Advances in Hardware and Software for Nuclear Medicine

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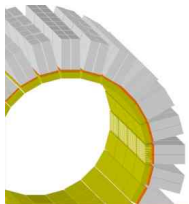
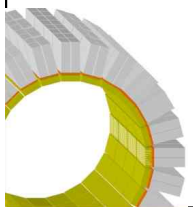
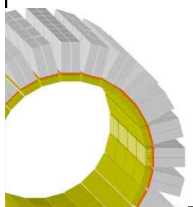


Advances in SPECT/CT

Deep learning for NM

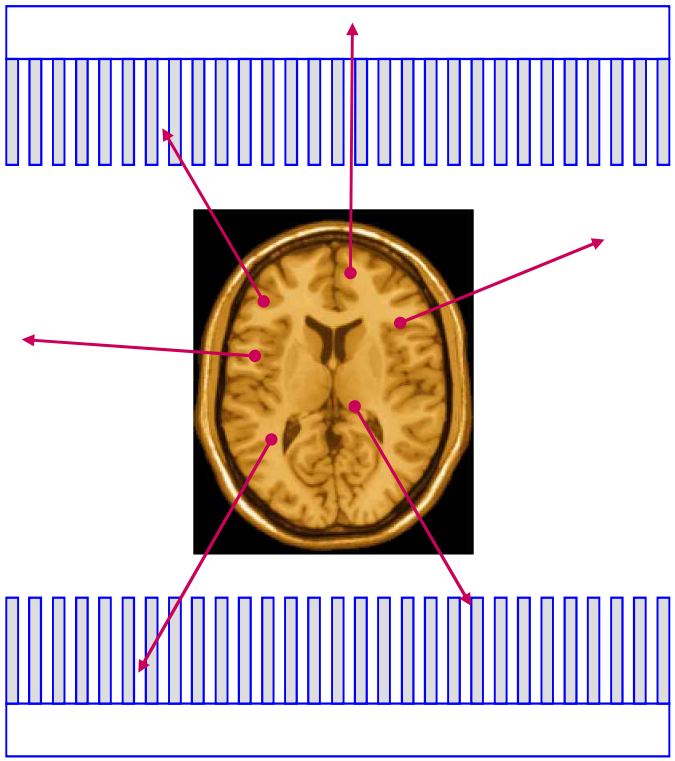


Advances in SPECT/CT



SPECT: Tomographic Imaging

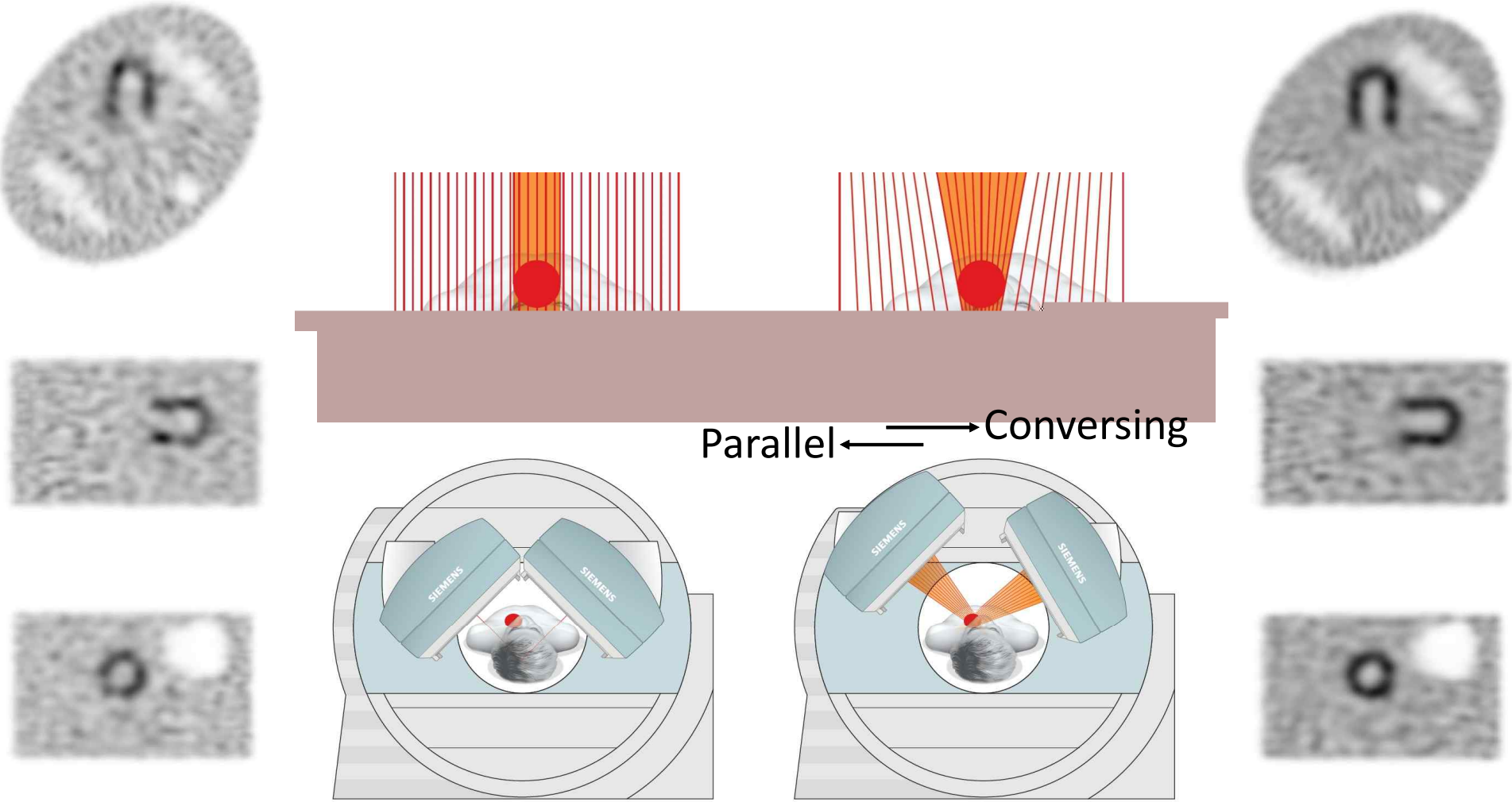
Single Photon Emission Computed Tomography



A gamma camera collects SPECT data by means of rotating around the object and acquiring multiple planar images from different angular projections

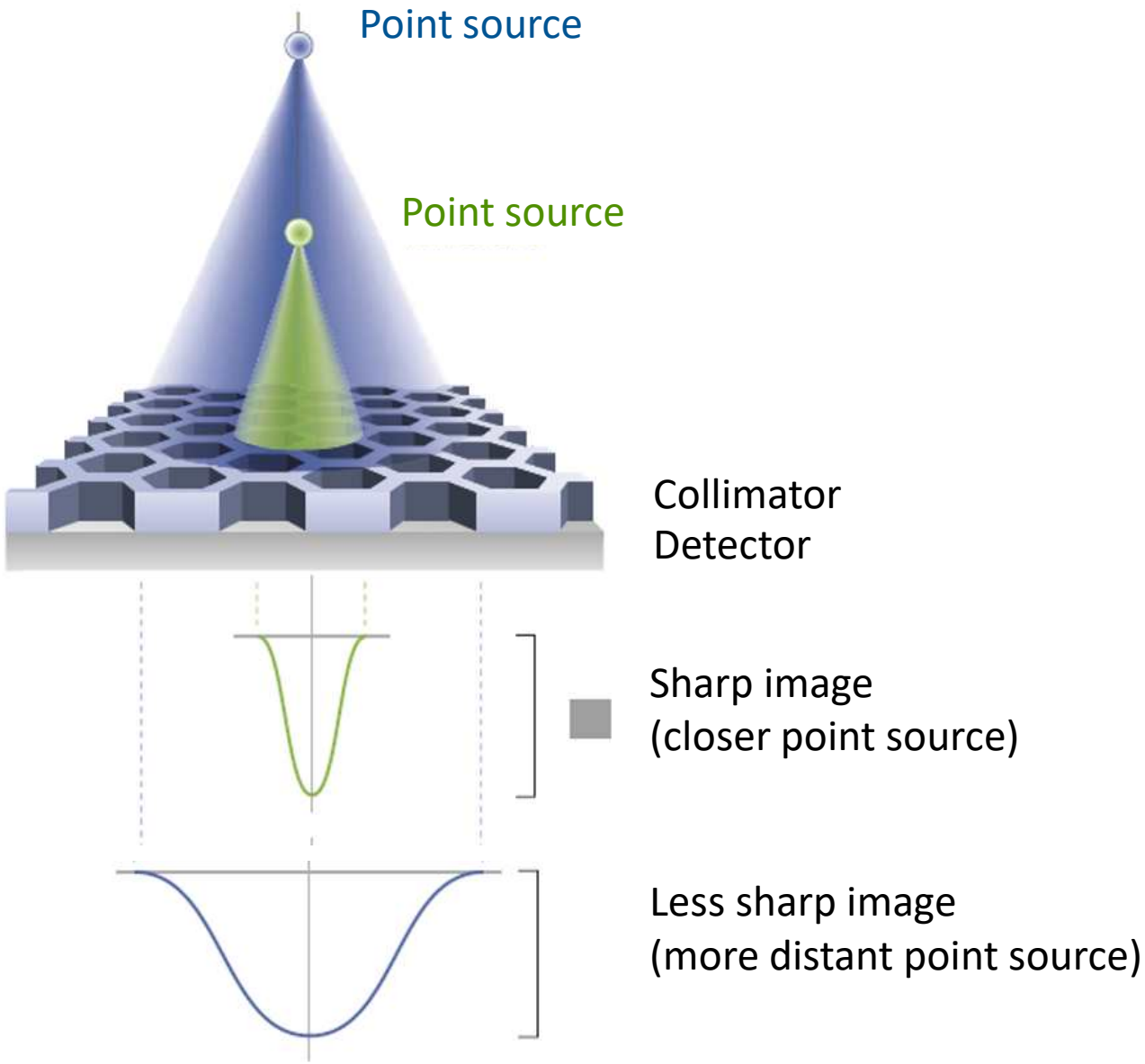
Dedicated Cardiac SPECT Systems

Cardio-focused Collimator



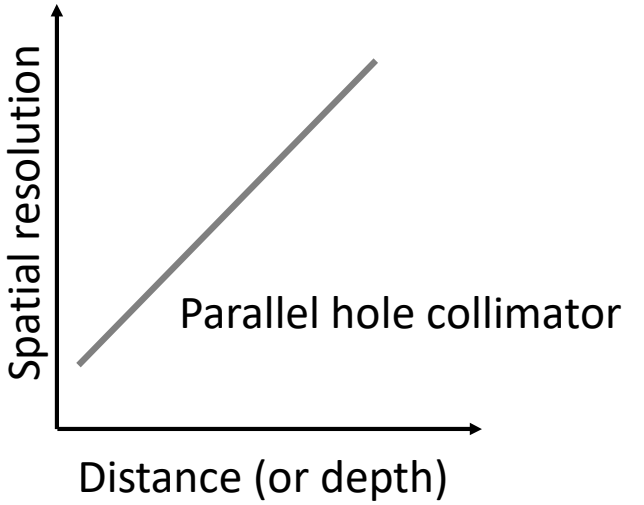
Courtesy of Siemens Healthcare

Collimator-detector Response Modeling



Courtesy of GE Healthcare

Collimator-detector Response Modeling

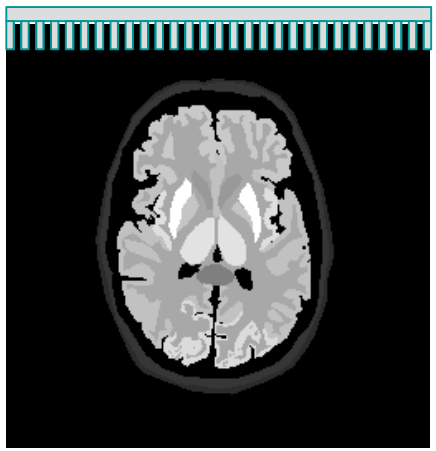


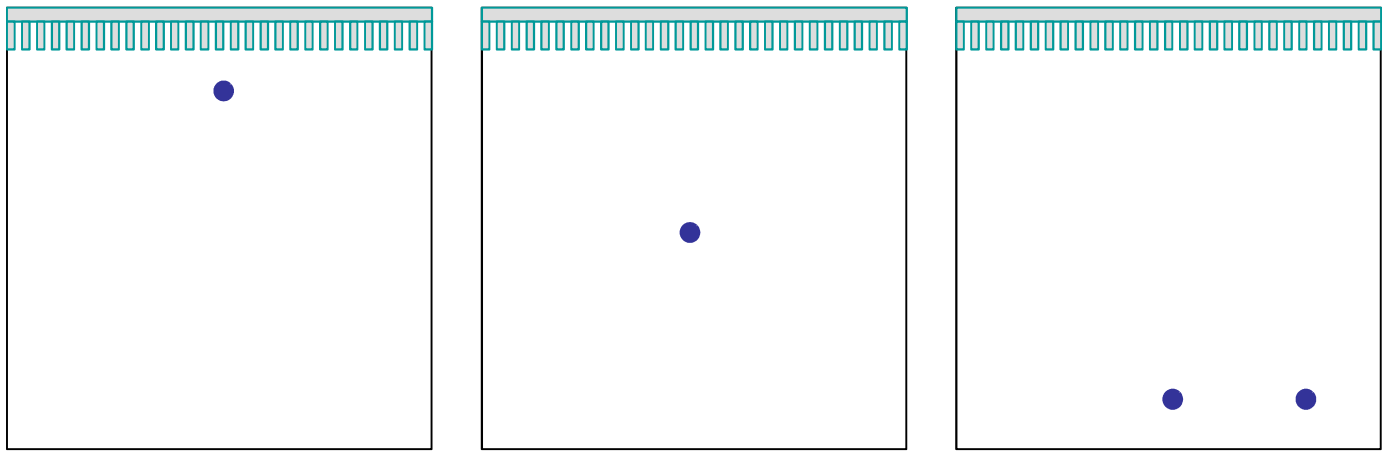
"Depth-dependent resolution degradation"

"Space invariant response at same depth"

Gamma camera with parallel hole collimator

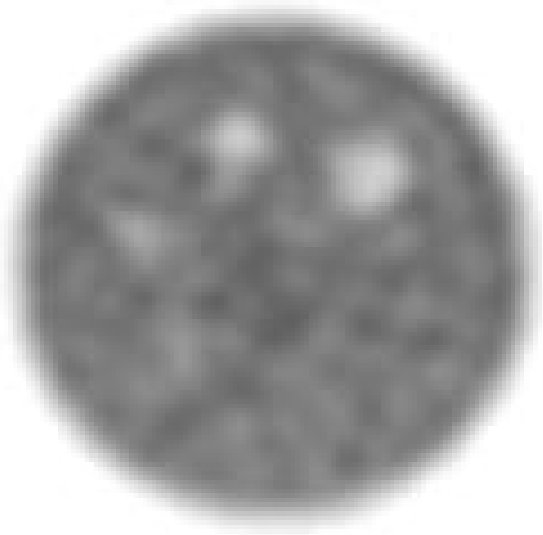
Projection profile



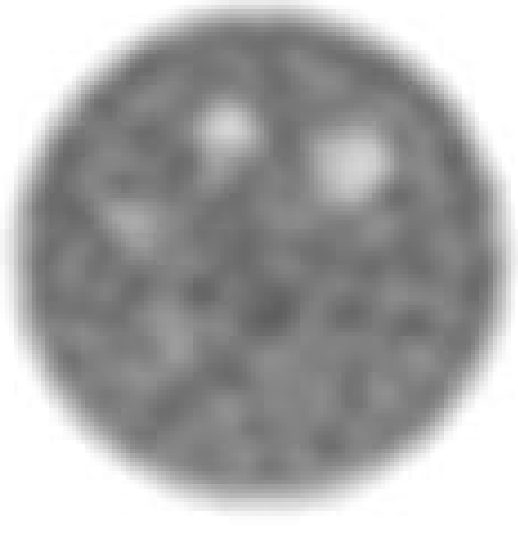


Collimator-detector Response Modeling

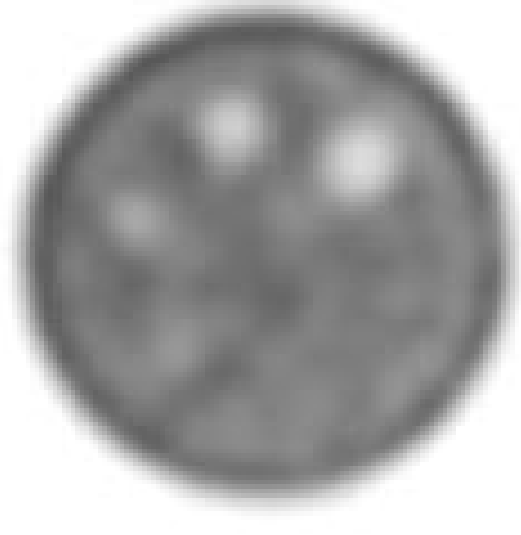
Tc-99m 8.15 mCi
(12 sec/frame)



2D MLEM



3D OSEM

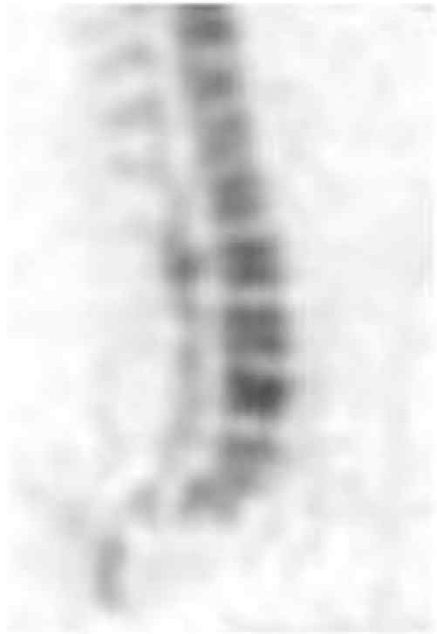


ASTONISH
(Philips)

Seung J et al., SNM (2010)

Collimator-detector Response Modeling

Conventional FBP



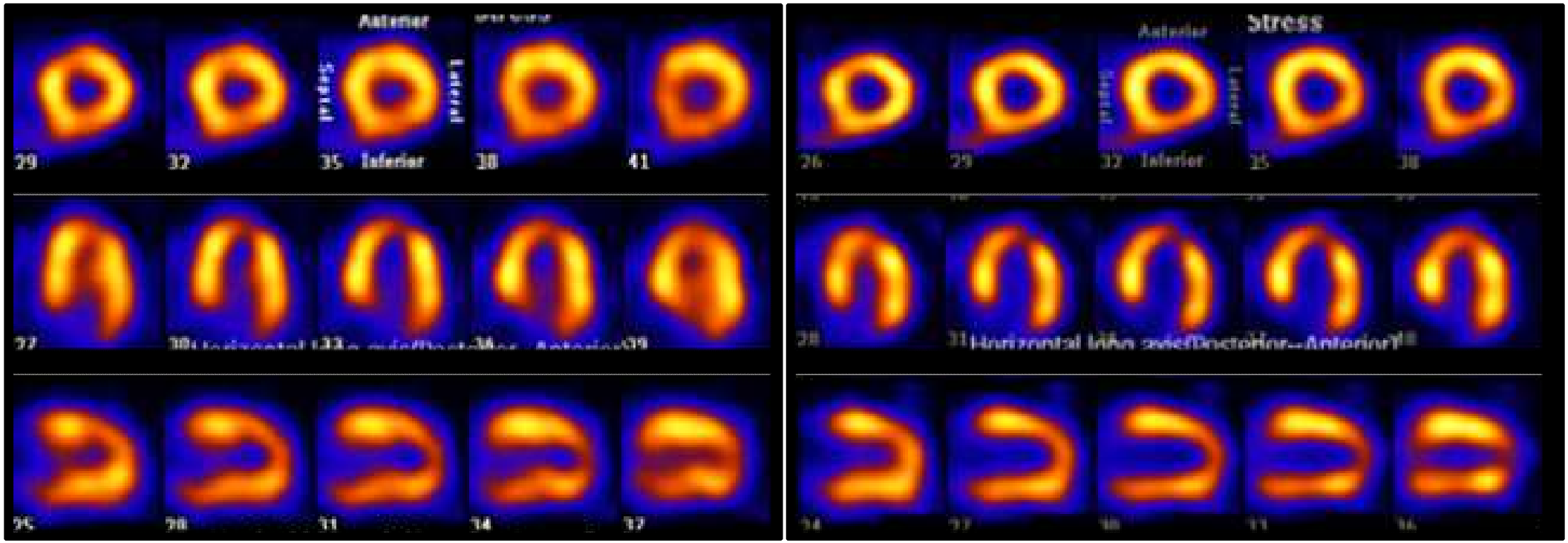
OSEM with CDR modeling

Stansfield et al., Radiology (2010)

Collimator-detector Response Modeling

2D MLEM

ASTONISH



23 sec/frame
(Feb 2, 2009)

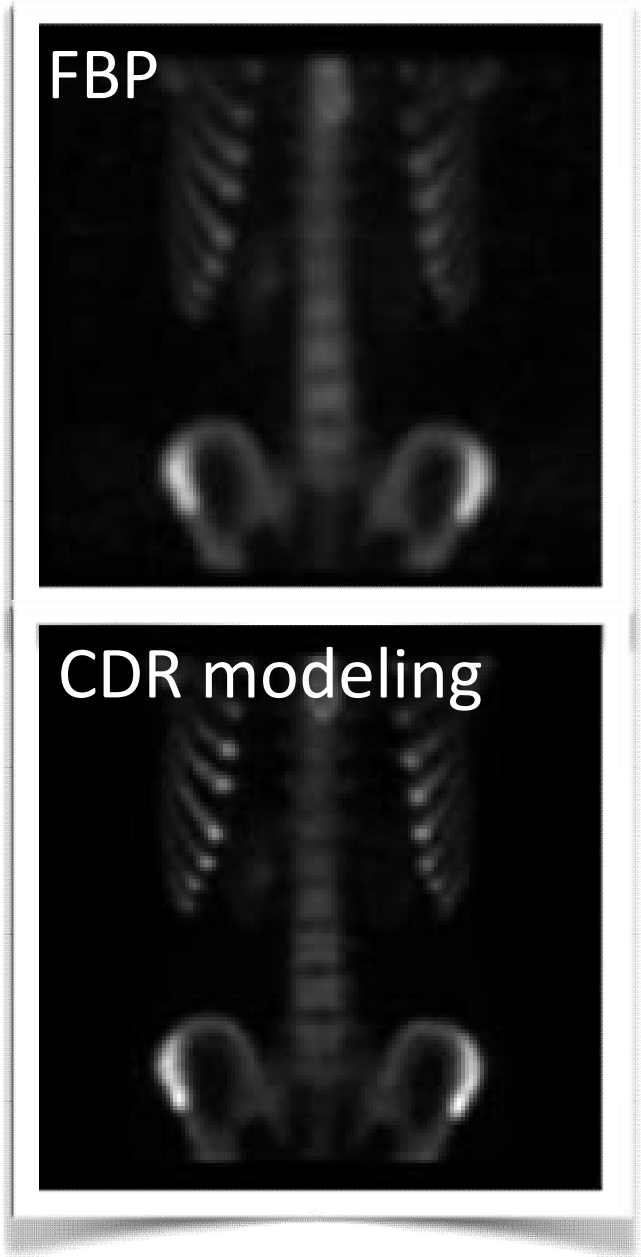
30% scan
time reduction

16 sec/frame
(Apr 22, 2010)

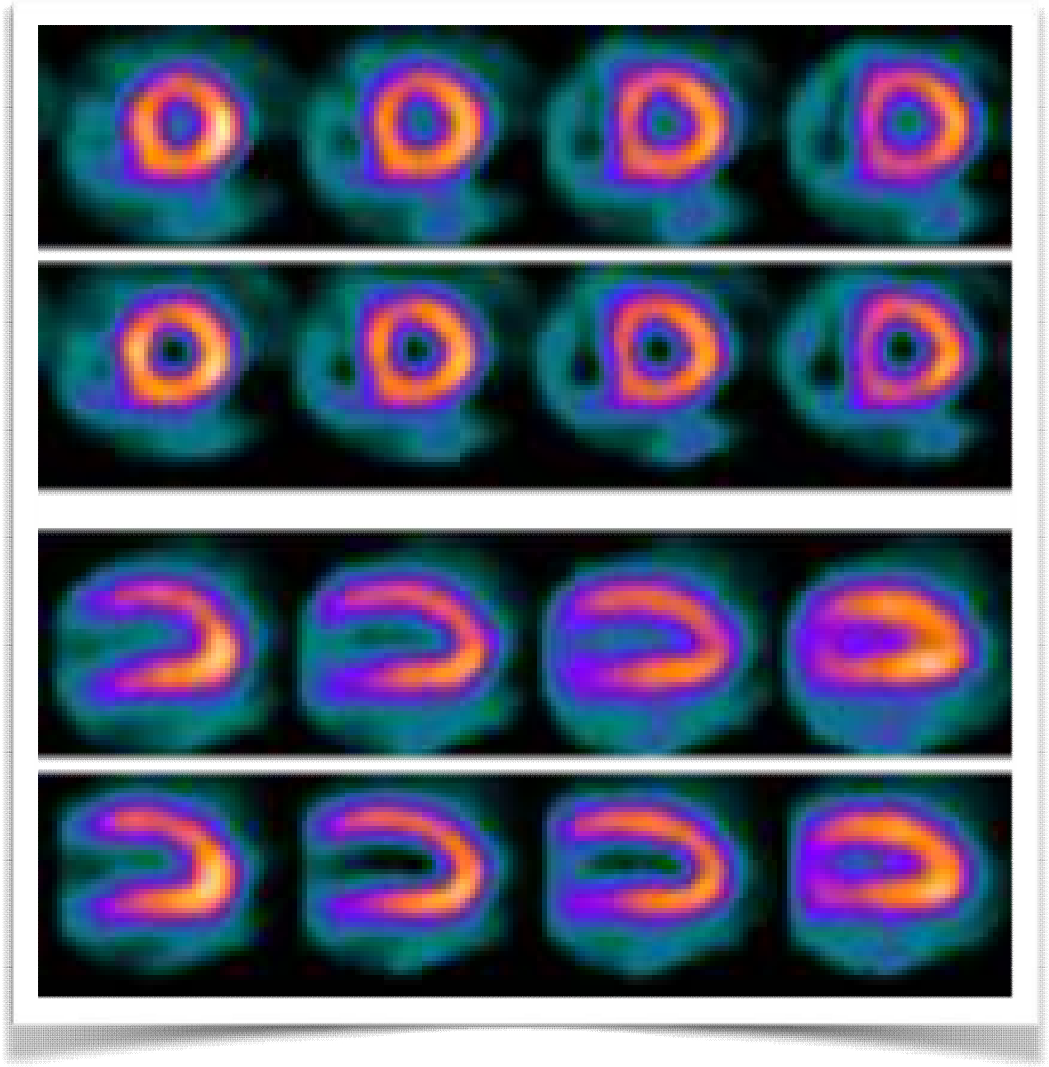
Seung J et al., SNM (2010)

Collimator-detector Response Modeling

Tc-99m MDP SPECT



Stress Cardiac SPECT



FBP (***12 min***)

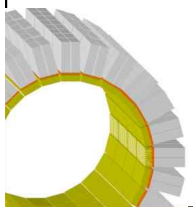
CDR (***6 min***)

FBP (***12 min***)

CDR (***6 min***)

Courtesy of GE Healthcare
(Evolution software)

Advances in Hardware



CdZnTe (CZT) SPECT

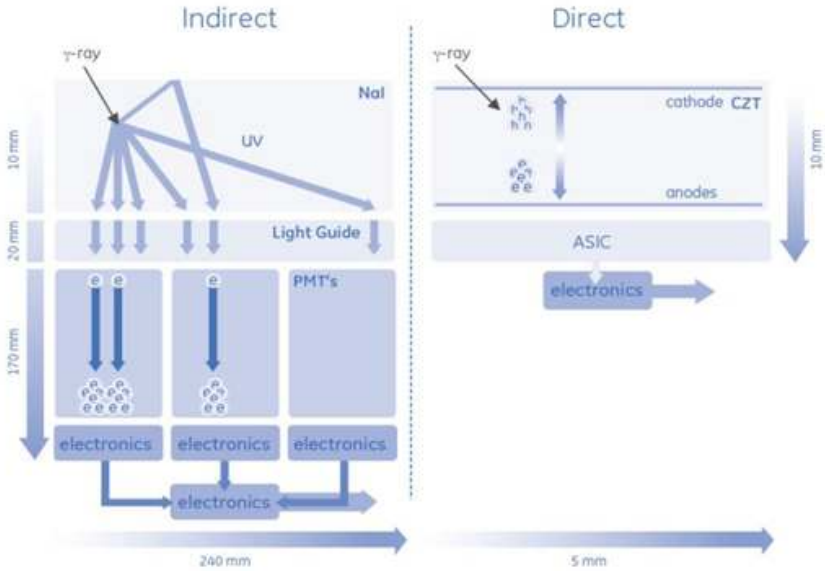
표 2-3. 방사선검출에 사용되는 반도체의 특성

물질	원자번호	밀도(g/cm^3)	*감쇠계수(cm^{-1})
Si	14	2.33	0.02
Ge	32	5.32	0.72
HgI2	80/53	6.40	8.03
CdTe	48/52	5.85	3.22
CdZnTe	30/48/52	~5.80	~3.07

* 140 keV 광자에 대한 감쇠계수

CdZnTe (CZT) SPECT

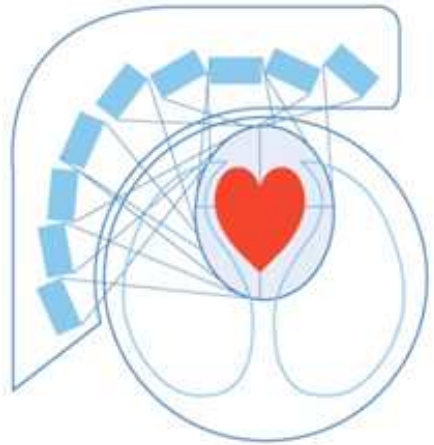
CZT is the direct convertor of gamma-ray to electric signal.



Stationary data acquisition without camera rotation

CZT semiconductor detector

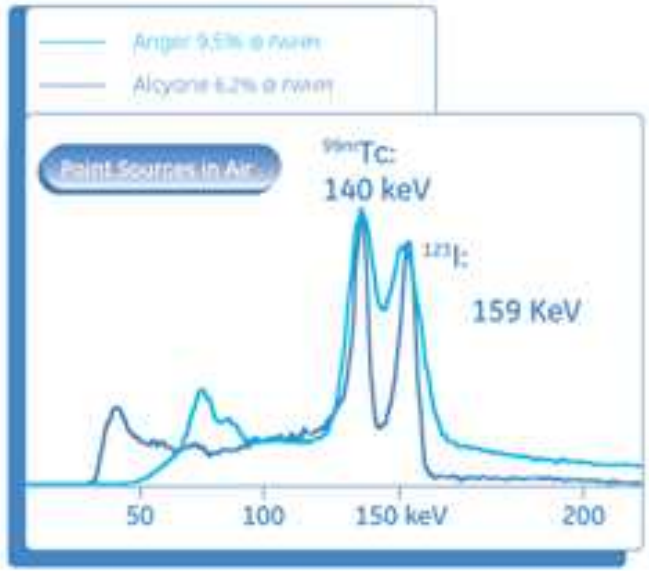
Multi-pinhole collimator



Courtesy of GE Healthcare

CdZnTe (CZT) SPECT

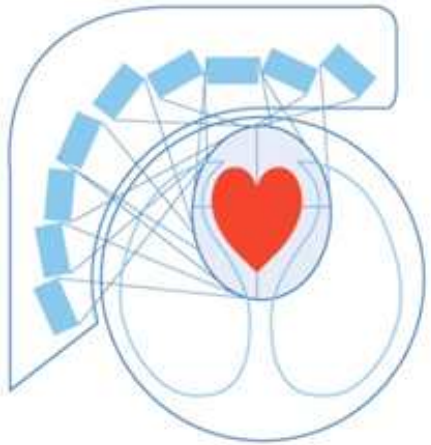
Better energy resolution provides the improved performance in the rejection of scatter and crosstalk photons



Stationary data acquisition without camera rotation

CZT semiconductor detector

Multi-pinhole collimator

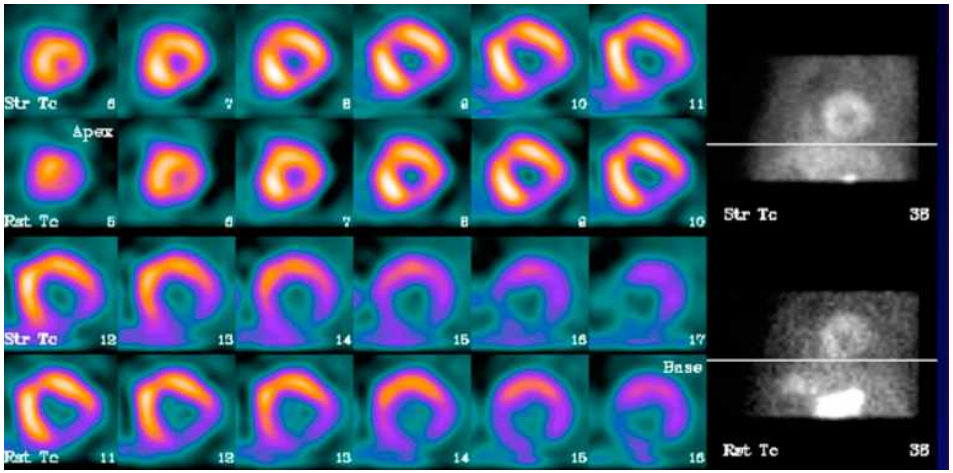


Courtesy of GE Healthcare

CZT vs Conventional SPECT

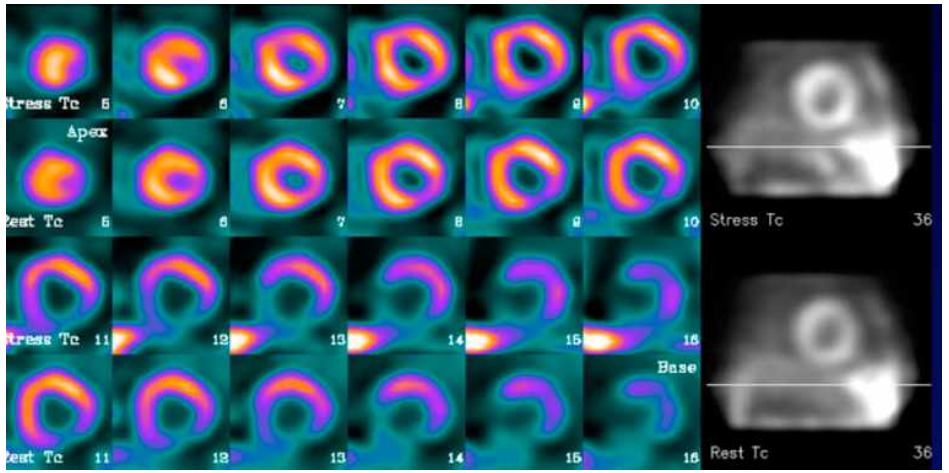
Conventional

14 min rest &12 min stress



CZT+Multipinhole

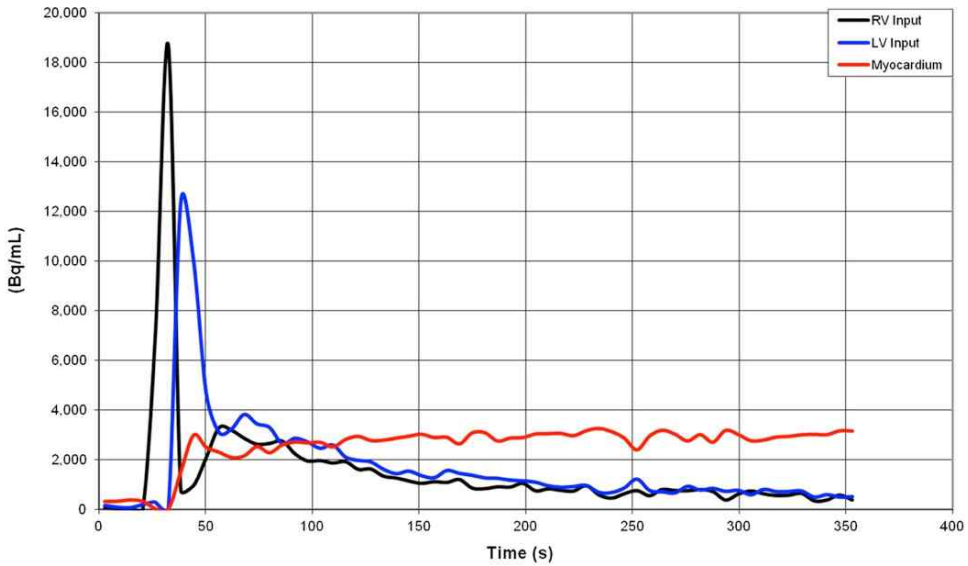
4 min rest & 2 min stress

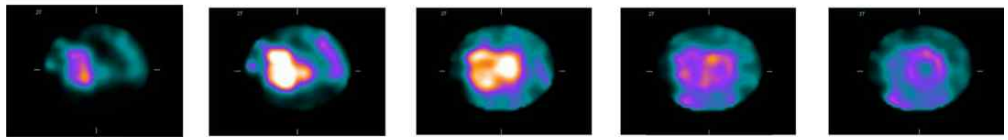


Garcia et al. JNM (2011)

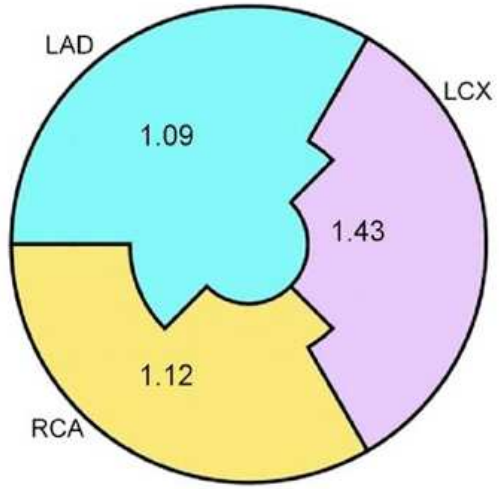
	Energy resolution	Spatial resolution (mm)			Sensitivity (kcps/mCi)		
		Central	Tangential	Radial	Point	Phantom	Patients
CZT	5.7%	4.9	4.3	4.3	41.24	35.34	2.2-4.7
Ventri	9.4%	10.9	7.5	10.9	5.71	5.57	.53-.67
Ratio	1.65	2.22	1.74	2.53	7.22	6.34	4.1-7.0
	x 2		x 2			x 6	

Quantitative Dynamic SPECT

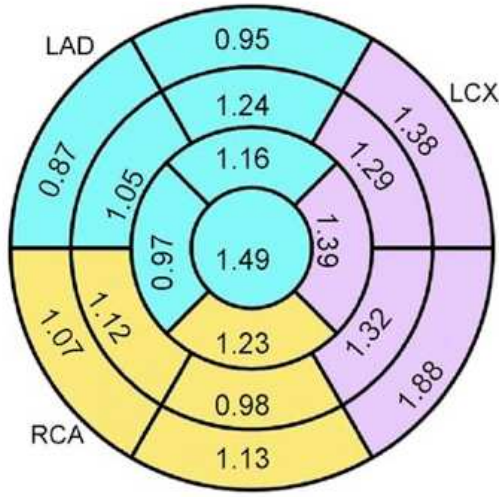




Myocardial Perfusion Reserve (MPR) = K_{1_stress}/K_{1_rest}



Global MPRi 1.2



Ben-Haim S et al. JNM (2013)

Whole-body CZT SPECT/CT

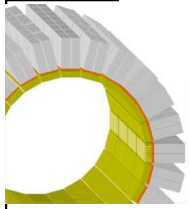
GE NM/CT 870 CZT

Spectrum Dynamics
VERITON-CT

SPECT/CT

Cone-beam CT based

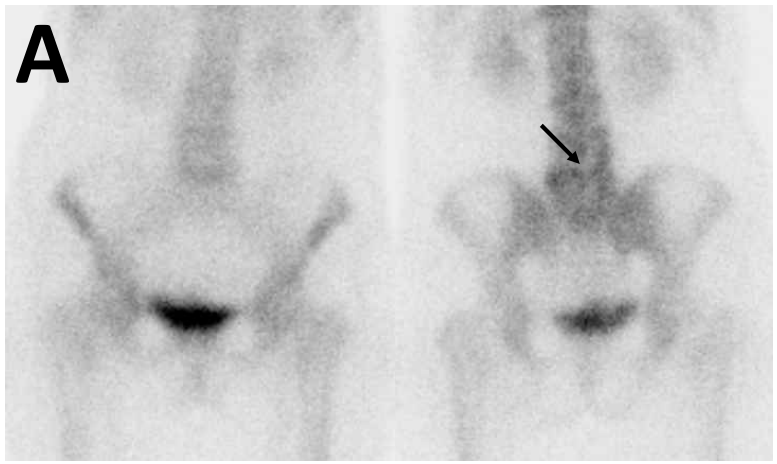
MD CT based

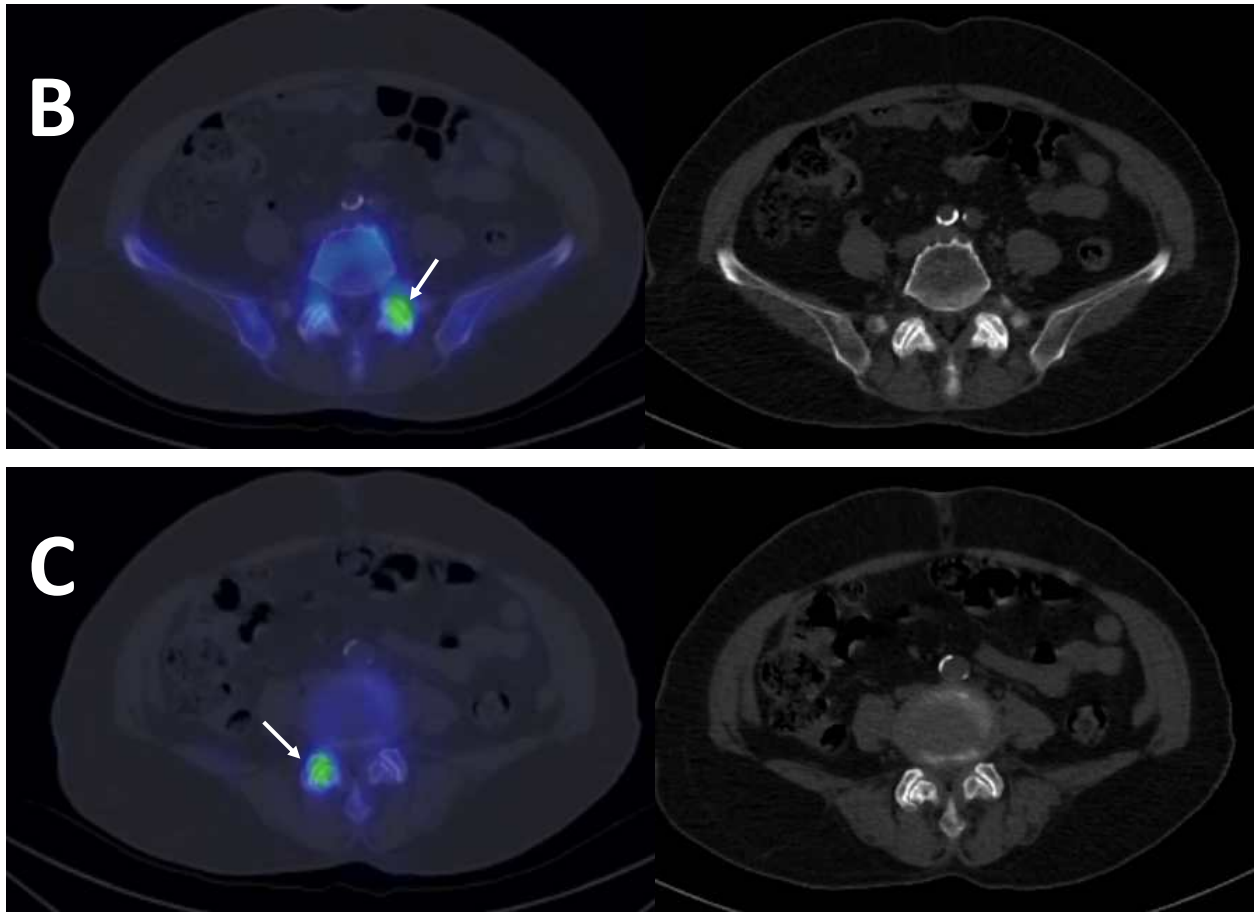


Advantages of SPECT/CT

- Simultaneous acquisition of functional and anatomic imaging dataset
- Anatomical localization and correlation with SPECT abnormality using CT
- More accurate reconstruction of SPECT data with quantitative capabilities using CT-based attenuation map
- Used in wide range of diseases including endocrinology, cardiology, and neurology

More Confident Anatomical Localization





A 76-year-old female patient who experienced lower back pain underwent bone scan and SPECT/CT imaging after injection of ^{99m}Tc-MDP to find the focus of active lesion. (a) On bone scan, a focal increased uptake was found in the left side of the L4–L5 intervertebral area. (b) On SPECT/CT, however, the focal uptake was revealed to be on the right facet joint of L4–L5. (c) In addition, a focal uptake was also found on the left facet joint of L3–L4 that was not noticed on the bone scan.

Lee JS & Kim JH, *Semin Musculoskelet Radiol* 2014

Improved Quantitative Accuracy

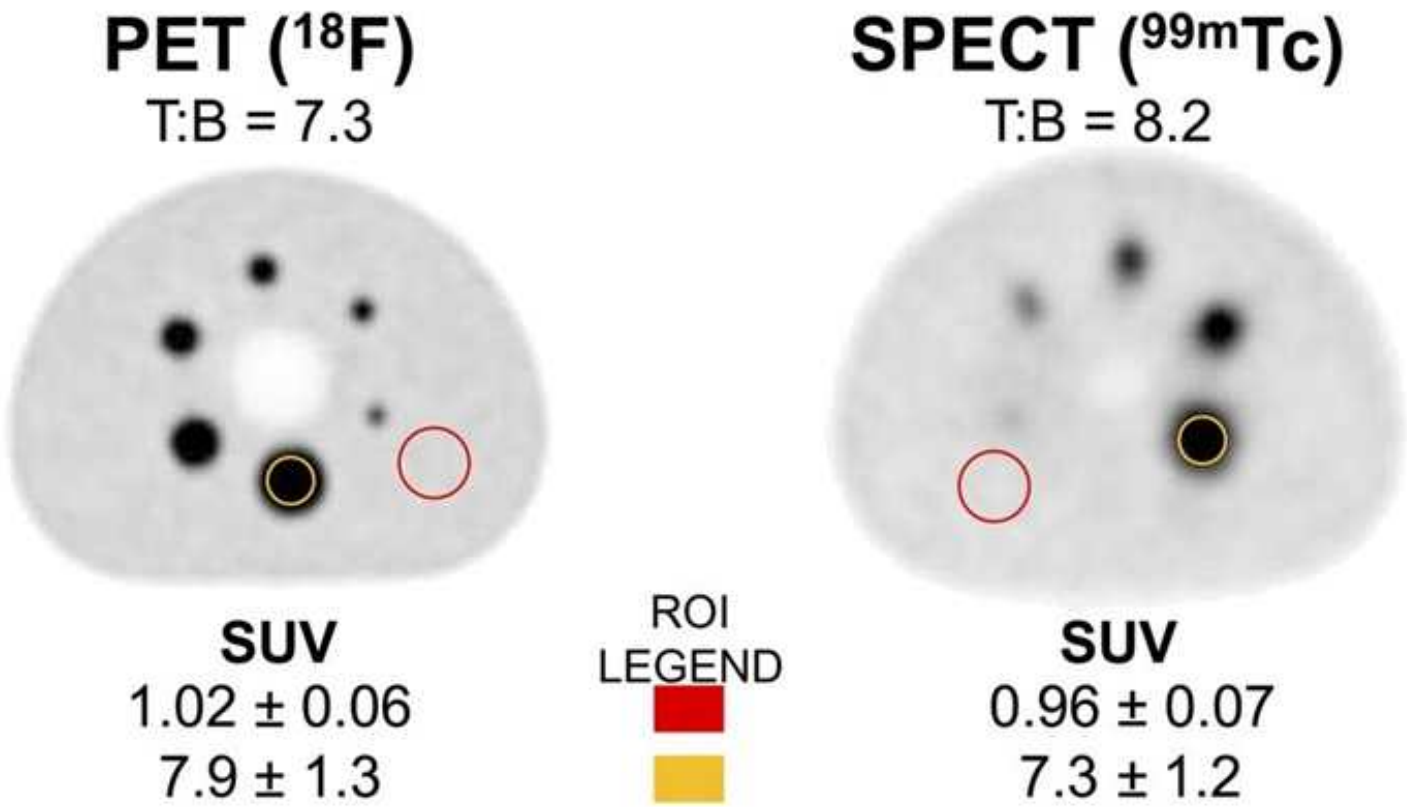


Fig. 7 An example comparing the quantitative accuracy of PET and SPECT images expressed as standard uptake value (SUV). ROI, region of interest. (Reprinted from Bailey and Willowson[40] with permission.)

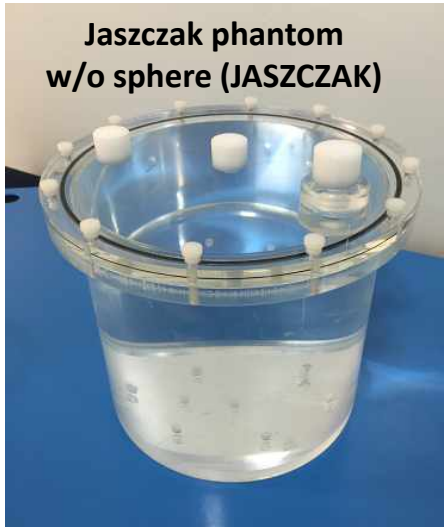
Evaluation of Accuracy of Quantitative SPECT

ϕ : 15 cm, h: 1.5 cm

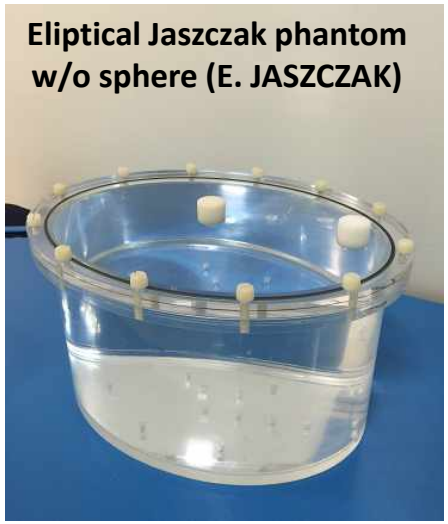
Dimension not measured
(200 mL)

ϕ : 12 cm, h: 15.5 cm
(1573 mL)

ϕ : 20 cm, h: 21 cm
(6250 mL)



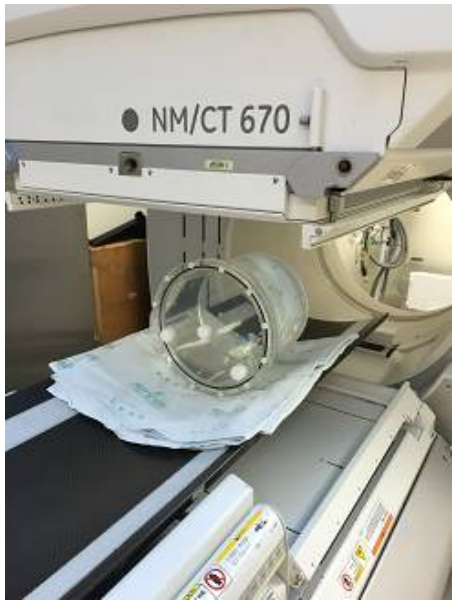
ϕ : 21.6 cm, h: 18.6 cm
(6900 mL)

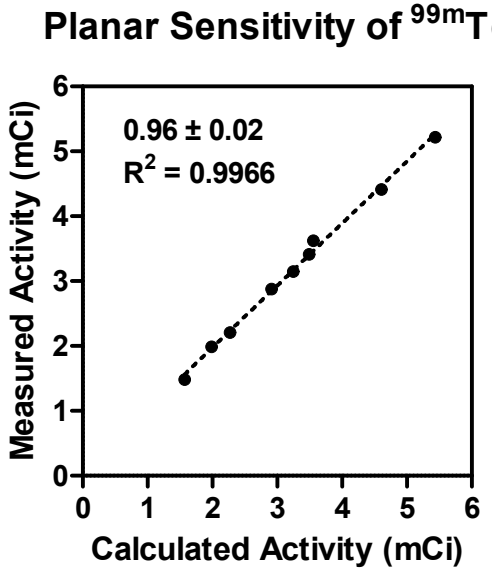


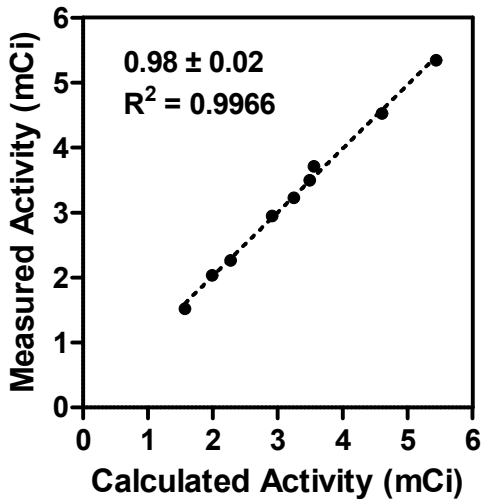
major axis : 30.5 cm, minor
axis : 22.1 cm, h: 18.6cm
(9847 mL)

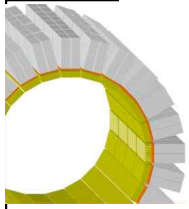
Sphere ϕ : 10, 13, 17, 22, 37 mm
Cylindrical insert : ϕ 51 x h 180 mm
(9700 mL)

Evaluation of Accuracy of Quantitative SPECT



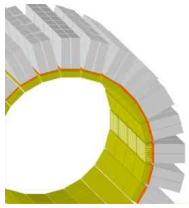






State-of-art SPECT/CT Scanners

- Compact detector heads (mostly dual)
- Digital Anger logic
- Auto-contour
- Adaptive filters
- Resolution recovery reconstruction
- Combined with MDCT
  - Iterative reconstruction for dose reduction
  - Real-time CT dose modulation



Summary

- SPECT is a tomographic imaging technique in which the different angular projections are acquired by rotating the gamma cameras.
- Recent technical advances in SPECT include
  - Adaptive noise reduction filter, collimator-detector response modeling, and stationary cardiac imaging using CZT cameras
  - SPECT/CT systems with better quantitative and diagnostic, and radiation dose management

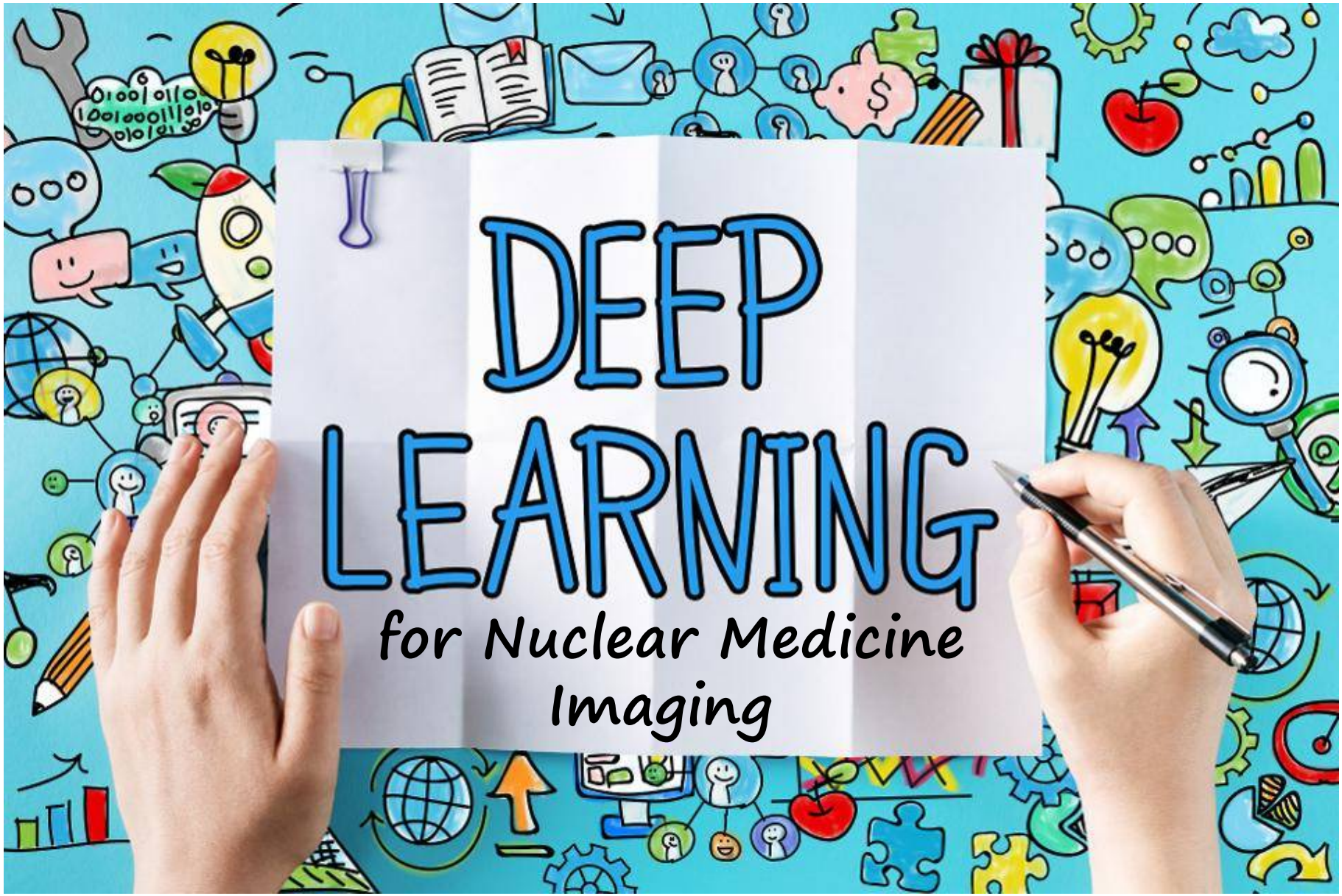
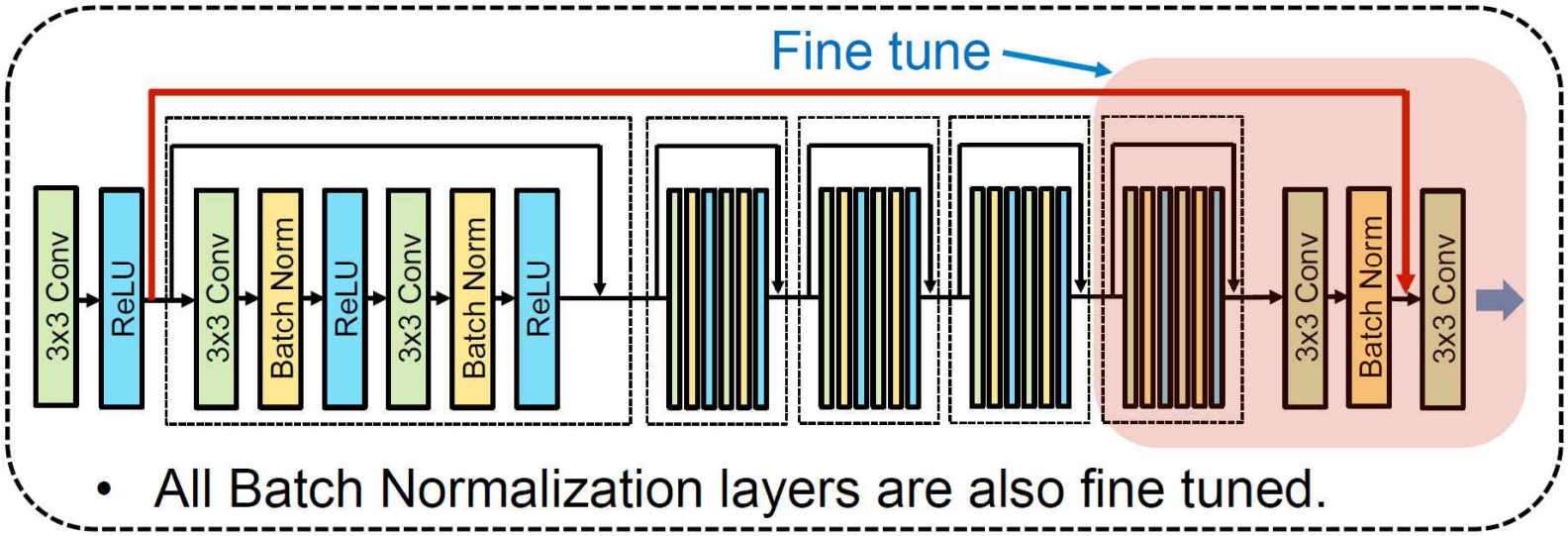

DEEP
LEARNING
for Nuclear Medicine
Imaging

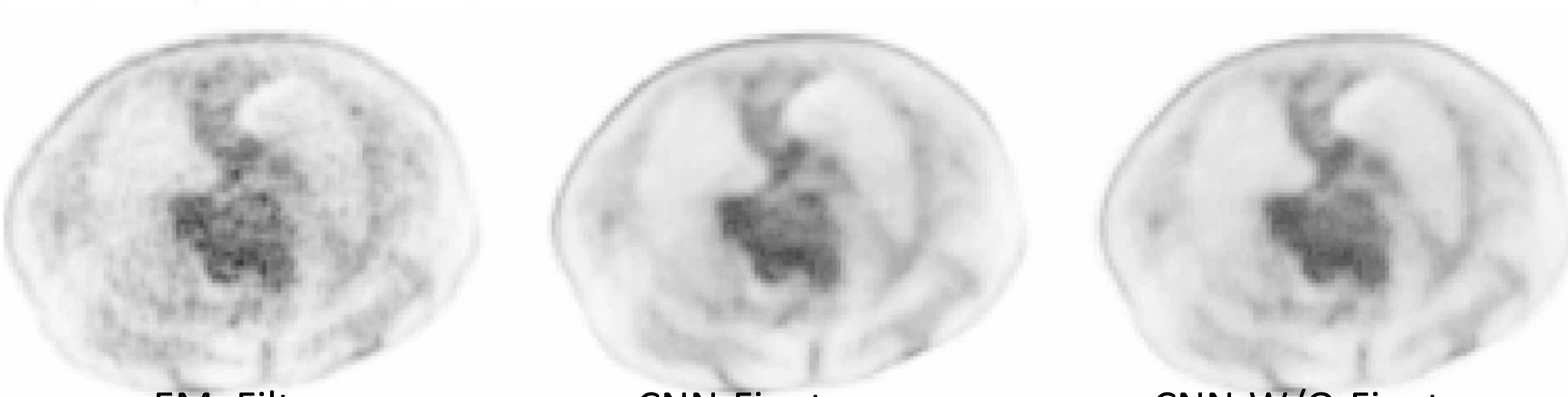
Image Restoration and Inpanting

PET Image Denoising

Low dose PET image



High dose PET image



EM+Filter | CNN-Finetune | CNN-W/O-Finetune

Courtesy of Prof. Qi Jinyi (UC Davis)

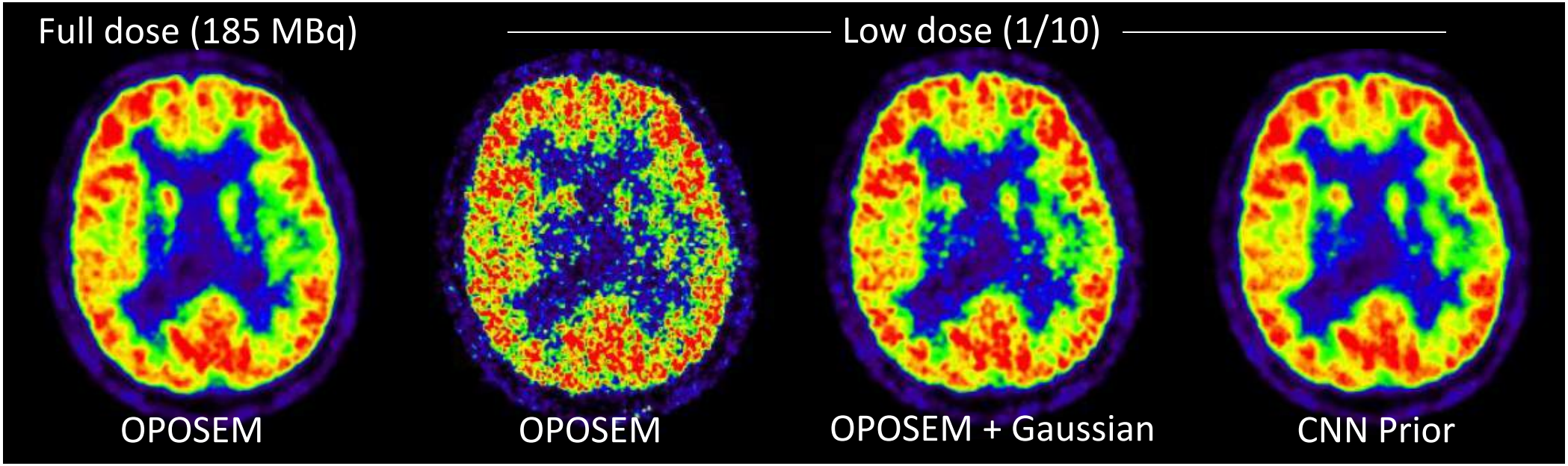
Gong K, Qi J et al. (2017 IEEE MIC)

Reconstruction using CNN Prior

Cost Function

Log-likelihood

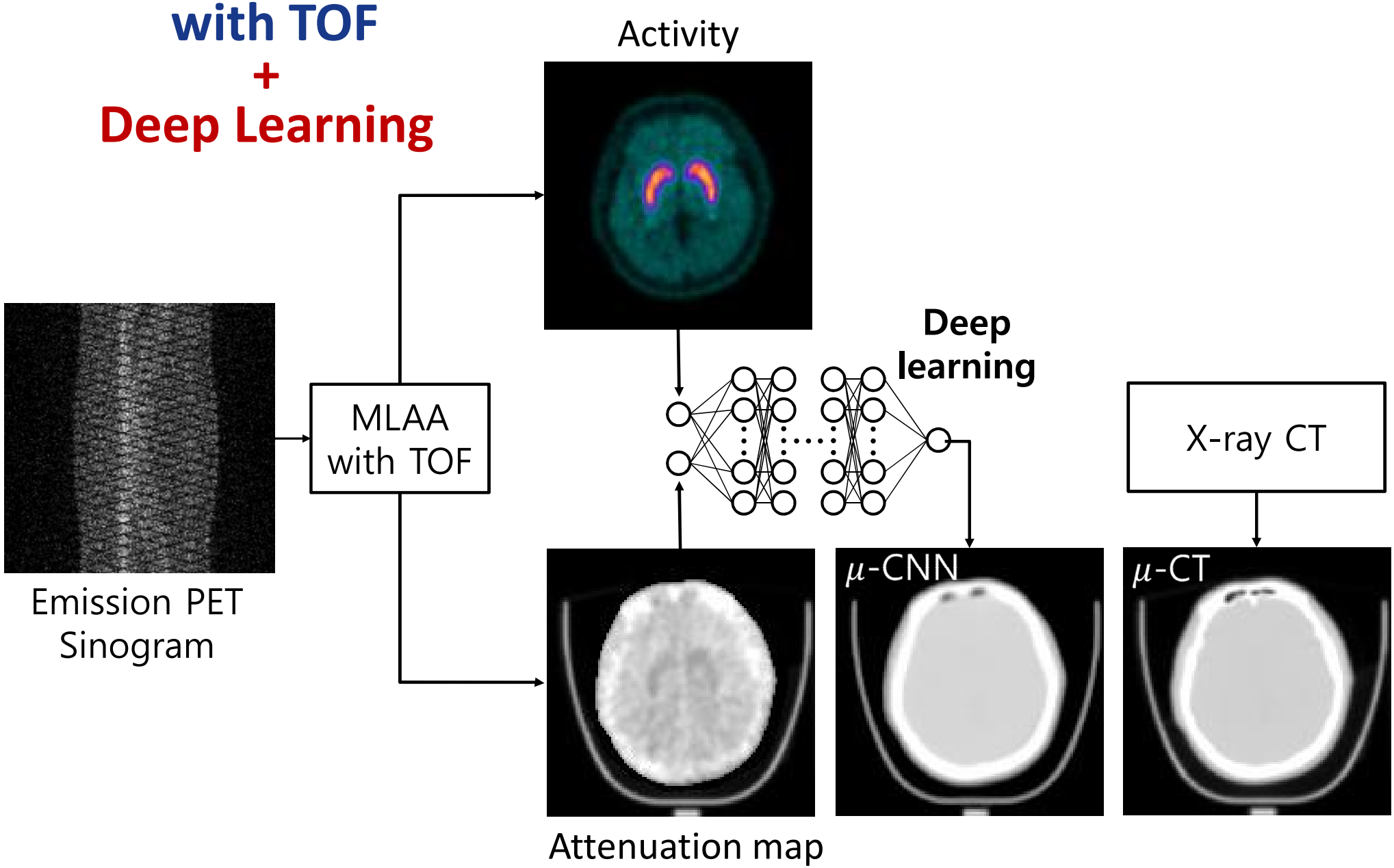
$$\min_{x,q,b} L(x)$$



Courtesy of Dr. Kim Kyungsang (MGH)

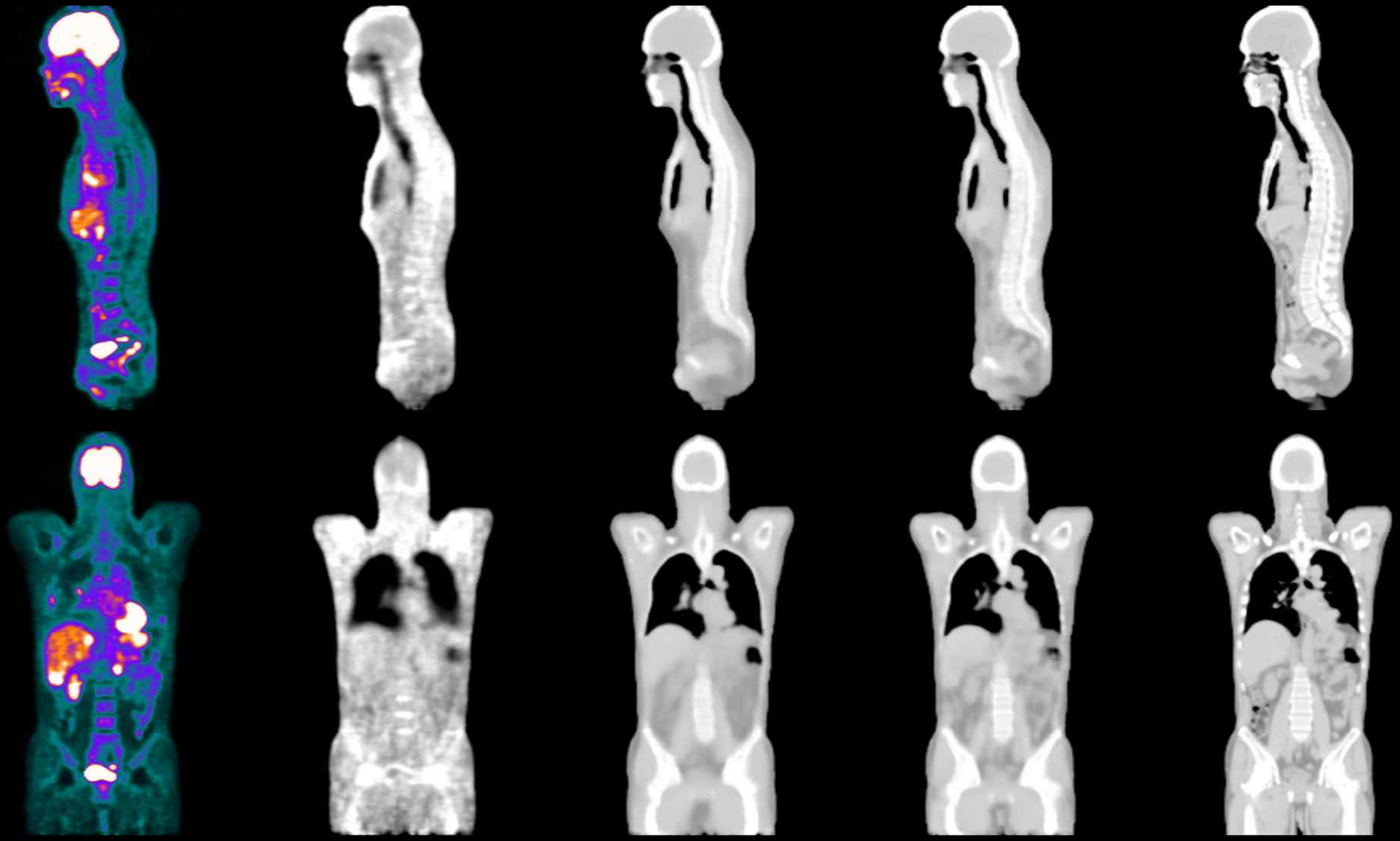
Kim K, Li Q et al. (2017 IEEE MIC)

Joint Reconstruction with TOF + Deep Learning



Hwang D, Kim KY et al. (J Nucl Med, 2018)

Results: Case 1



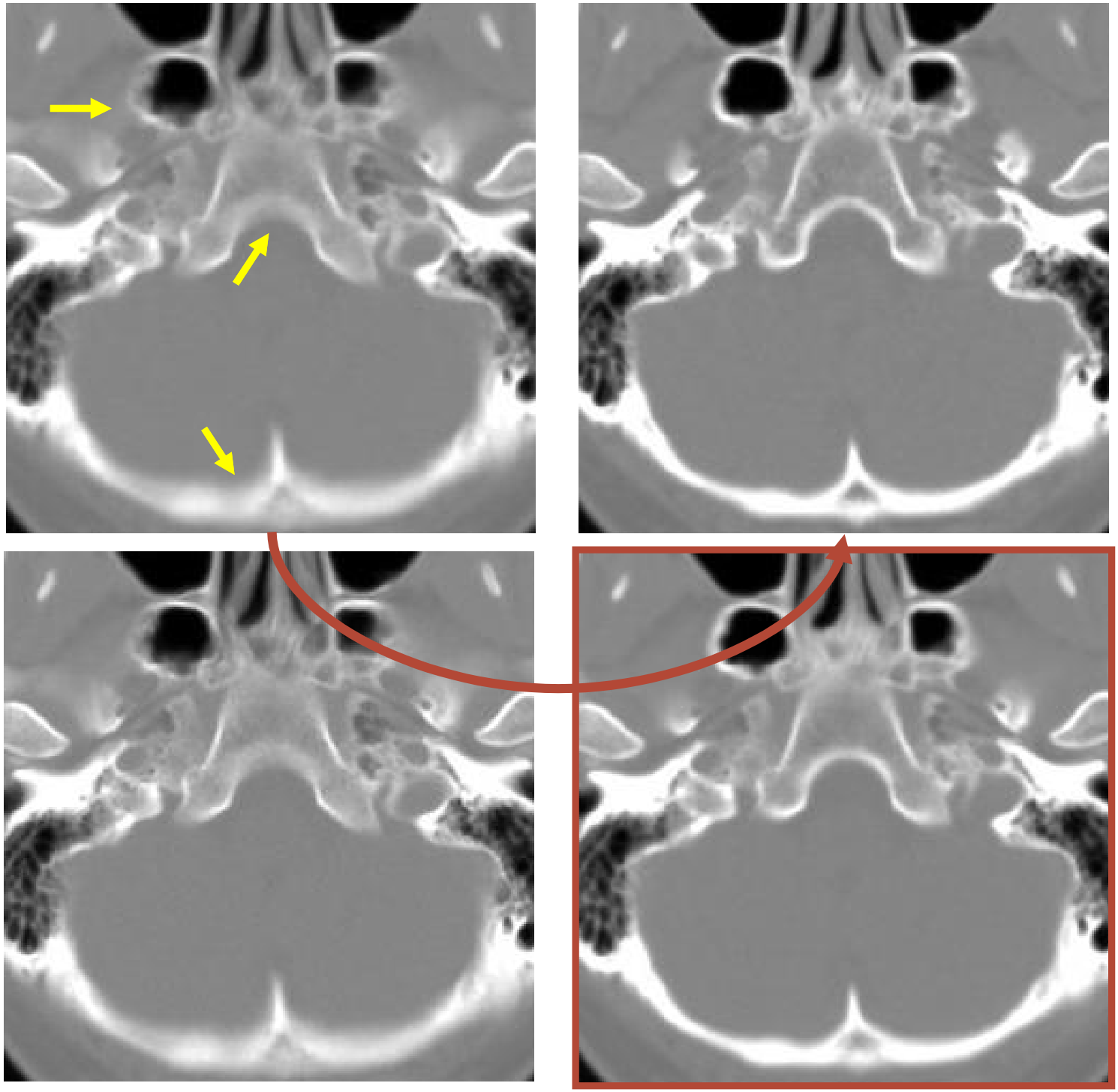
MLAA act (λ) & atn (μ)

CNN1
(Input: μ)

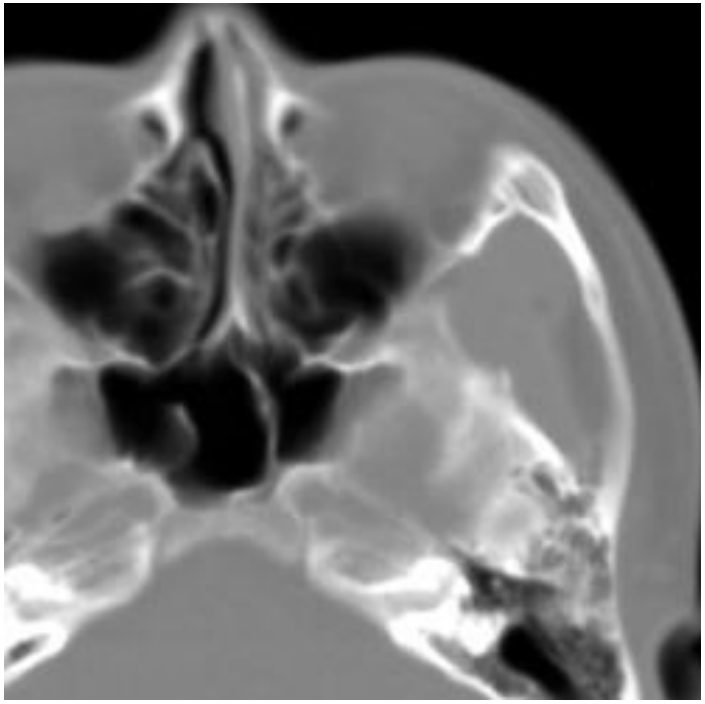
CNN2
(Input: λ & μ)

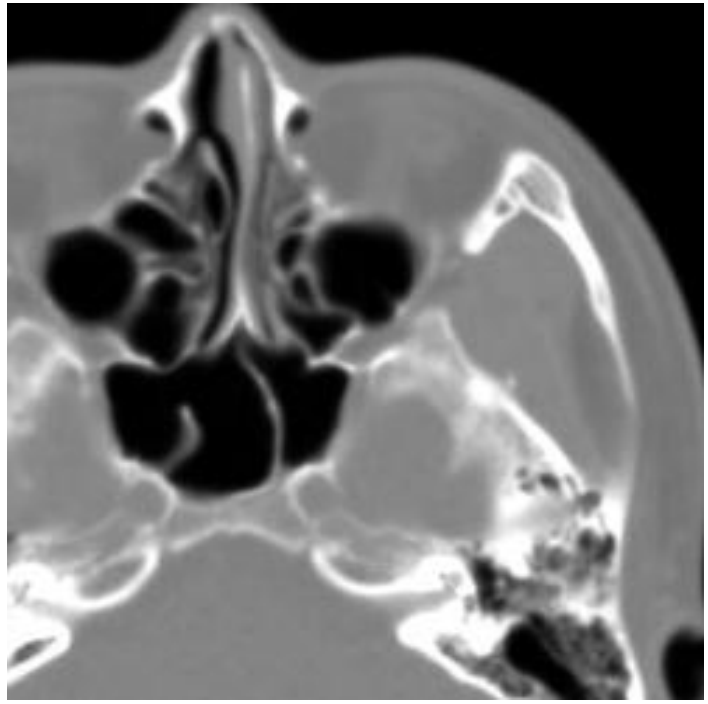
CT-based

Super Resolution & Pixel Restoration


Input
Ground truth
Sharp Filter
Richardson–Lucy deblurring
Deep Learning

Input

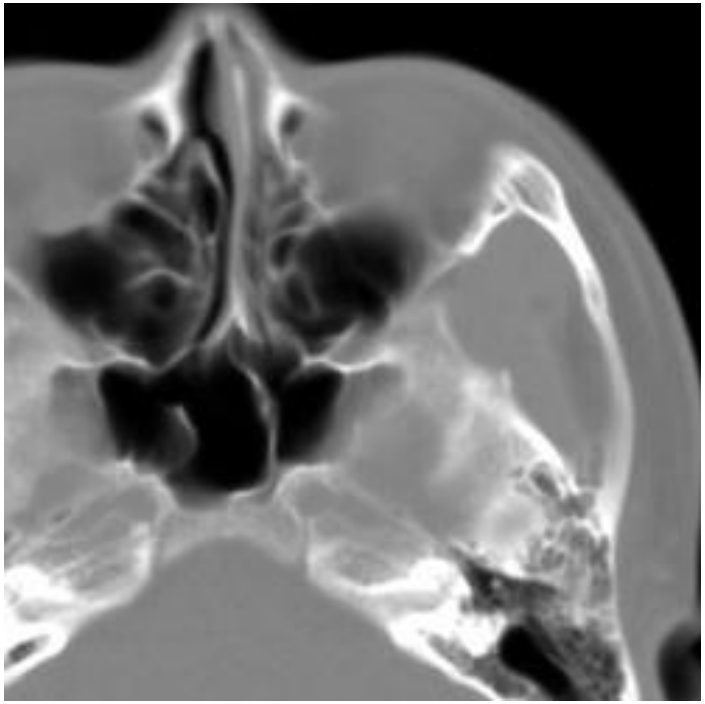


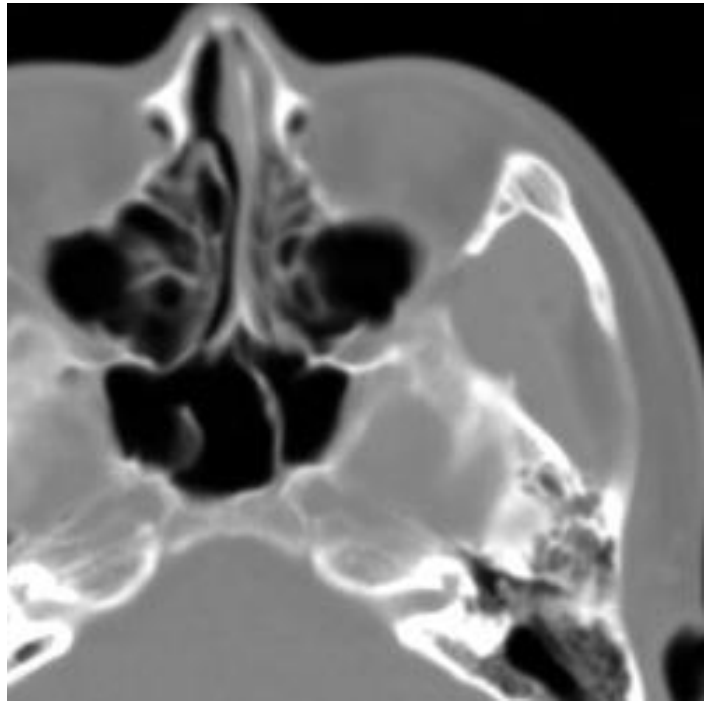


Ground truth

Sharp Filter

Richardson–Lucy deblurring

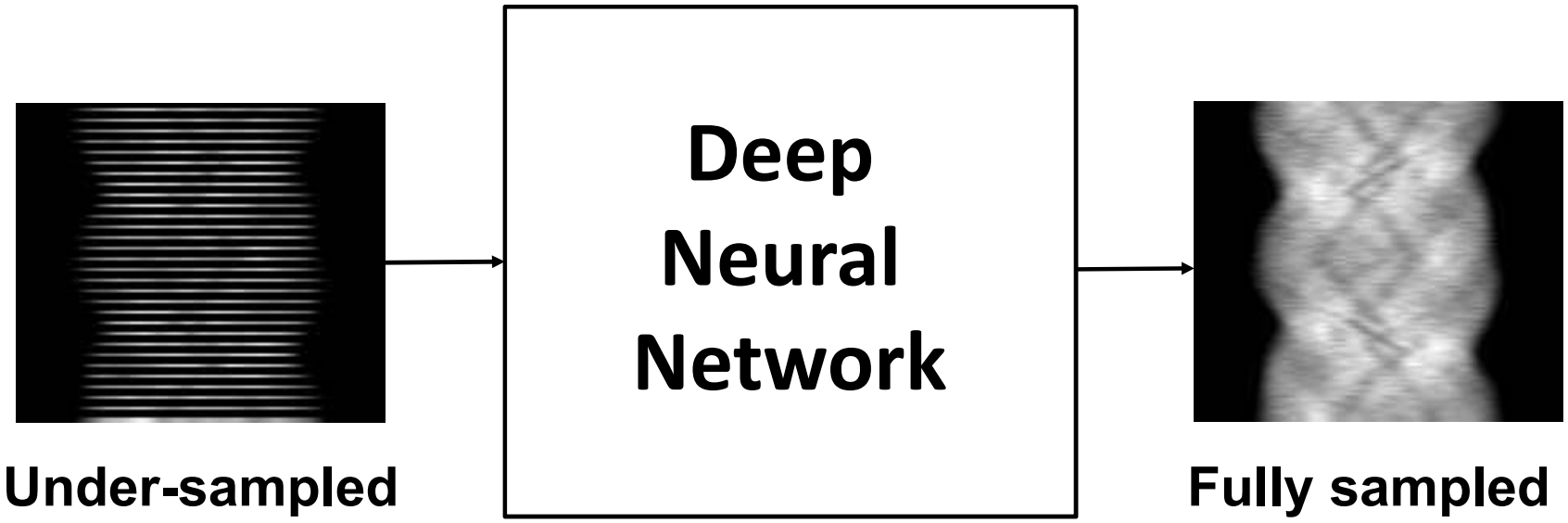




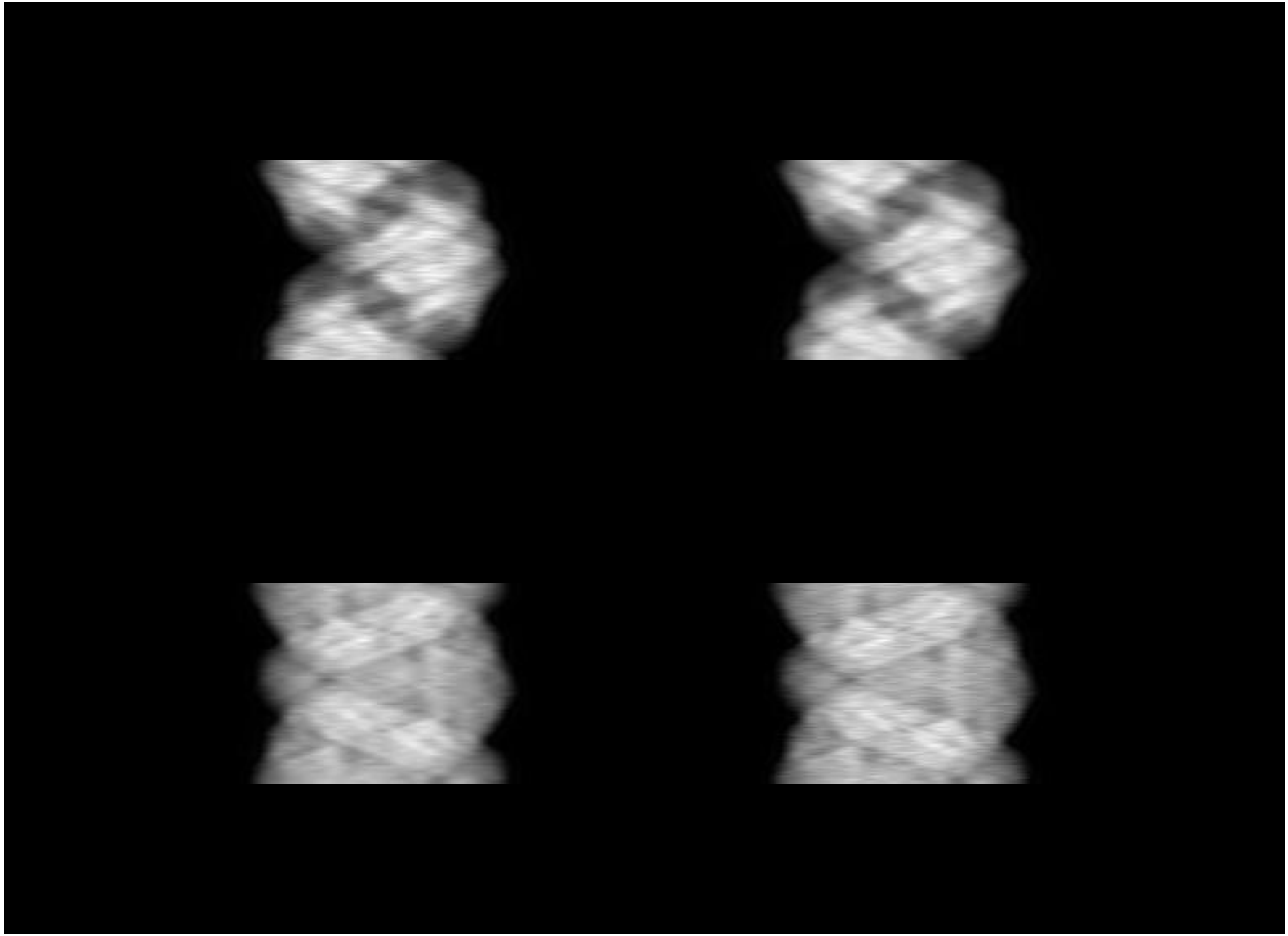
Deep Learning

Park J et al., Phys Med Biol 2018

Training

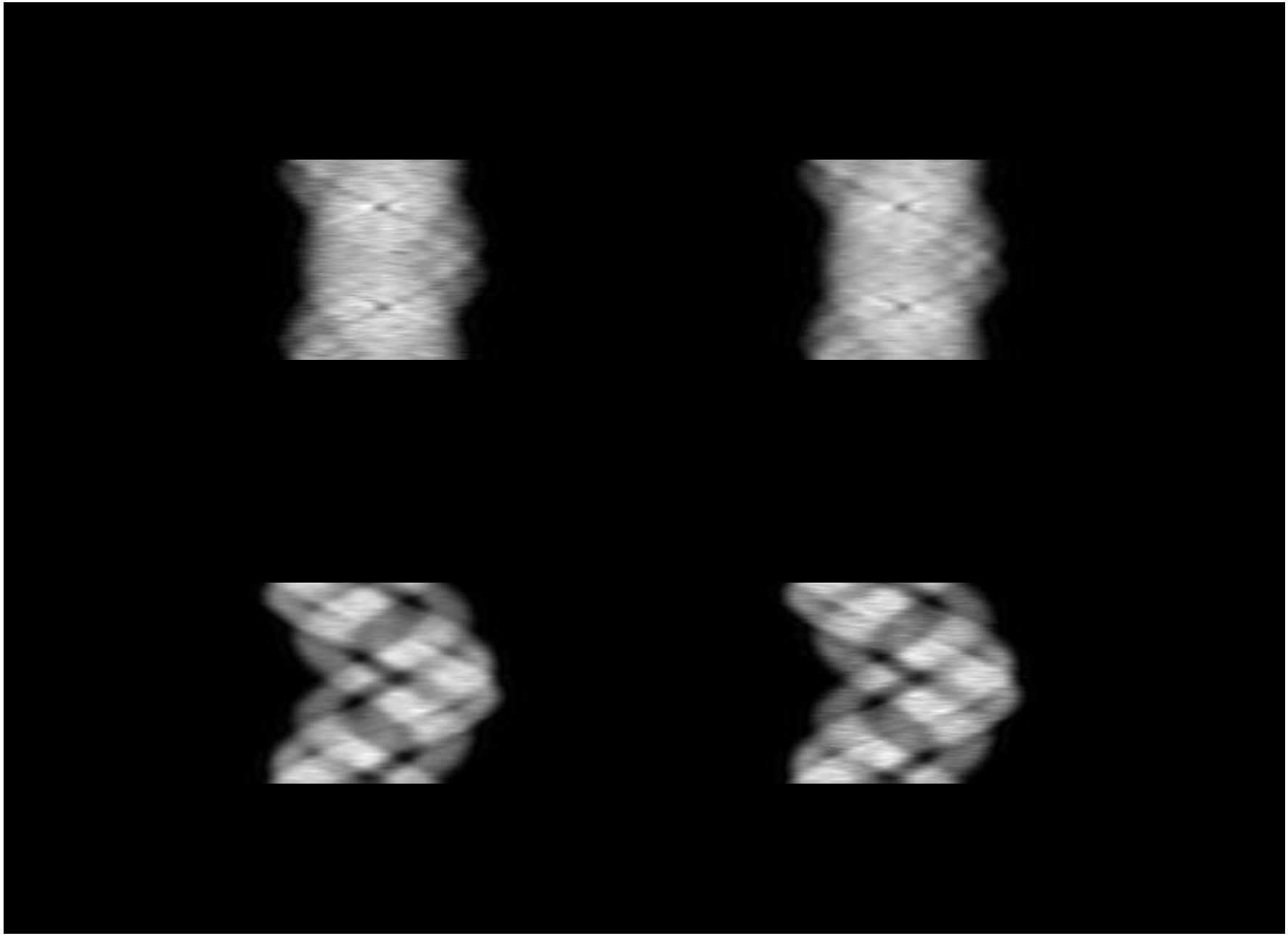


Which is Real ?



Kang SK et al. (unpublished data)

Which is Real ?

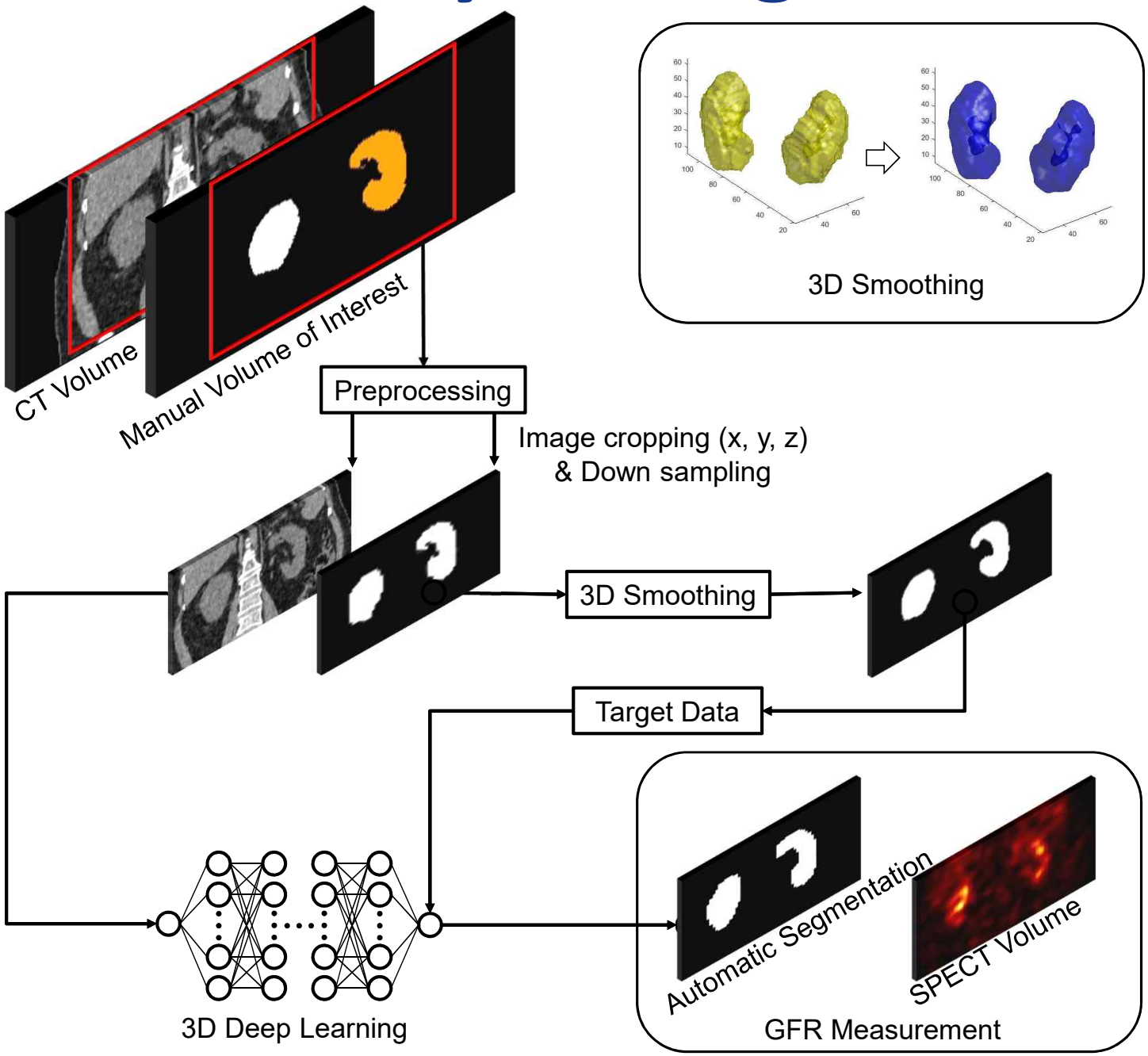


Kang SK et al. (unpublished data)

½ Under-sampled

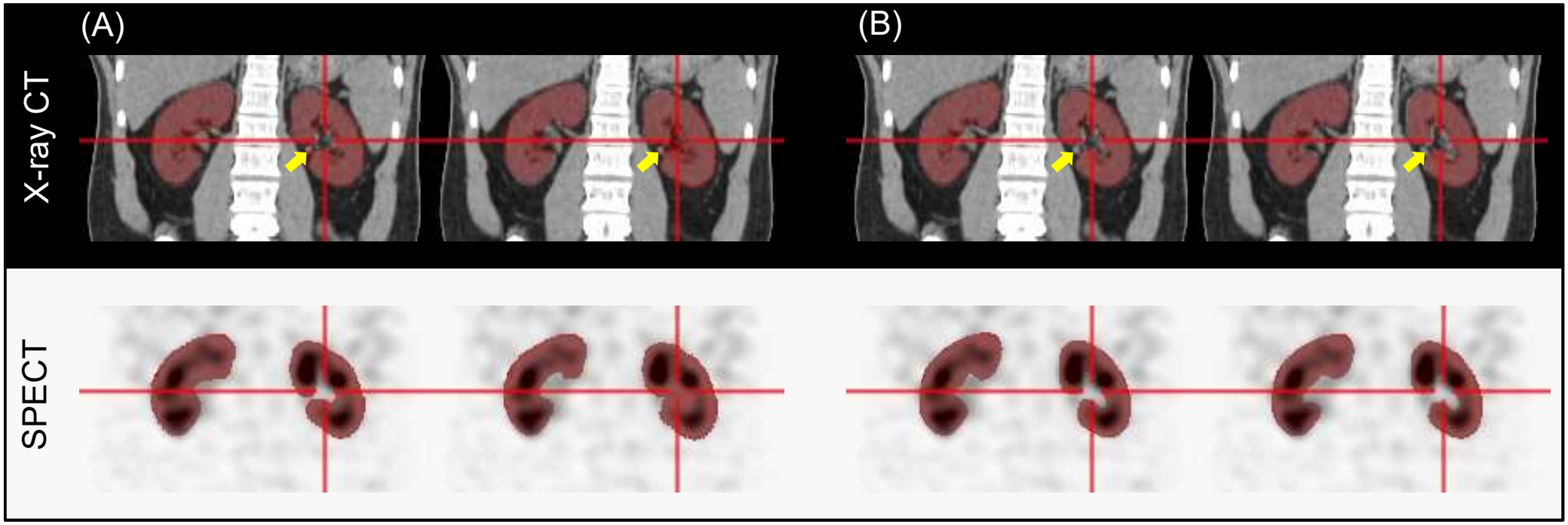
Kang SK et al. (unpublished data)

Renal Parenchyma Segmentation



Park J et al., (unpublished data)

Manual *vs*. U-net



Park J et al., (unpublished data)

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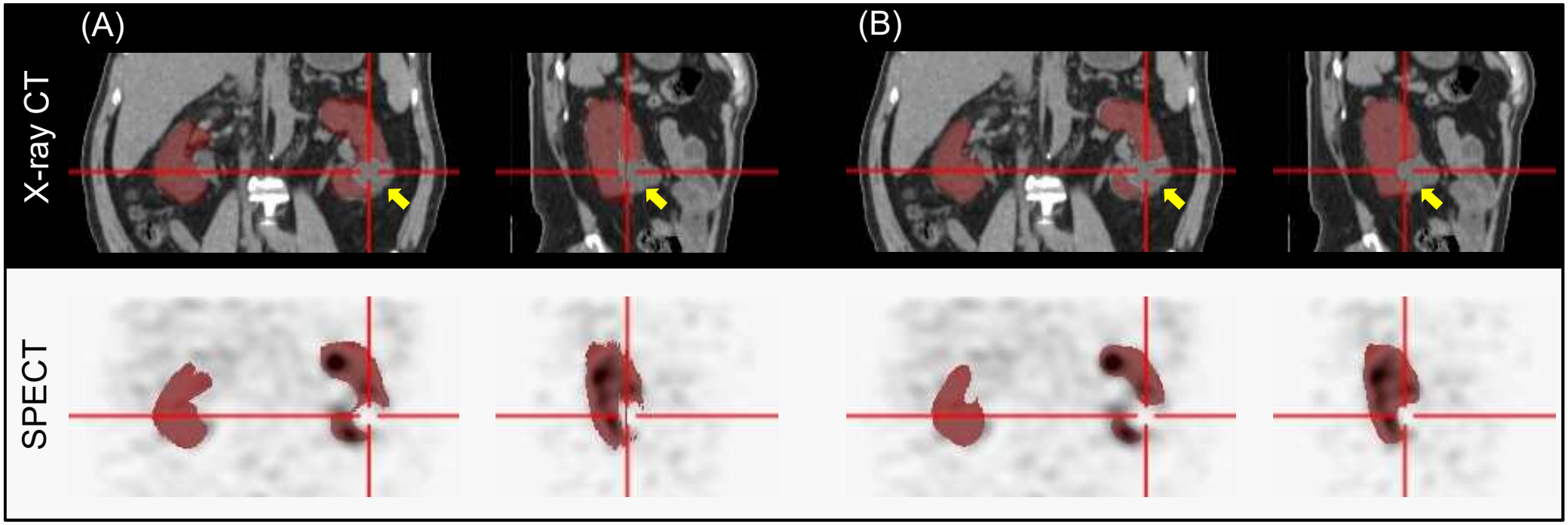

Park J et al., (unpublished data)

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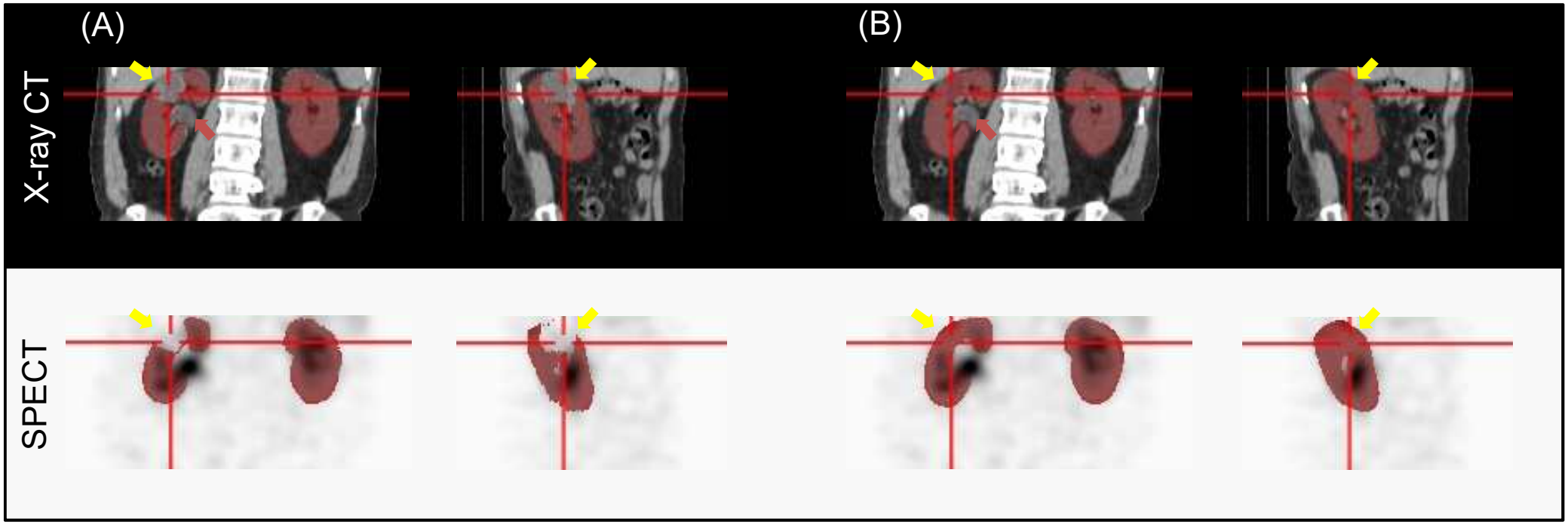

Park J et al., (unpublished data)

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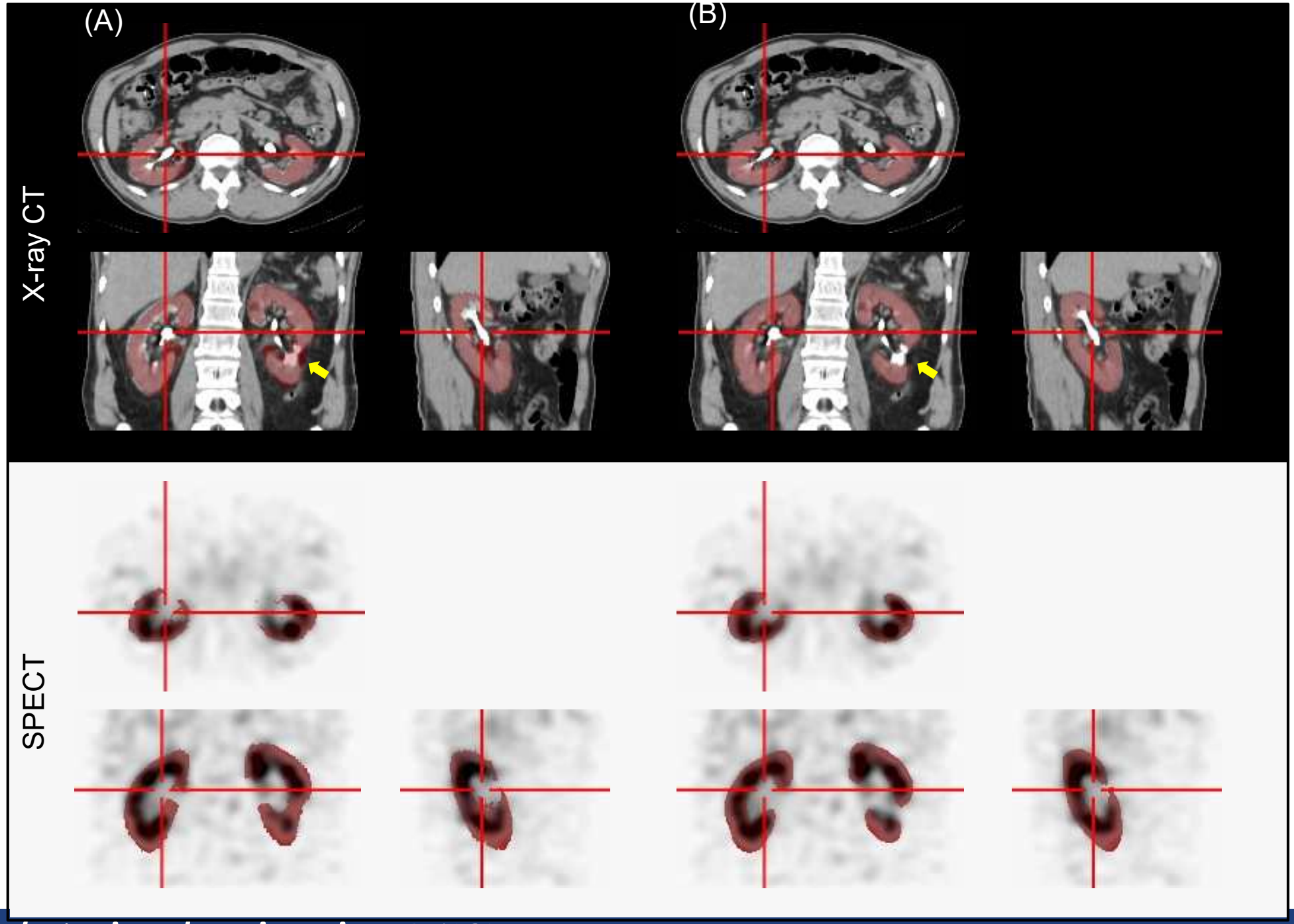

Park J et al., (unpublished data)

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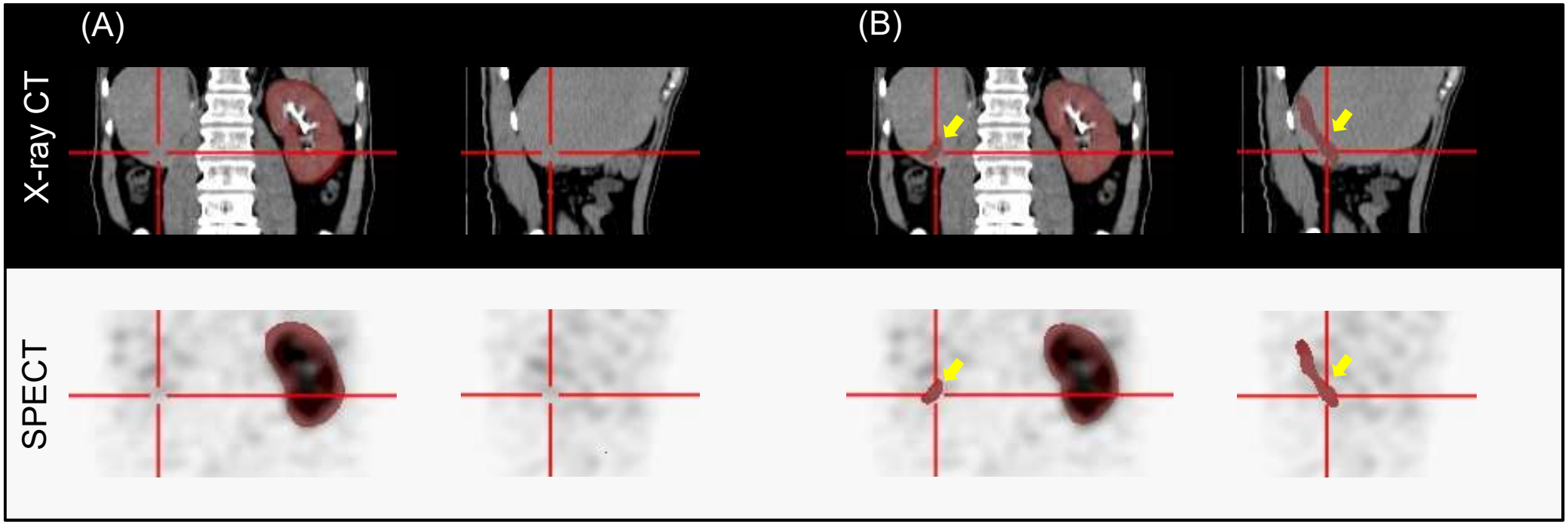
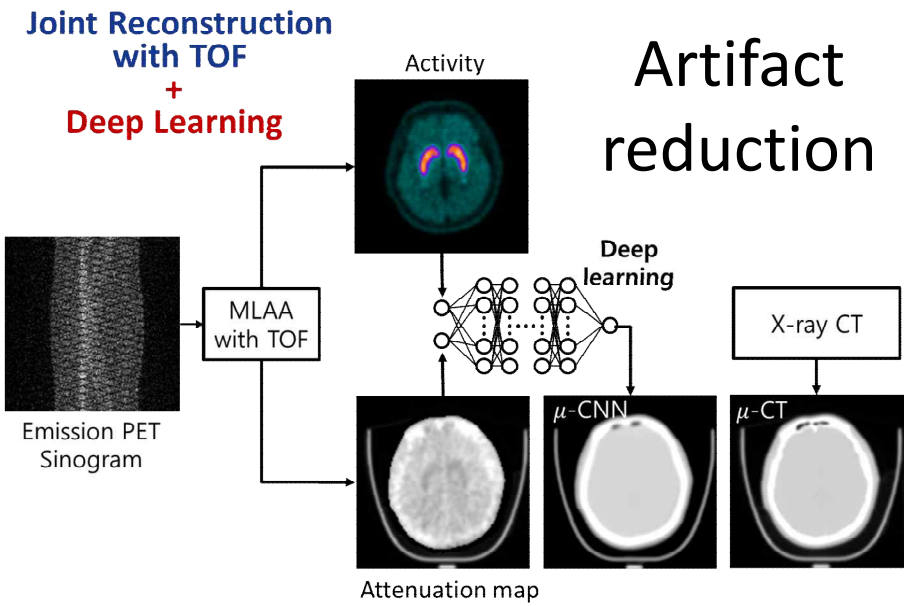
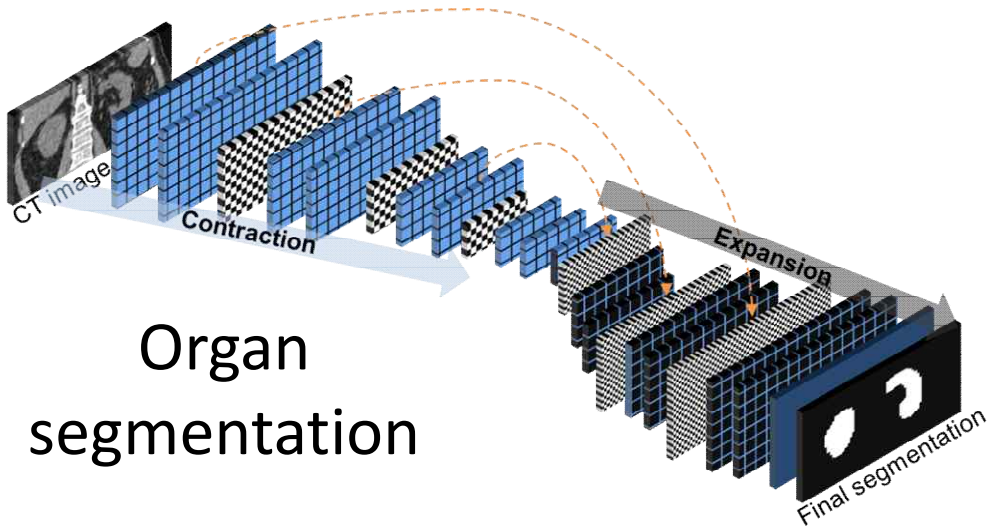


Park J et al., (unpublished data)

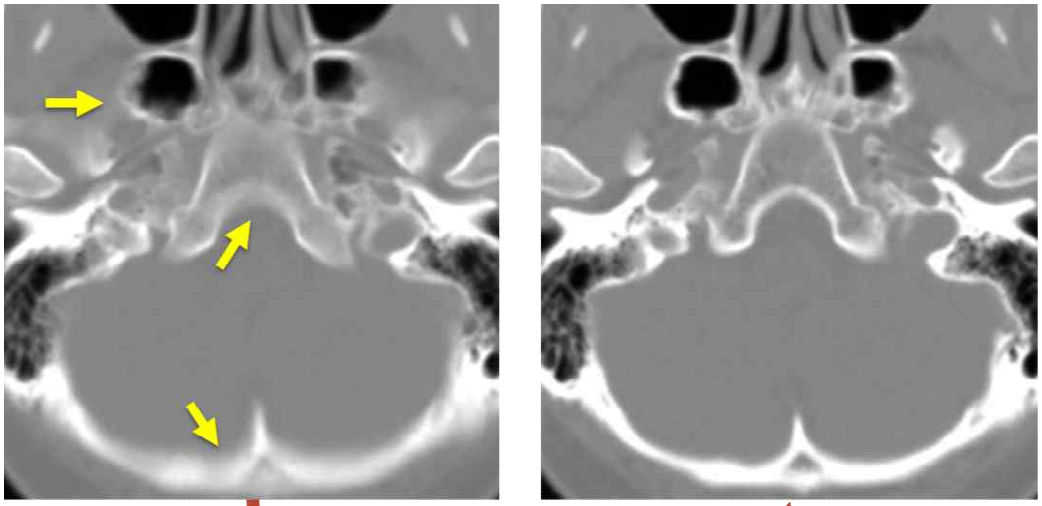
Deep Learning Researches



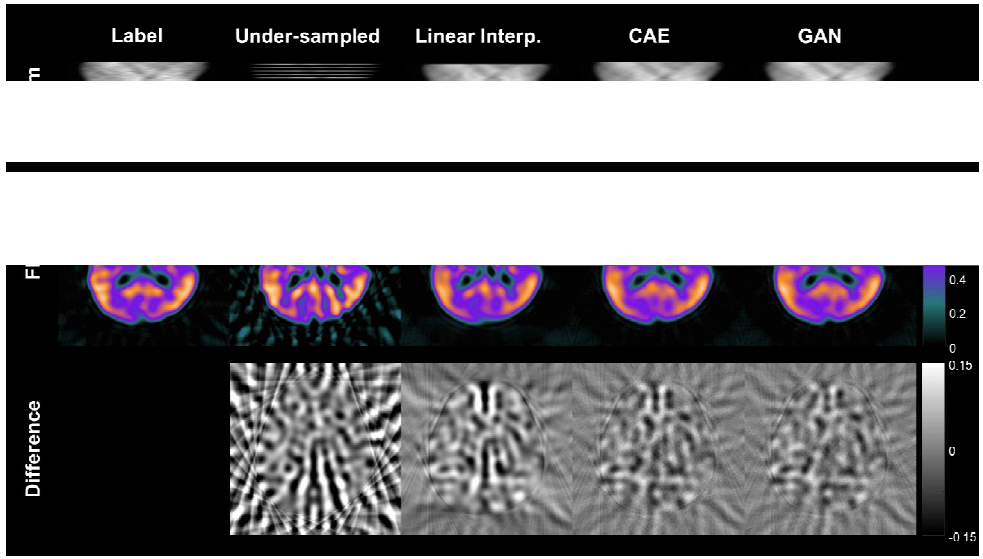
Artifact reduction



Organ segmentation



Super resolution



Scan time reduction