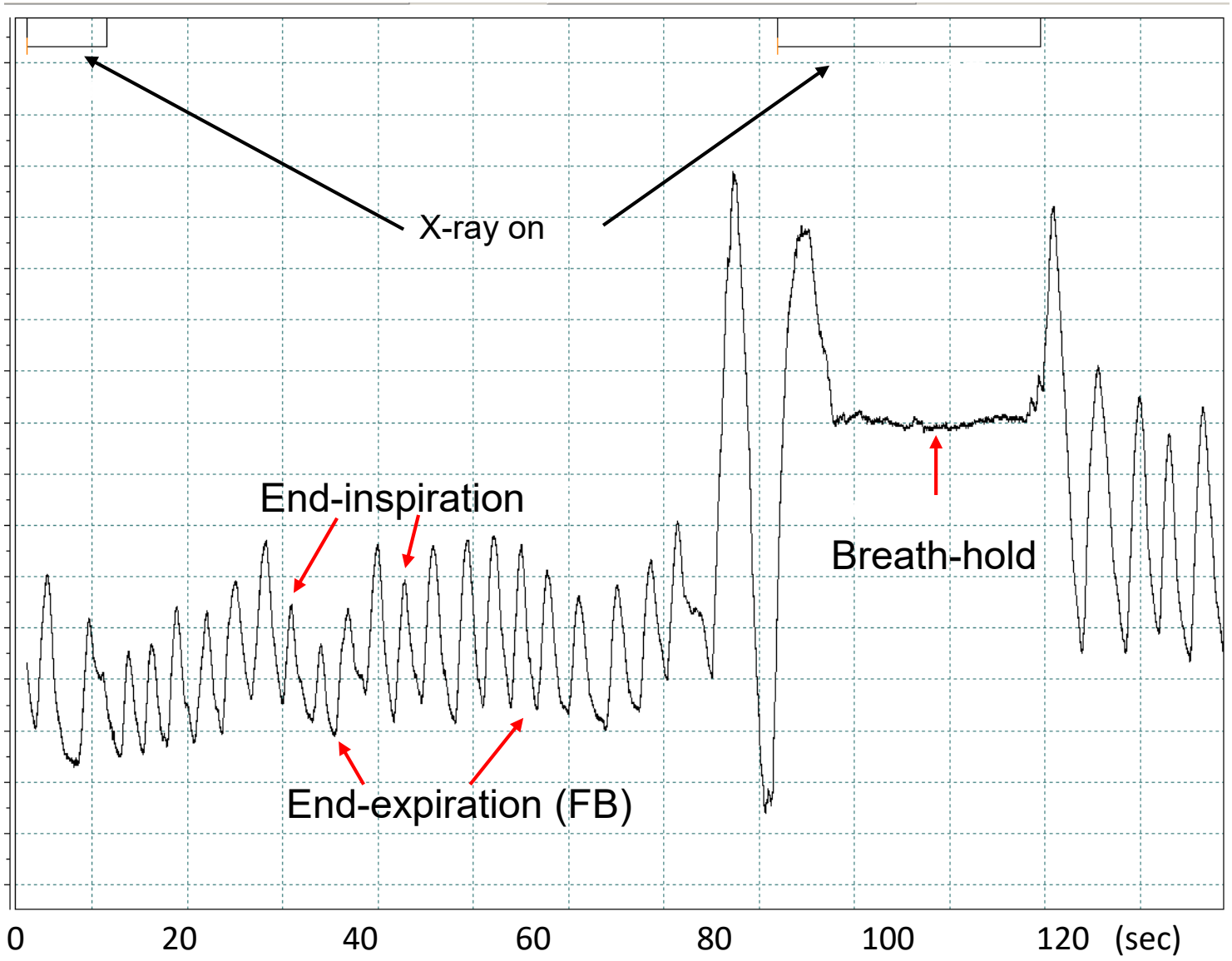
Pan et al, *Med Phys* 2008

PET/CT scan characteristics

- Free-breathing
- CT is acquired in sub-sec, PET in minutes
- If there is **mis-registration** between CT and PET, it is almost always the **fault of CT**.
- Most of the PET/CT scans are free of mis-registration artifacts
  - Light breathing
  - No lesion involved
  - Expiration longer than inspiration

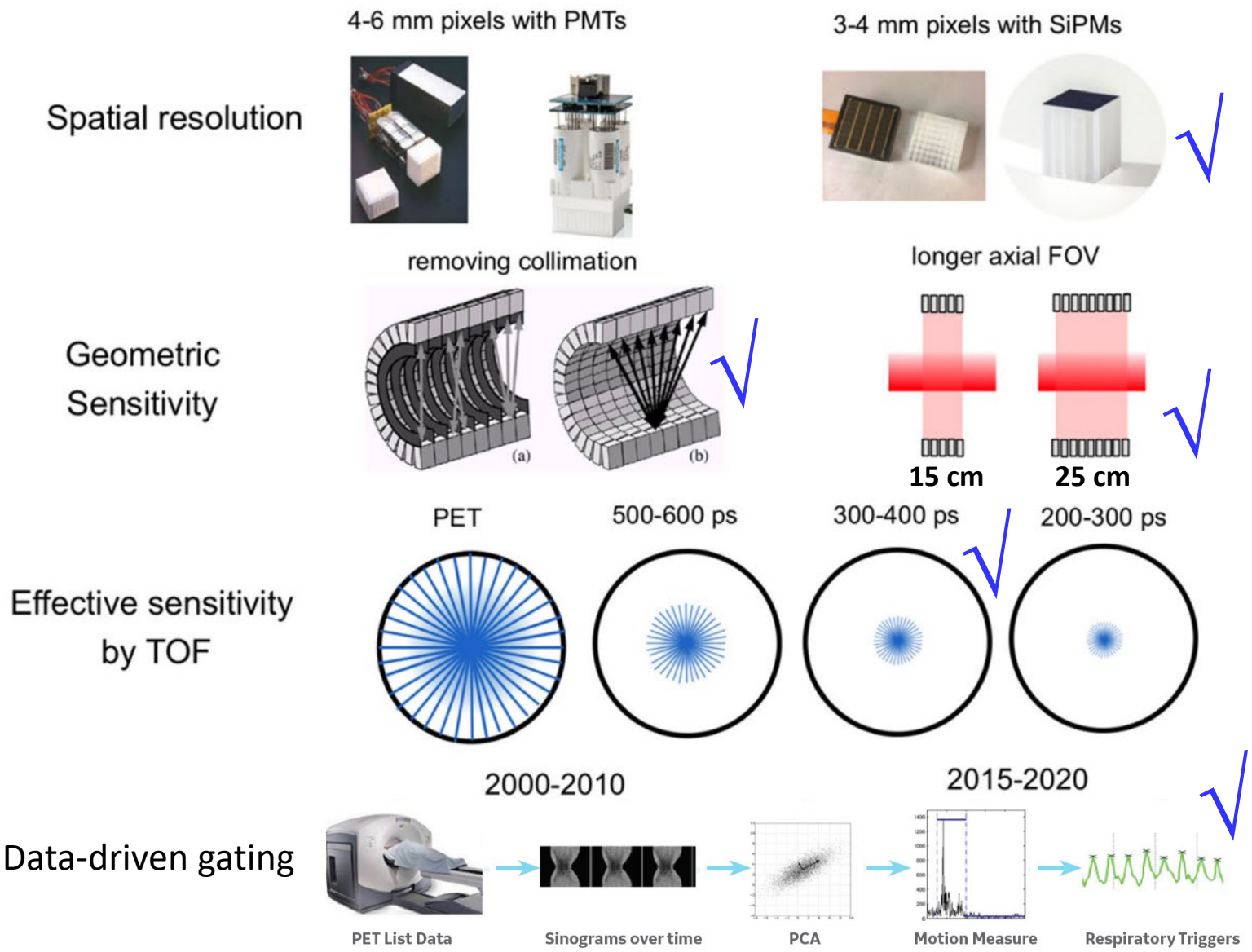


Mis-registration from couching



Pan et al, JNM, 2005

Major improvements in PET technology



Modified from Vandenberghe, et al. *EJNMMI Phys* **7,** 35 (2020)

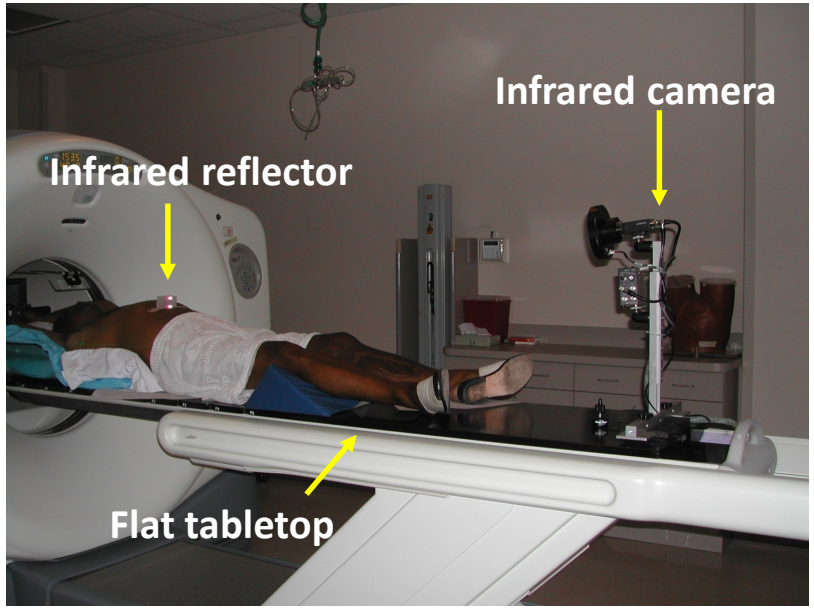
Respiratory gating devices

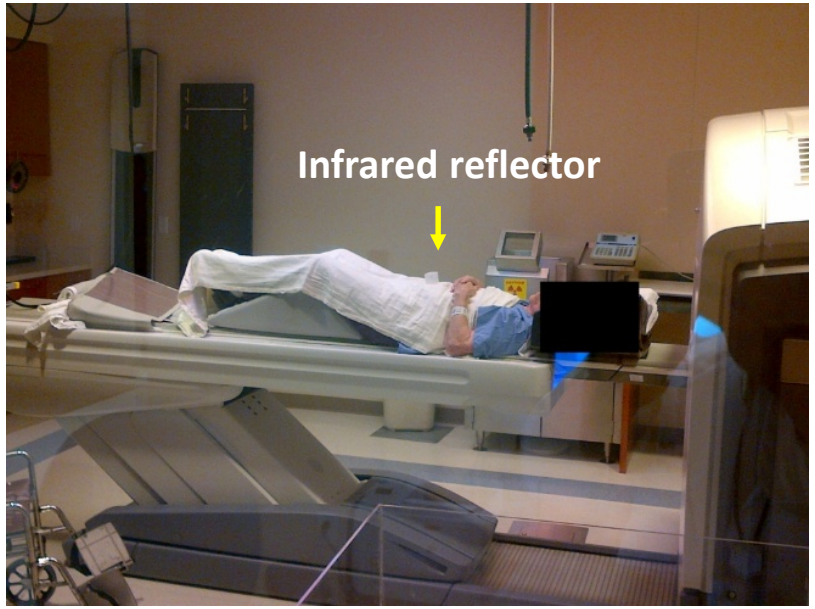
Varian (Optical)

Anzai (Pressure)

Philips (Air Bellows)

Radiation Oncology





Diagnostic Imaging

Discovery MI (25 cm) and 710 (15 cm)

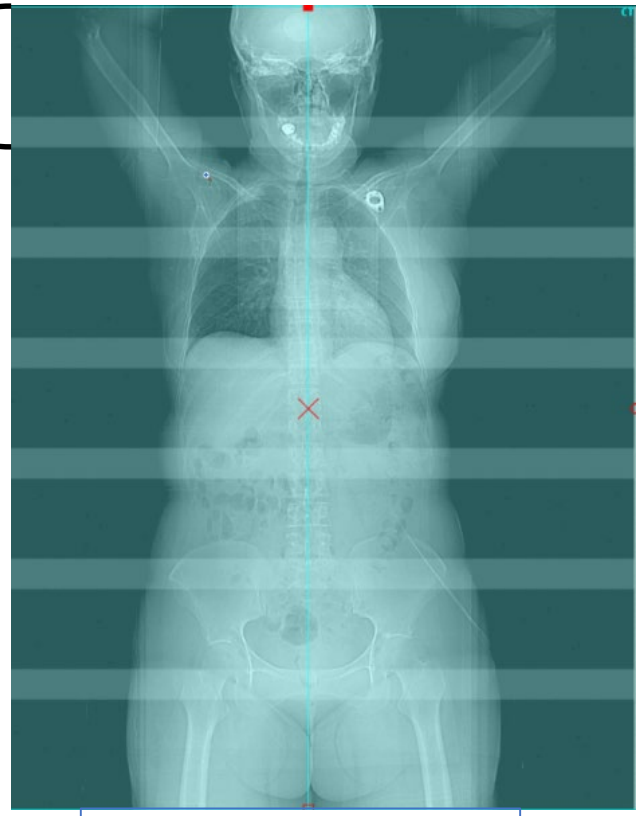
	MI - 25 cm	710 - 15 cm
Scintillator material	LYSO (SiPM)	LYSO (PMT)
Scintillator dimensions (mm^3)	3.95 x 5.3 x 25	4.2 x 6.3 x 25
Sensitivity (cps/kBq)	19.6	7.3
Slices x Thickness(mm)	89 x 2.8	47 x 3.27
Spatial resolution(mm)@1cm	4.3	4.6
Spatial resolution @10cm	4.9	5.1
Scatter Fraction %	40.5	38.9
Clinical NECR (kcps)	84 @ 2.4 kBq/cc	42 @ 2.4 kBq/cc
Peak NECR (kcps)	268.9 @ 21 kBq/cc	133.1@ 31.2 kBq
Timing resolution (10^{-12} sec)	385	545
% overlap between beds	28.1% (25 slices)	27.6% (13 slices)
Advancement per bed (cm)	17.9	11.8
Matrix size	256 x 256	192 x 192

RefleXion LinacPET has sensitivity of ~ 0.2 cps/kBq

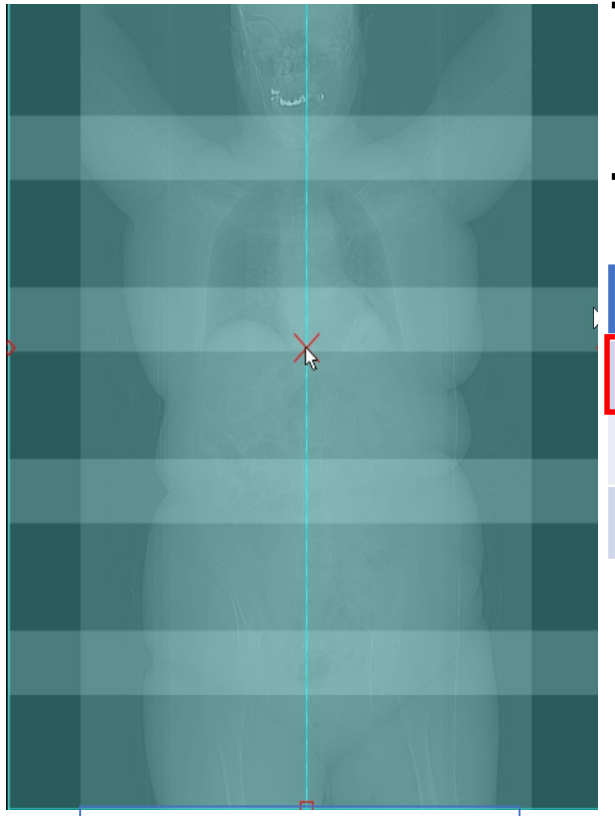
Pan et al, *Med Phys* 2019

SNR improvement from 15 to 25 cm axial FOV

15 cm



25 cm



15 cm PET/CT

BMI	(min/bed)
<25	2 (1.5) torso (leg)
(25 to 40)	3 (2)
(40 to 45)	4 (2)

25 cm PET/CT

BMI	(min/bed)
<35	2 (1.3)
(35 to 40)	2.5 (1.67)
(40 to 45)	3 (2)

21 min (= 7 x 3 min)

10 min (= 5 x 2 min)

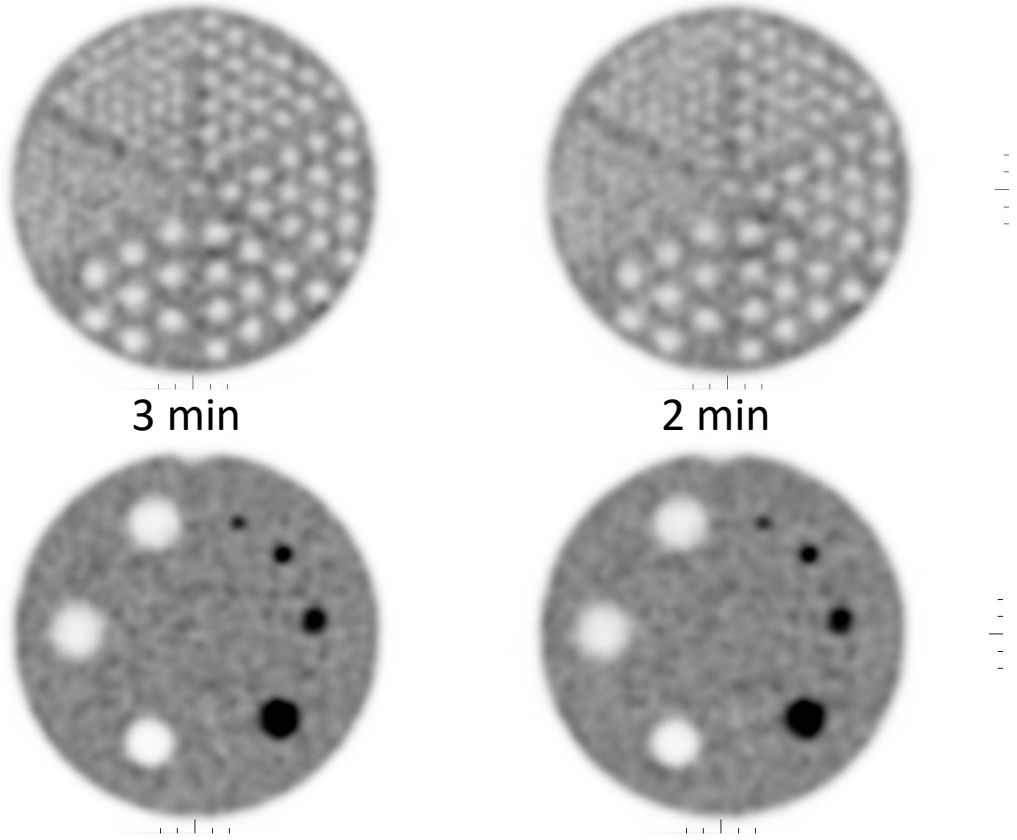
Every PET scan can be respiratory gated

$$SNR \approx \sqrt{\frac{\text{Sensitivity} \times \text{Time}}{\Delta t}}$$

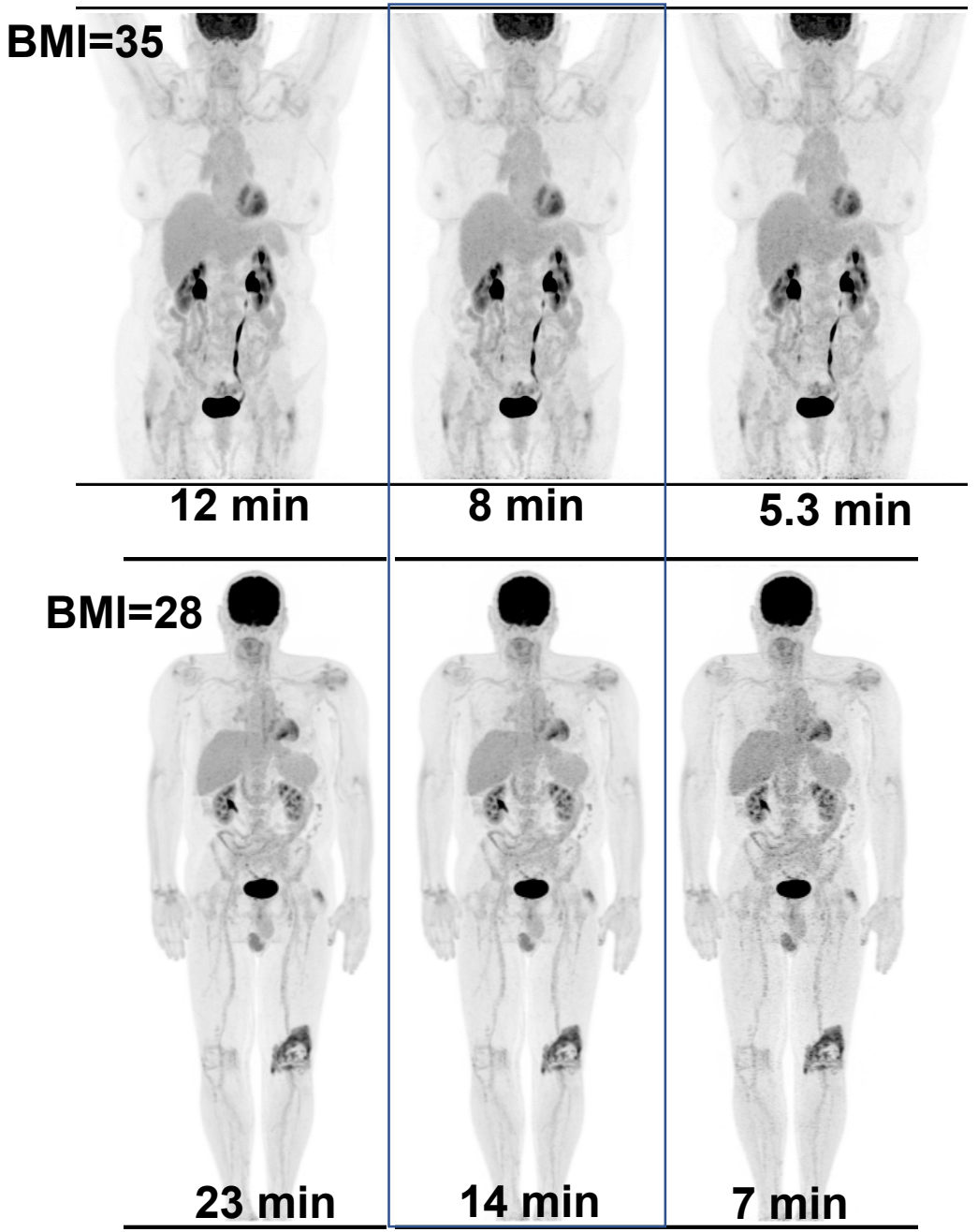
Sensitivity (cps/kBq)
Time: scan duration
Δt: *Time of flight* timing resolution

Sensitivity ↑ 2.7 & Time ↓ 0.67 & Δt ↑ 1.42 → SNR ↑ 60 % (Counts ↑ 2.5)

ACR Phantom @ 370 MBq

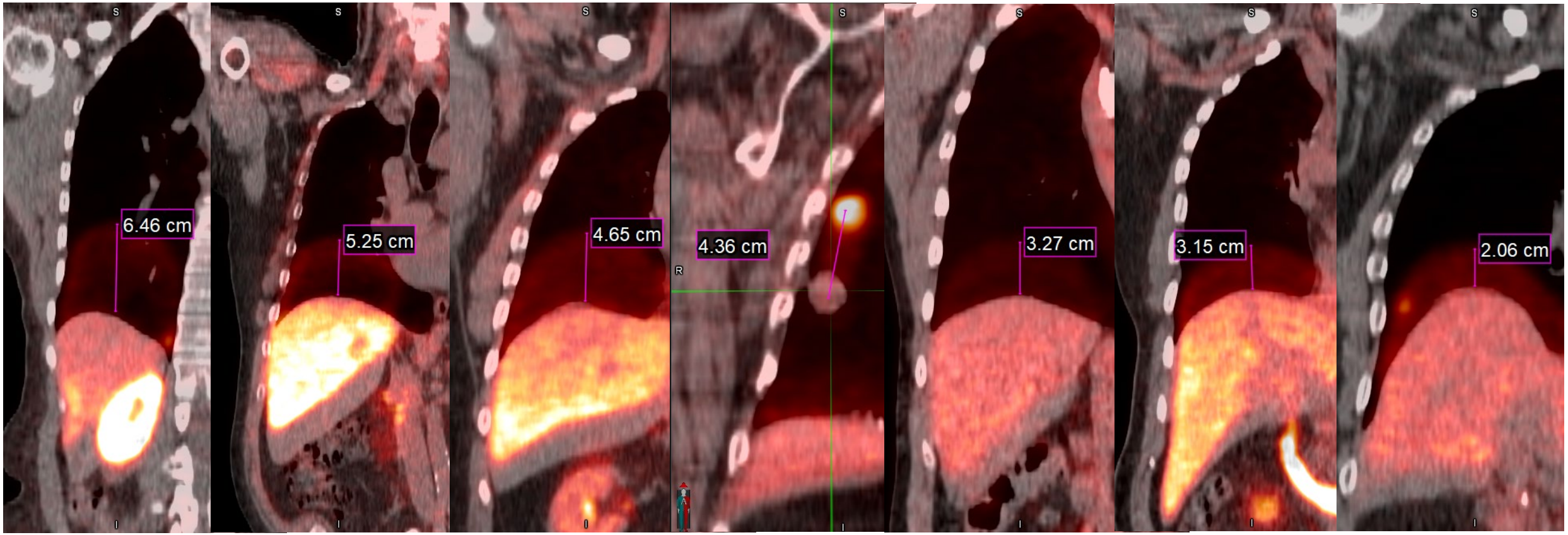


Need <u>two technologists</u> to run a scanner when the scan time < 10 min per patient because of paper work ≈ 10 min



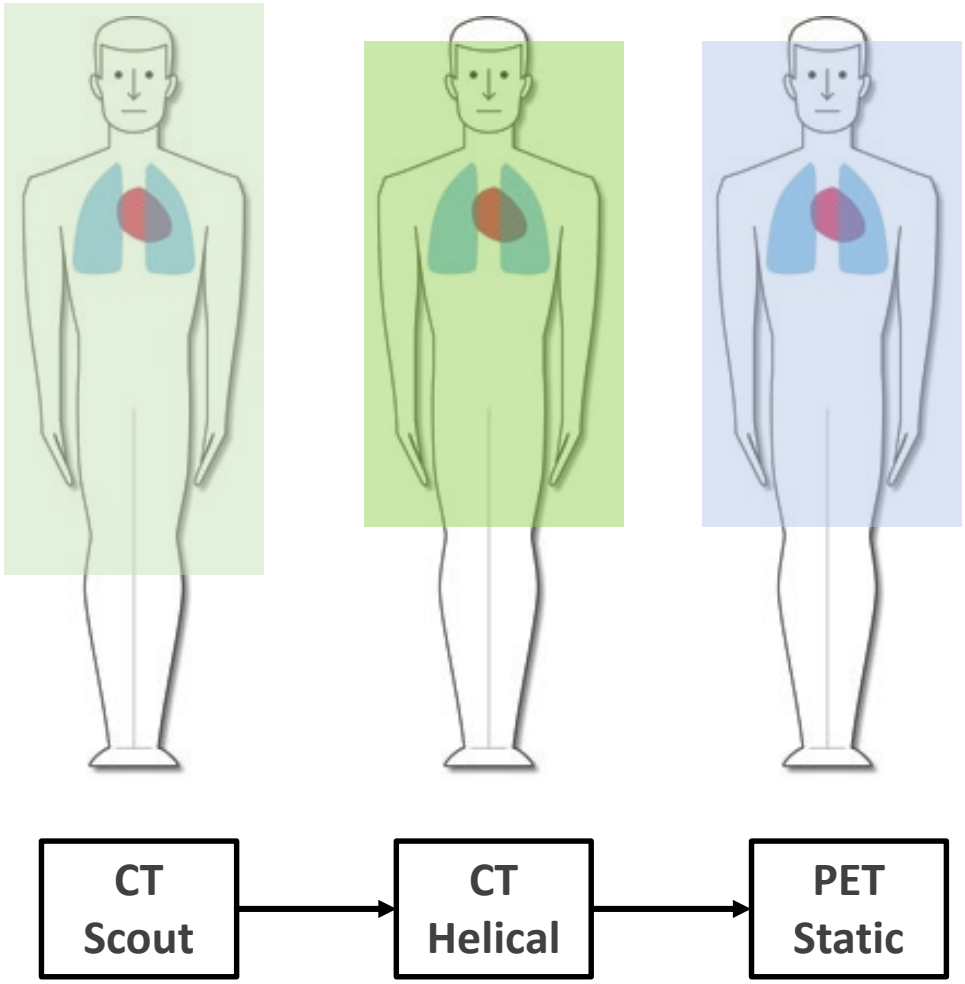
Pan et al, *Med Phys* 2019

Mis-registration

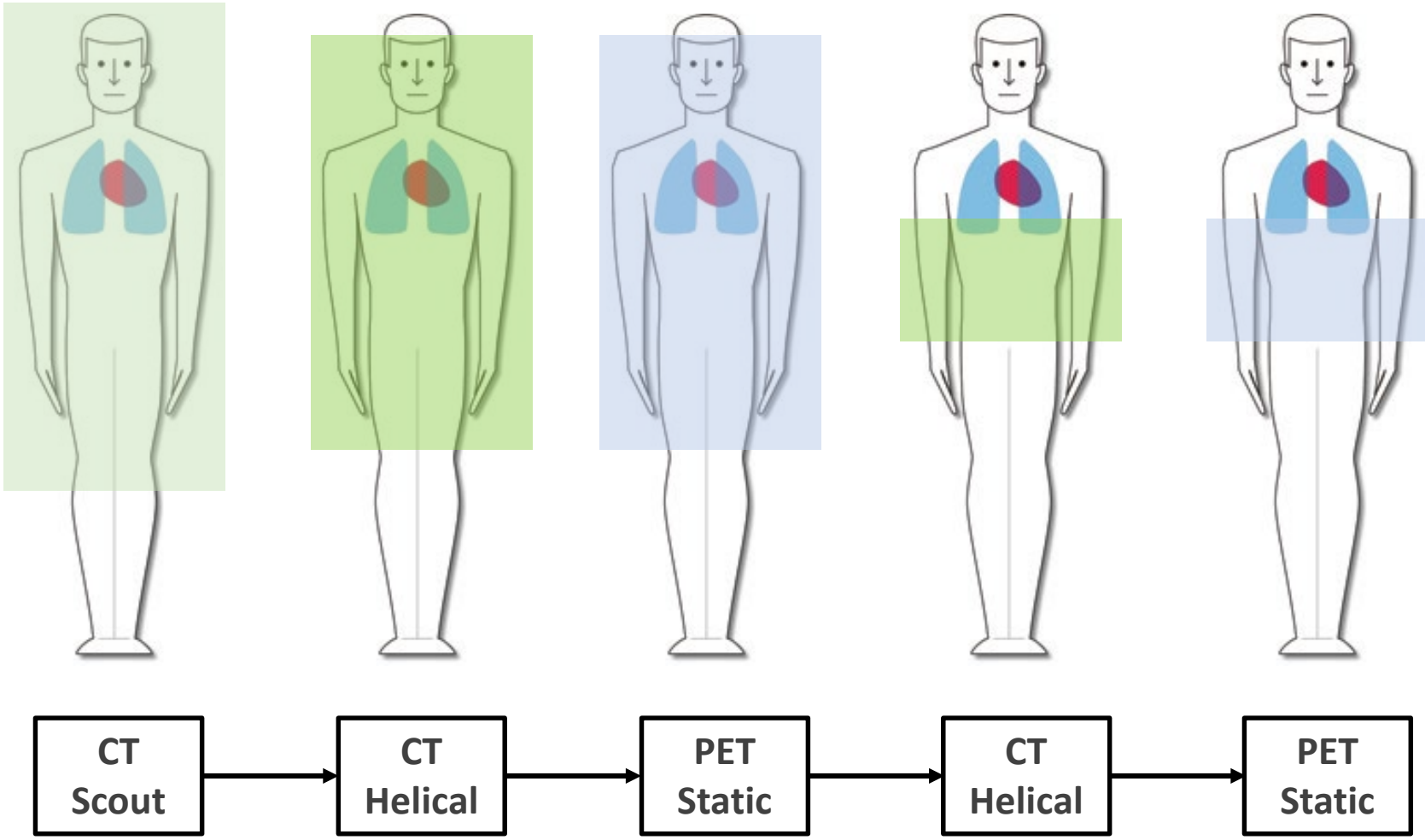


^{68}Ga-Dotatate ^{18}F-FCABC ^{18}F-FCABC ^{18}F-FDG ^{18}F-FDG ^{18}F-DCFPyL ^{68}Ga-Dotatate

Conventional PET/CT

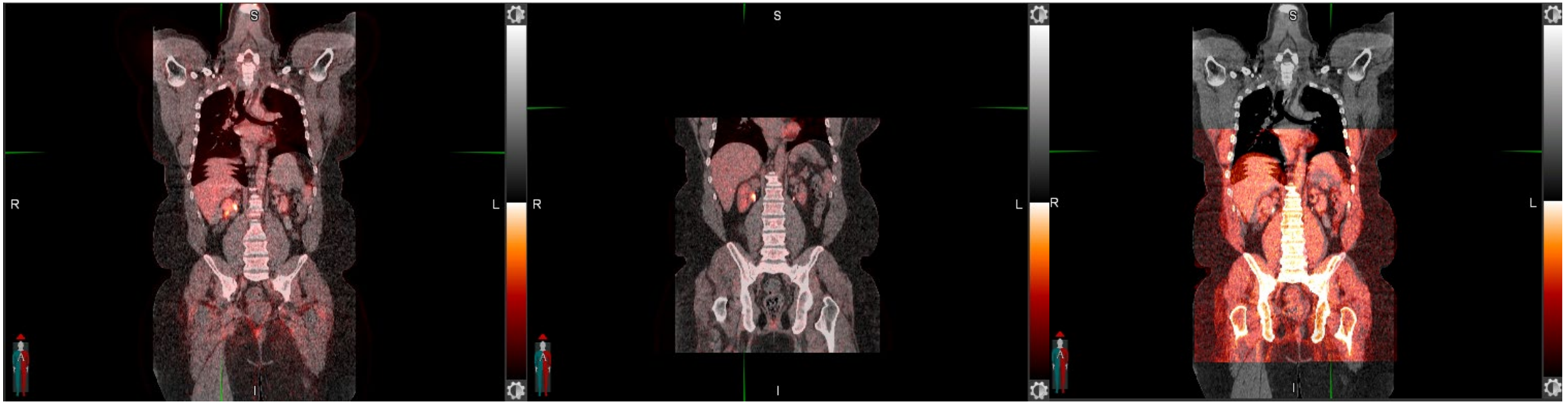


Conventional PET/CT and repeat PET/CT



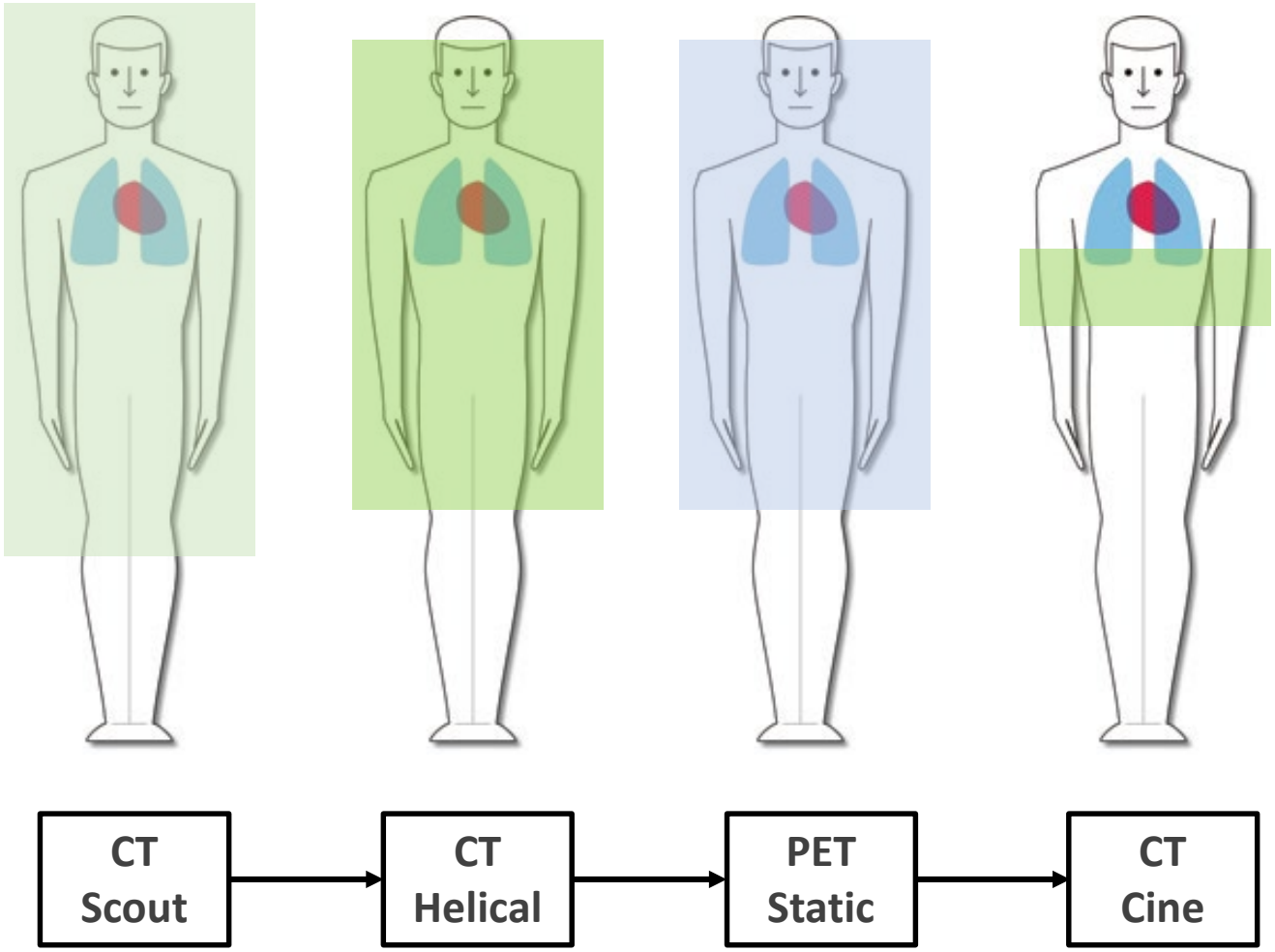
(radiation dose↑, scan time ↑)

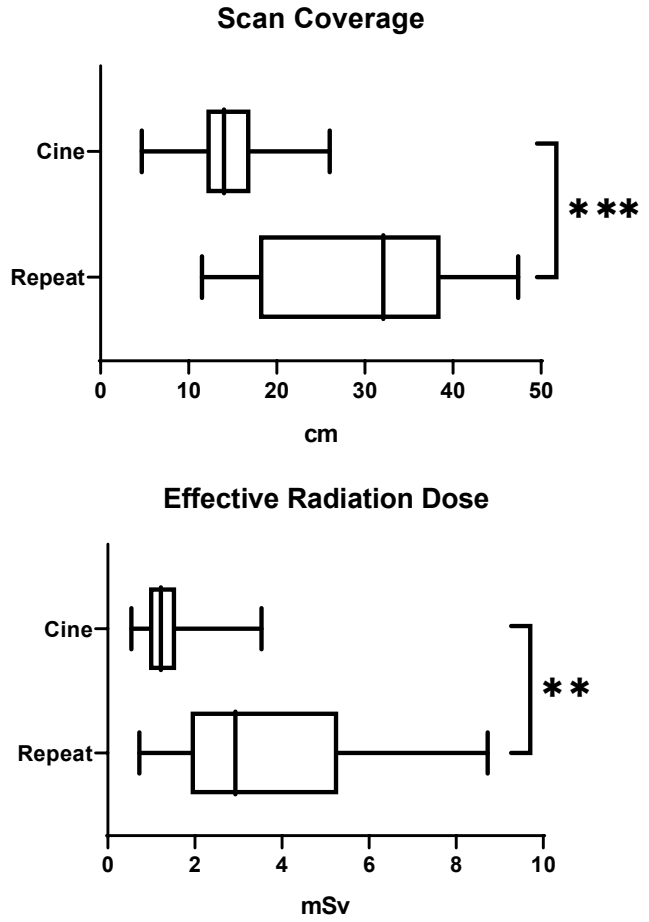
Repeat PET/CT
(radiation dose↑, scan time ↑)



Whole body PET/CT **Repeat PET/CT** **Fusion of WB CT and Repeat CT**

Conventional PET/CT and Cine CT for DDG CT



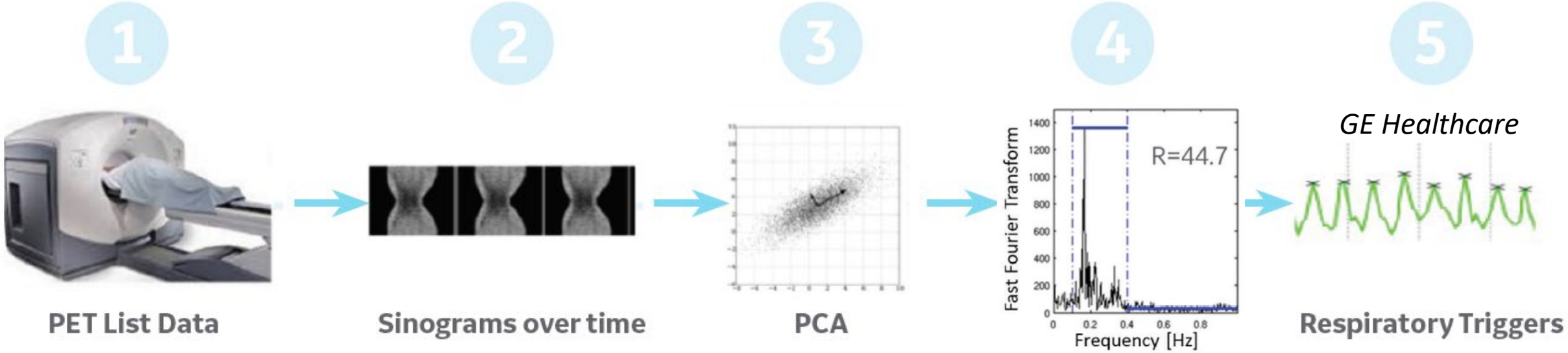


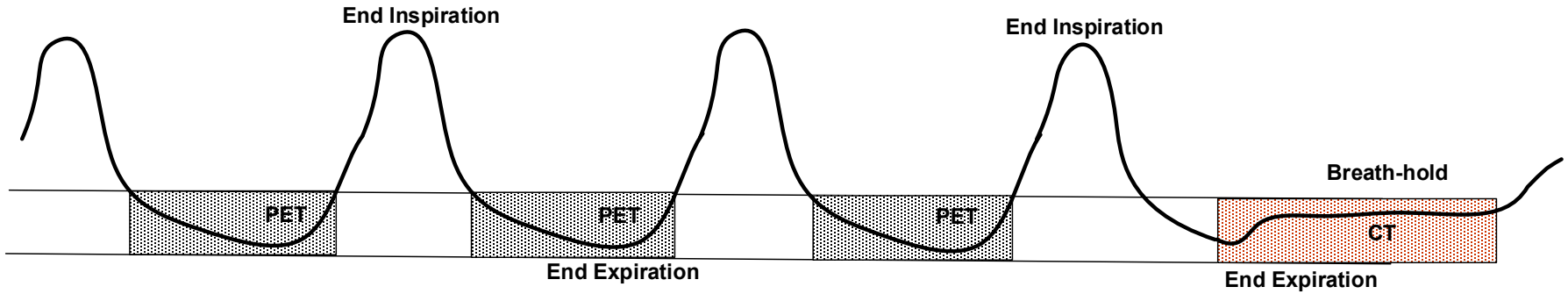
Significant difference in scan coverage (***p<0.001) and effective radiation dose(**p<0.01)

(radiation dose↓, scan time ↓)

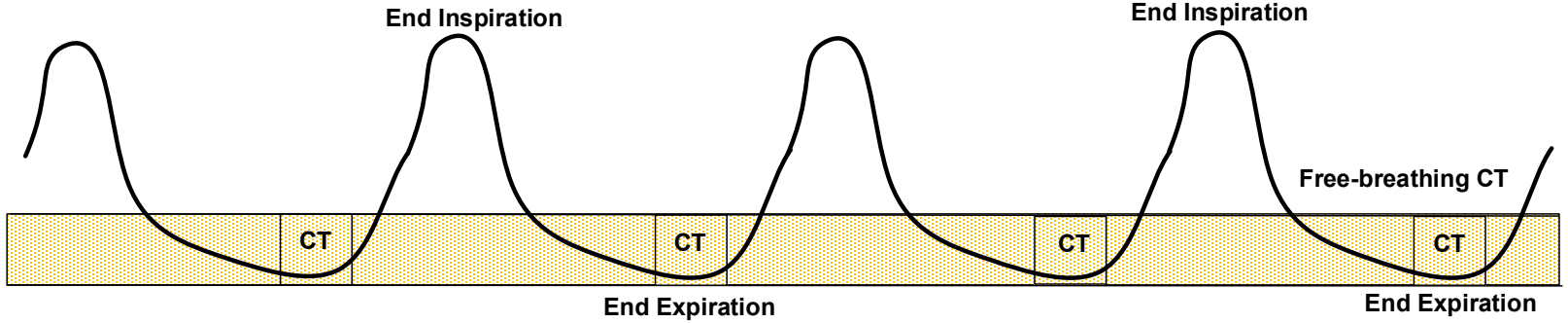
Pan et al, *IJROBP* 2021

Data Driven Gated (DDG) PET



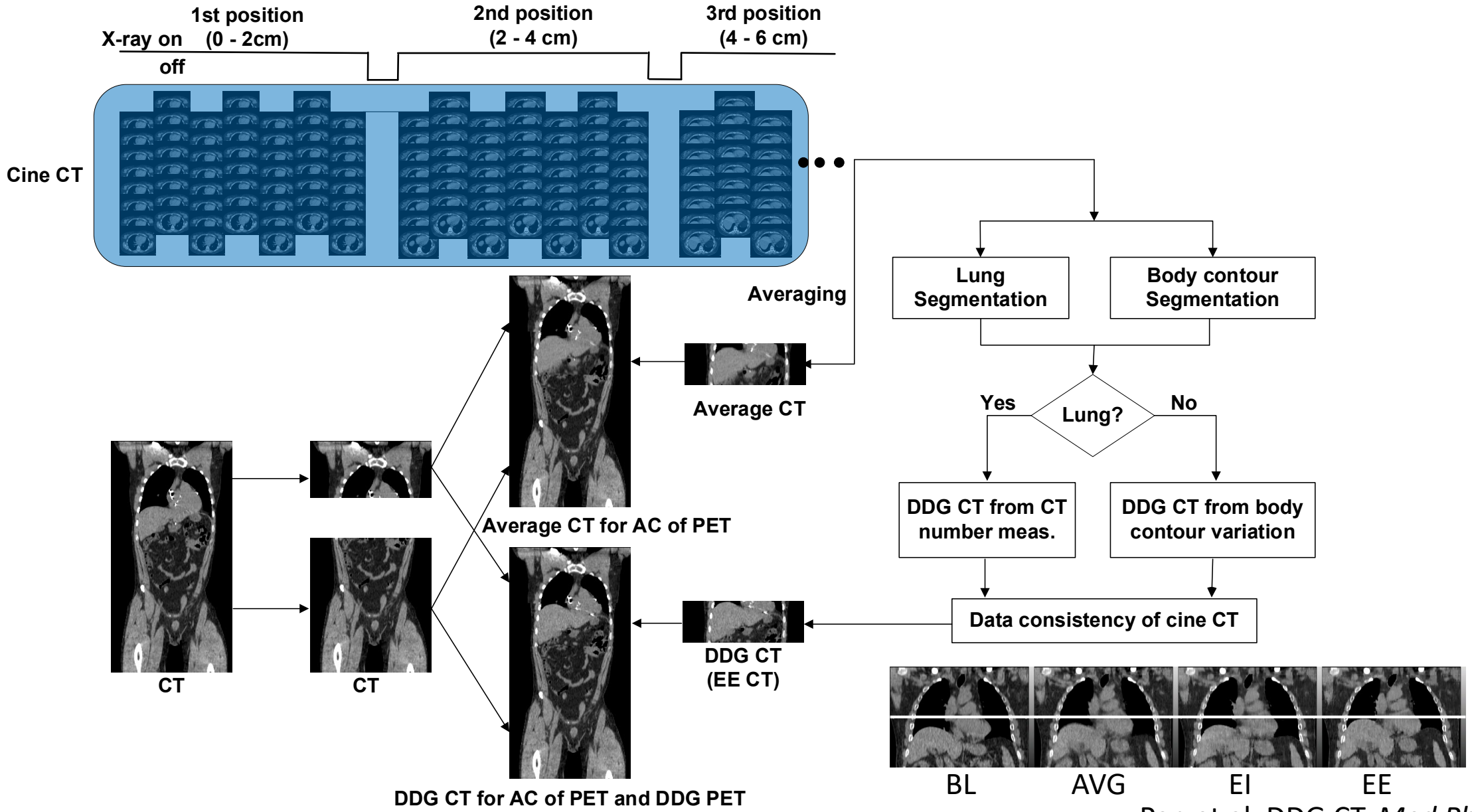


CT needs hardware gating such as RPM
Daouk et al, CMPB 2008



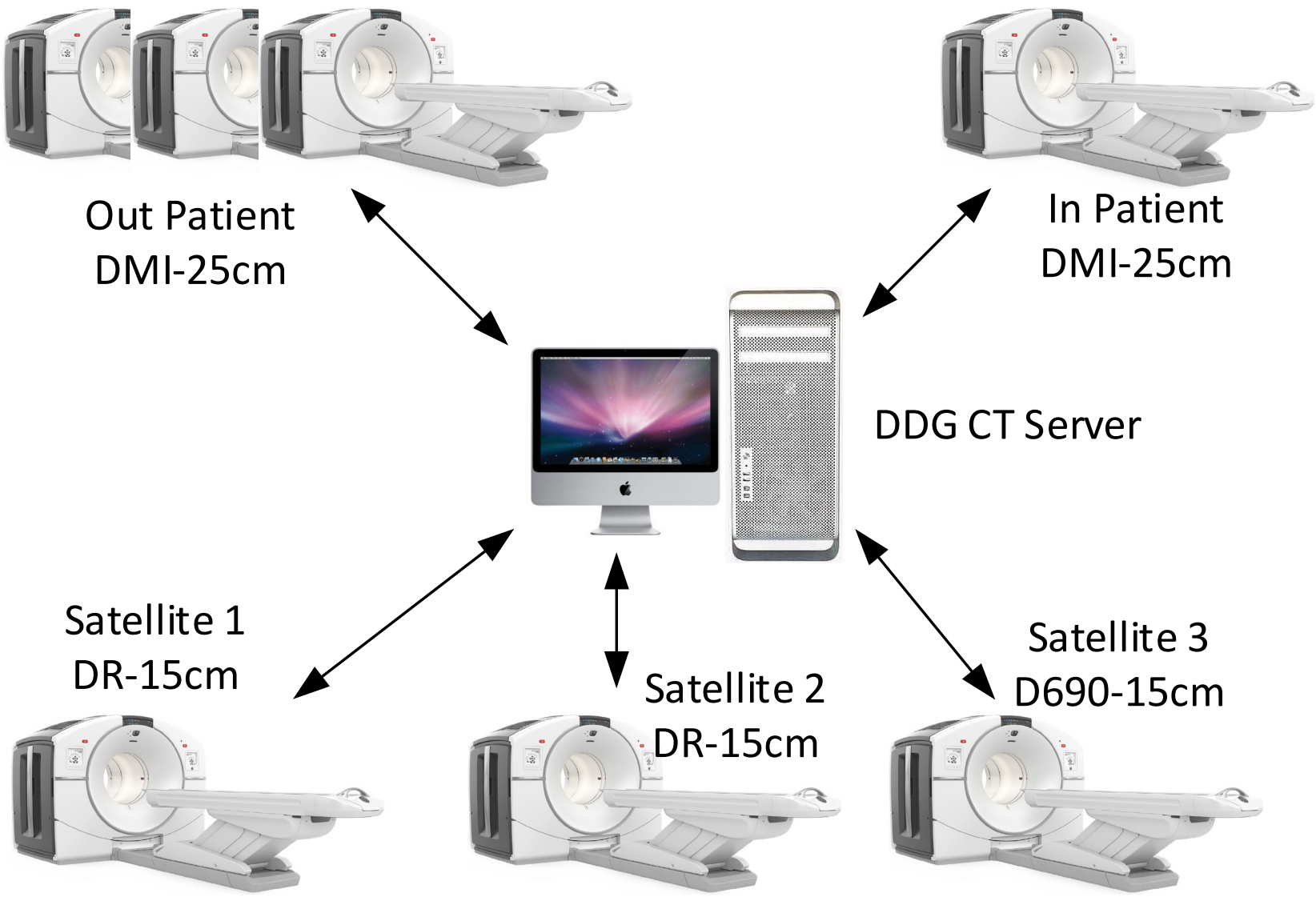
Data-driven gated CT
Pan et al, Med Phys 2022

Cine CT to average CT and DDG CT



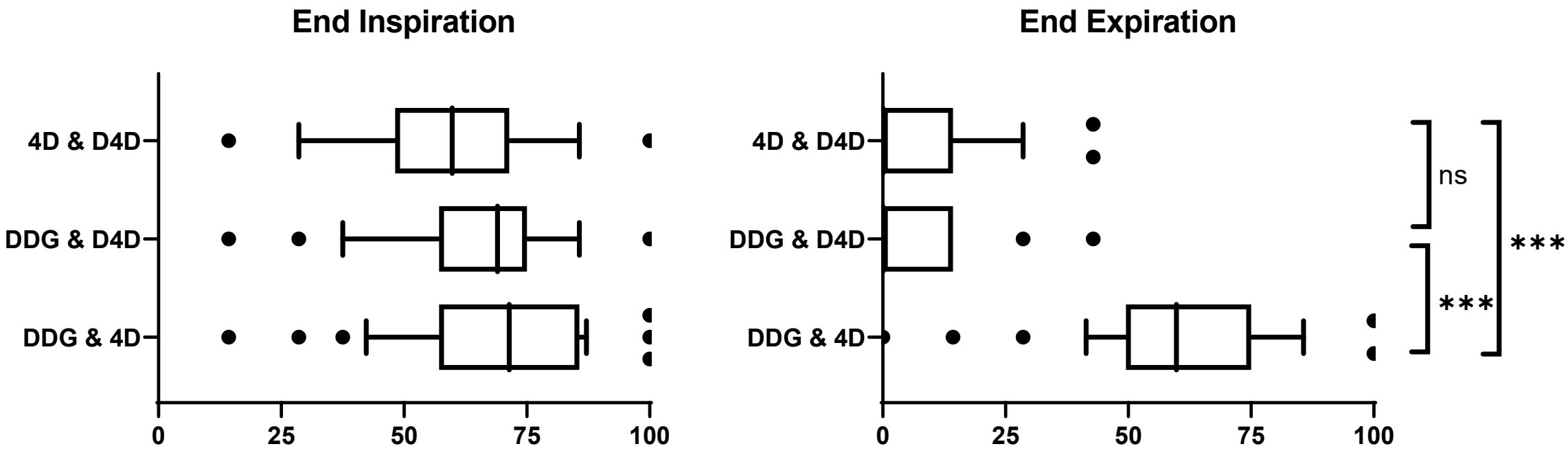
Pan et al, DDG CT, *Med Phys* 2022

DDG CT Server



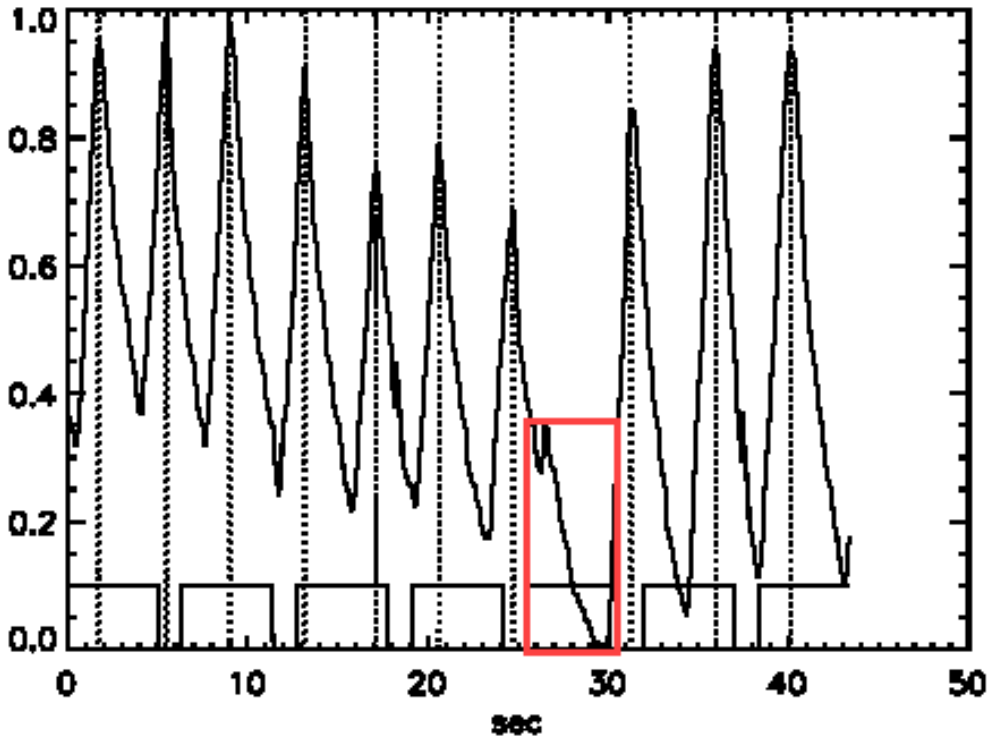
Pan et al, DDG CT, *Med Phys* 2022

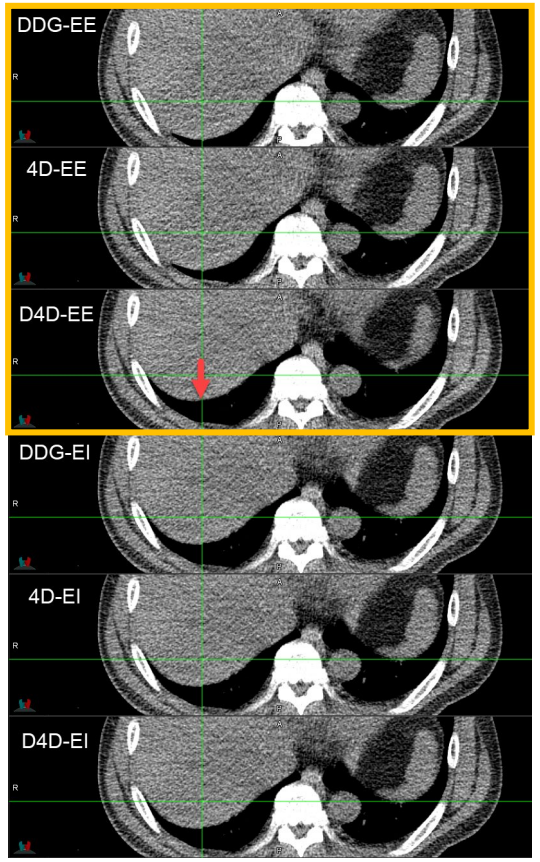
Comparison of 4D-CT, D4D and DDG on 38 patients



Pan et al, DDG CT, *Med Phys* 2022

DDG CT > 4D CT > D4D CT



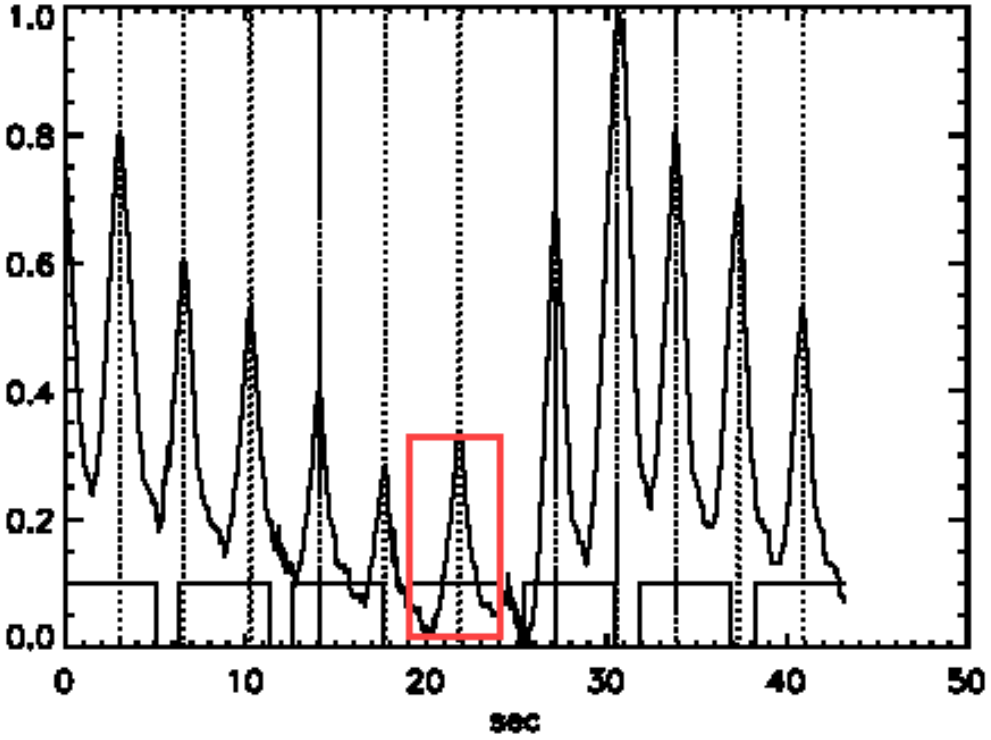


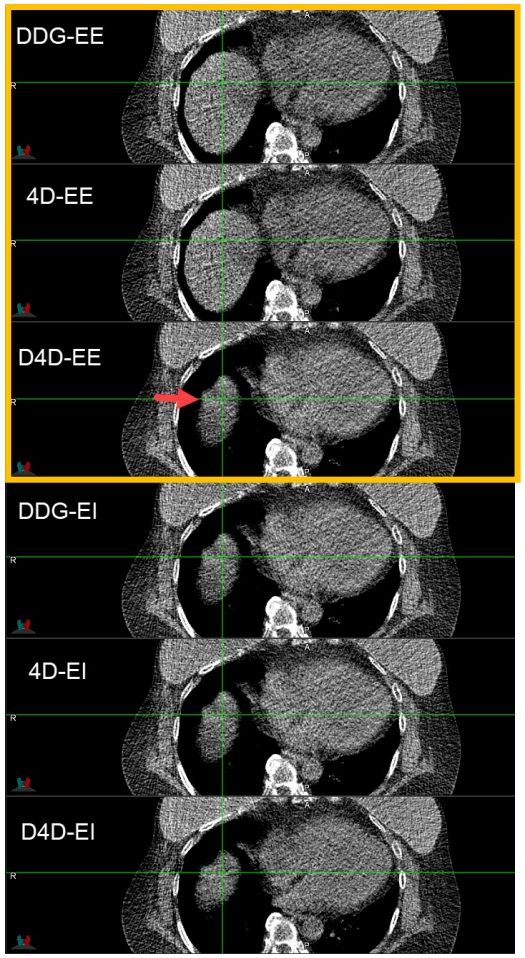
5-th

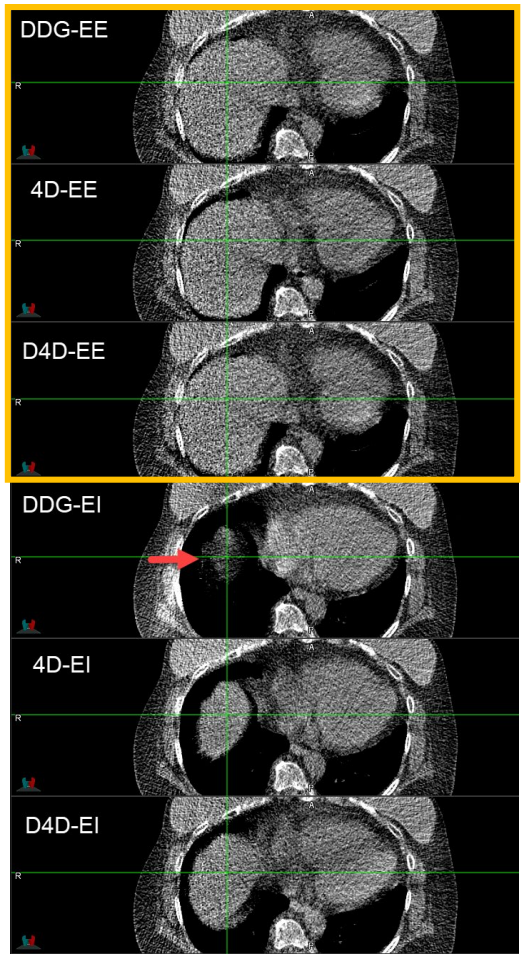
6-th

Pan et al, DDG CT, *Med Phys* 2022

DDG CT > 4D CT > D4D CT

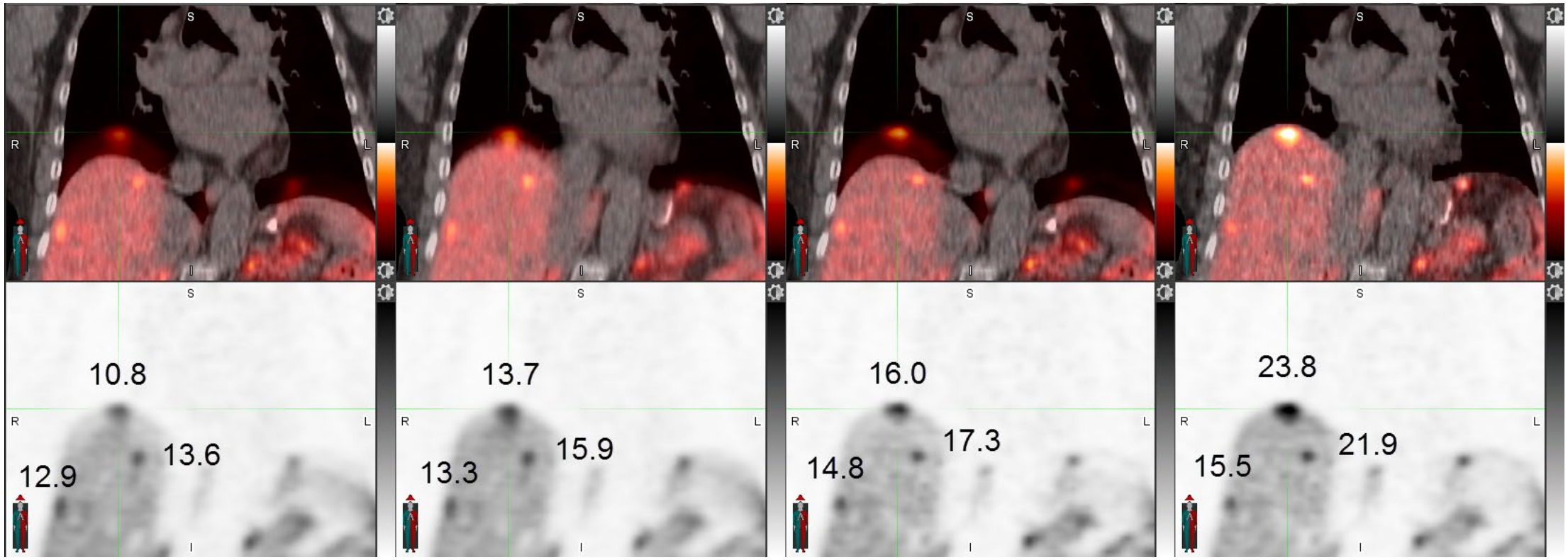






Pan et al, DDG CT, *Med Phys* 2022

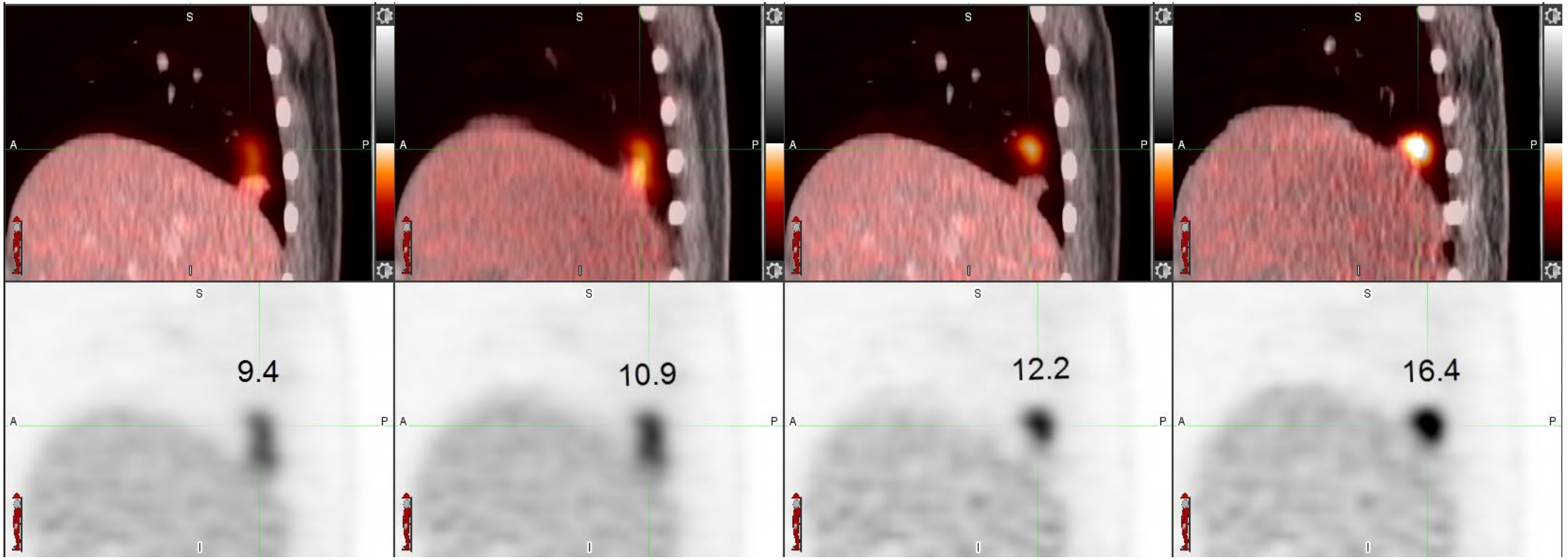
^{68}Ga-DOTATATE study



Baseline PET/CT **Average PET/CT** **DDG PET/baseline CT** **DDG PET/CT**

Pan et al, *IJROBP* 2021

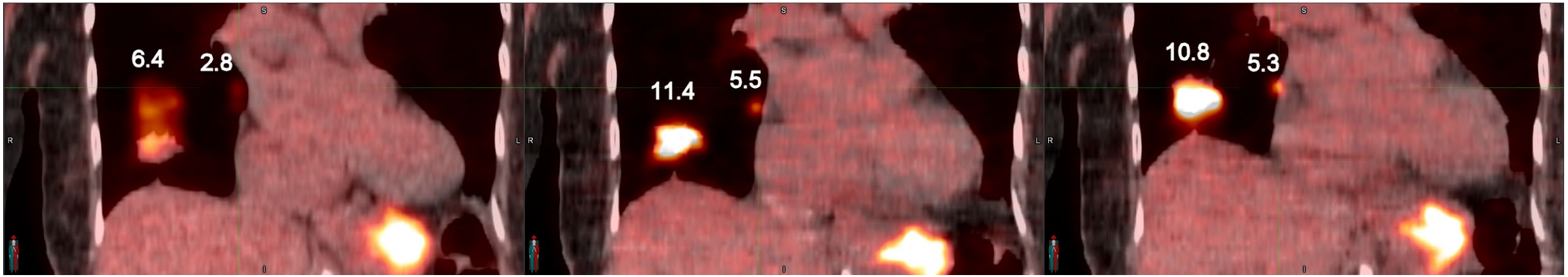
^{18}F-FDG study

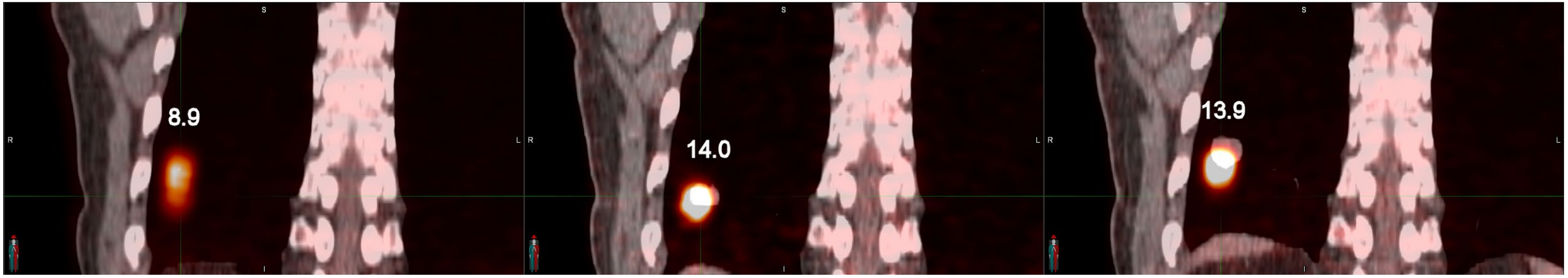


Baseline PET/CT **Average PET/CT** **DDG PET/baseline CT** **DDG PET/CT**

Pan et al, *IJROBP* 2021

Examples of DDG PET/CT

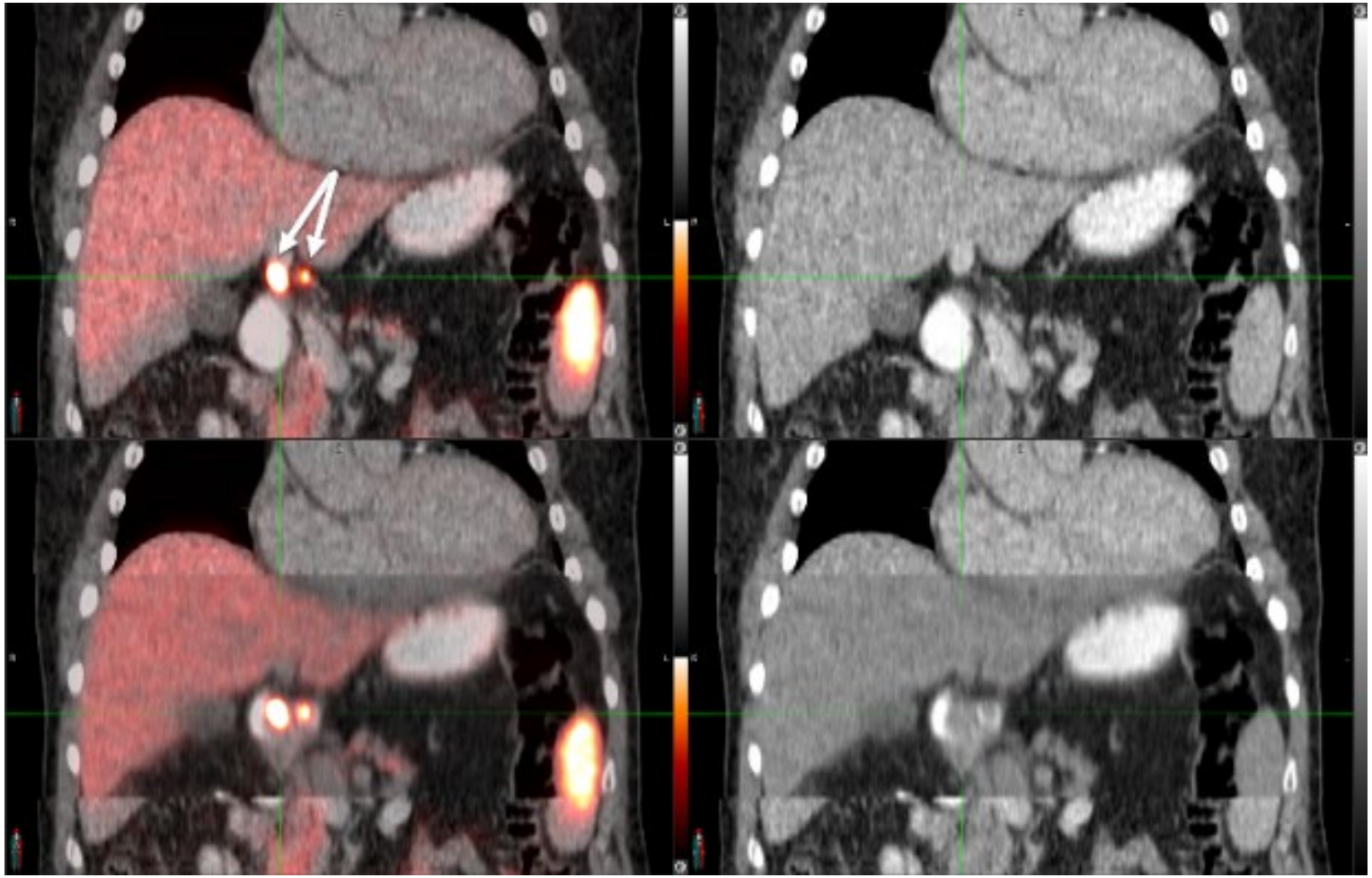




Registration improved assessment of nodal disease

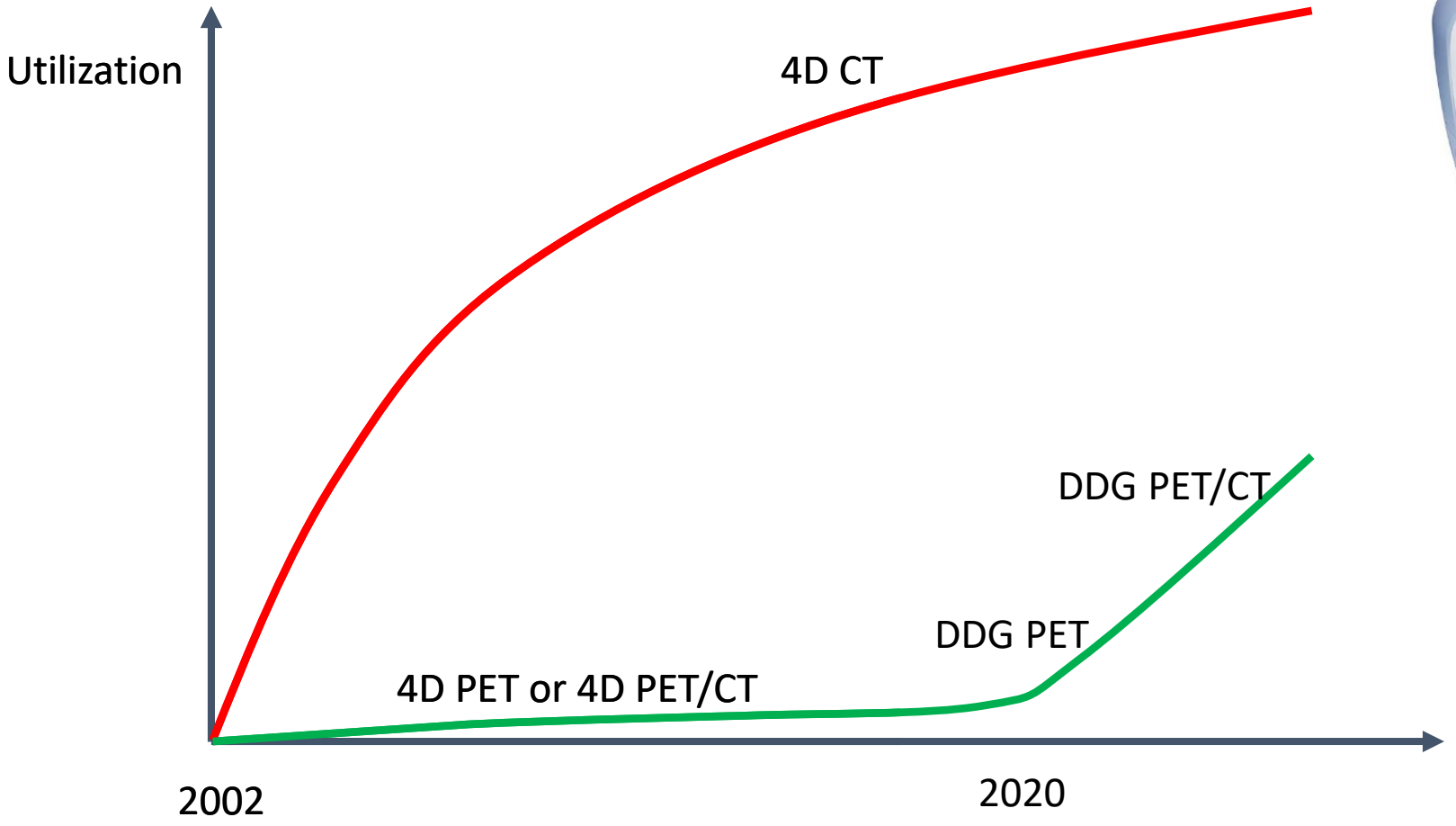
Baseline PET/CT

Registered PET/CT



A 65-year-old man with duodenal carcinoid tumor underwent ^{68}Ga-DOTATATE PET/CT for initial staging. The baseline PET/CT showed 2 avid foci (arrows) in the portal hepatic region. These 2 foci were not correlated with any corresponding CT abnormalities but were correlated with 2 nodular wall thickenings in the proximal duodenum, corresponding to the known primary cancer, in the registered PET/CT (bottom row). Thus, the registered PET/CT provided important information for the clinical management of the patient to become a candidate for surgery.

Utilization of 4D-CT and 4D-PET



Turn every PET/CT free of misregistration or motion artifacts

Summary

- PET/CT scan time 10 min
- PET/CT with DDG CT (> 4D CT > D4D)
- PET/CT free of mis-registration and motion artifacts
- No more respiratory monitoring devices