Feasibility Study of Micro-Dose Total-Body Dynamic PET Imaging Using the EXPLORER

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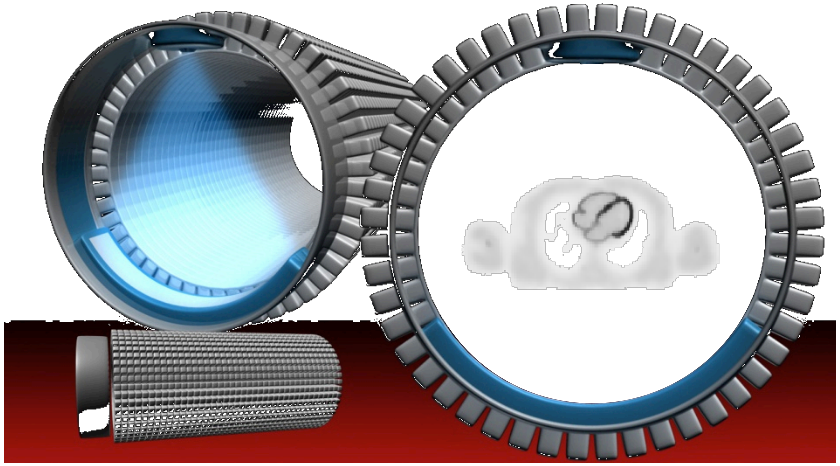
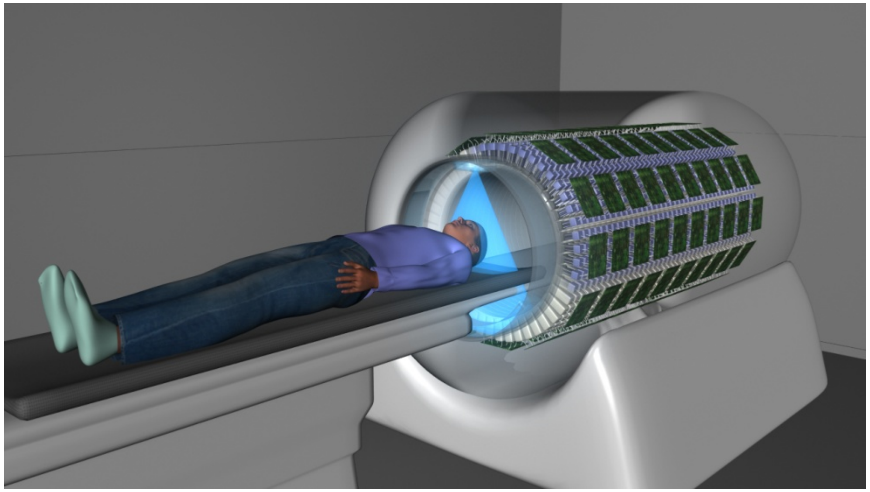
EXPLORER: Extreme-Performance Long-Axial Research Scanner





	Current PET Scanners	EXPLORER
Axial Length	~ 22 cm	**200 cm**
Dose Level	200 ~ 500 MBq	**10 ~ 500 MBq**
Whole-body Dynamic Imaging for Kinetic Studies	Multi-bed and multi-pass w/ large temporal gap	**Simultaneous total-body imaging w/ high temporal resolution**
Sensitivity for Human Imaging (cps/MBq)	1,400	**43,000**

Objectives

- Perform computer simulation studies to investigate the feasibility of micro-dose total-body dynamic PET imaging
  - At a dose level close to a round-trip inter-continental (e.g., Los Angeles-London) flight (0.1~0.2 mSv)
  - Typical natural background radiation in US is 3.1 mSv per year

- Enabling technologies:

<u>Ultra-sensitive EXPLORER</u> + <u>New kernel-based reconstruction</u>

- Impact: expanding PET applications to pediatric and adolescent populations, studying and monitoring chronic disease, and much more!

System Parameters of the EXPLORER

Scintillator	**LSO**
Crystal pitch size (mm^3)	3.42 x 3.42 x 20 (3.34 mm crystal and 80 μm reflector)
Number of crystals per block detector	15 x 15
Number of block detectors per ring	48
Number of block rings	**36**
Ring diameter	800 mm
Transaxial FOV	**700 mm**
Gap size between adjacent block rings	3.42 mm (one crystal pitch)
Total crystal rings (+ virtual gap rings)	540 (575)
Axial FOV	**1,966 mm**
Energy resolution	13%
Energy window	440 – 665 keV
TOF resolution	530 ps

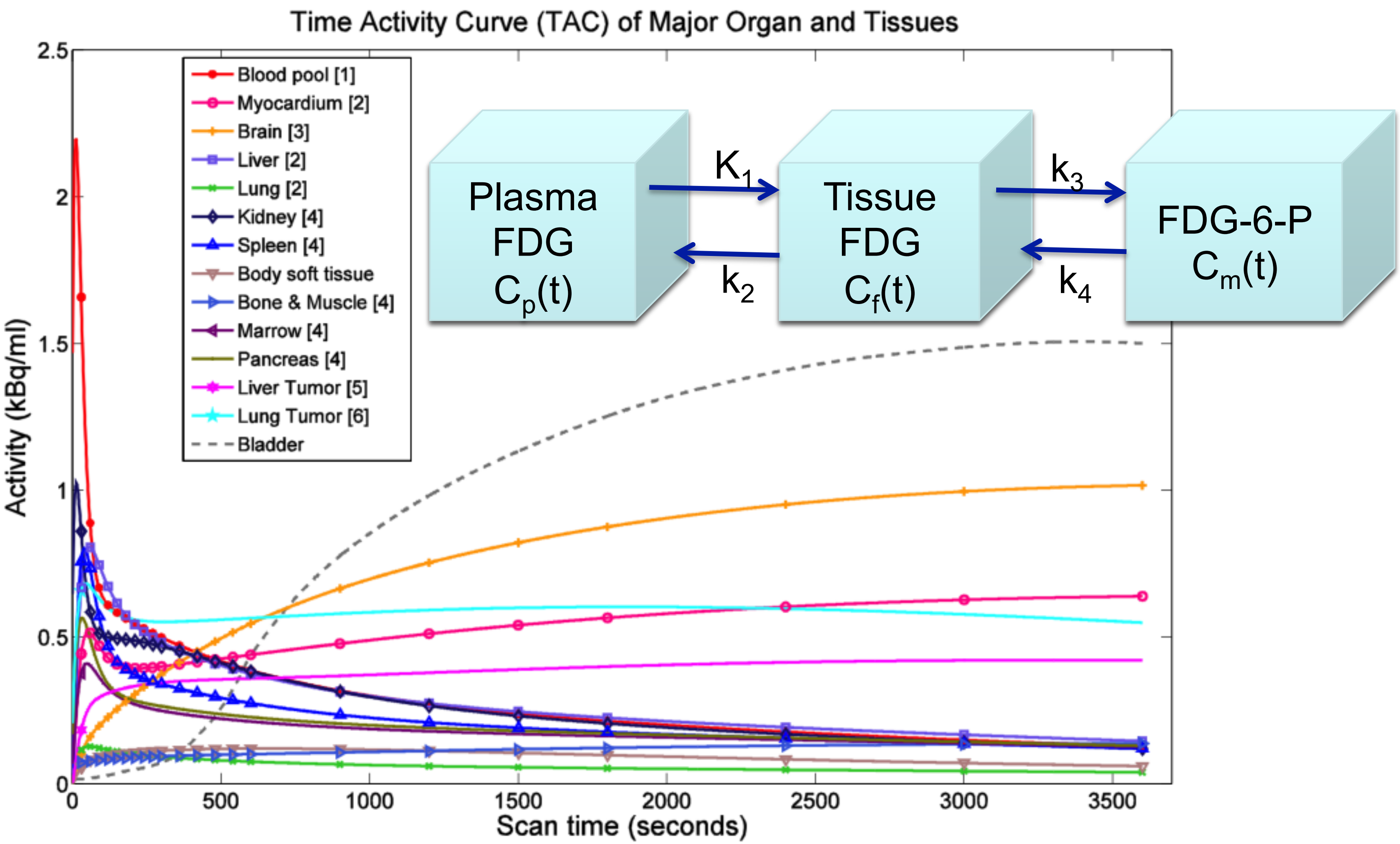
^{18}F-FDG Total-body PET Imaging Simulation

- SimSET Monte-Carlo Toolkit
- XCAT 2.0 male phantom (Courtesy of Dr. Segars from Duke University)
- 390×390×1,054 with 1.71mm voxels (height 179 cm)
- 18 major organs and tissues with realistic TACs
- Injected activity: 0.27 mCi (10 MBq), about **1/40** of standard injection activity
- Acquired 22 frames over 60 minutes: 10×30 sec, 5×60 sec, 4×300 sec, and 3×600 sec
- Total number of events = 2.21B (70.4% trues and 29.6% scatters)

Activity index

μ map (511keV)

Simulated Time Activity Curves



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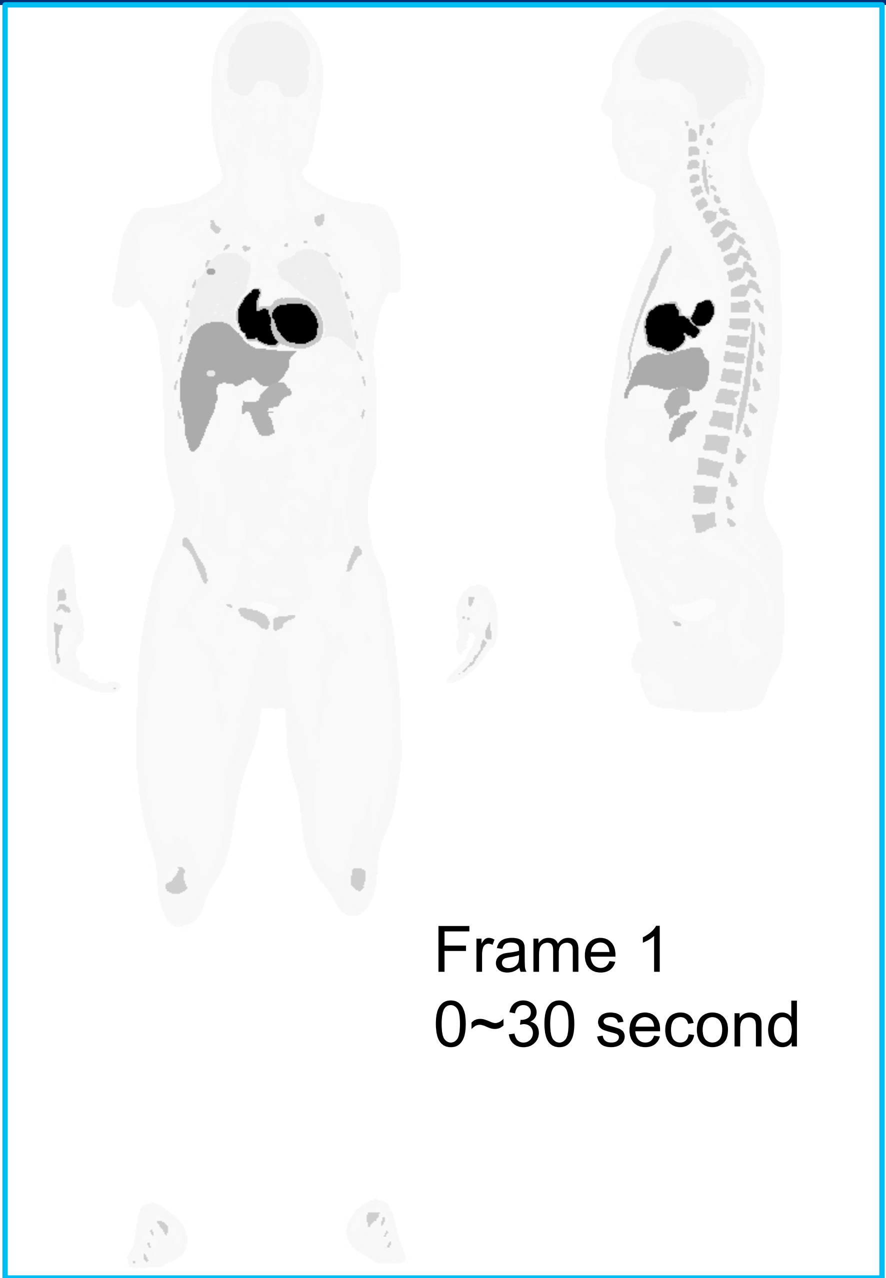
Static Images



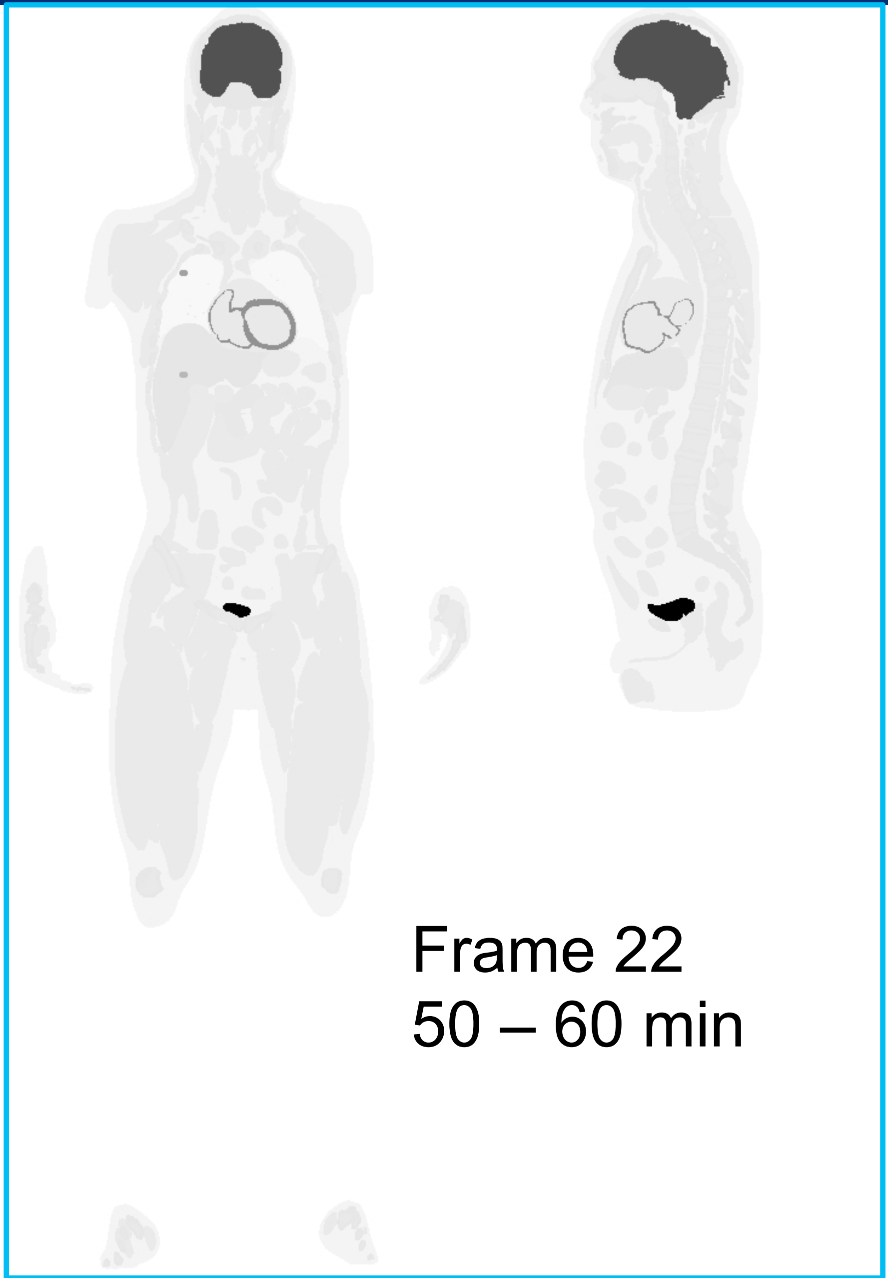
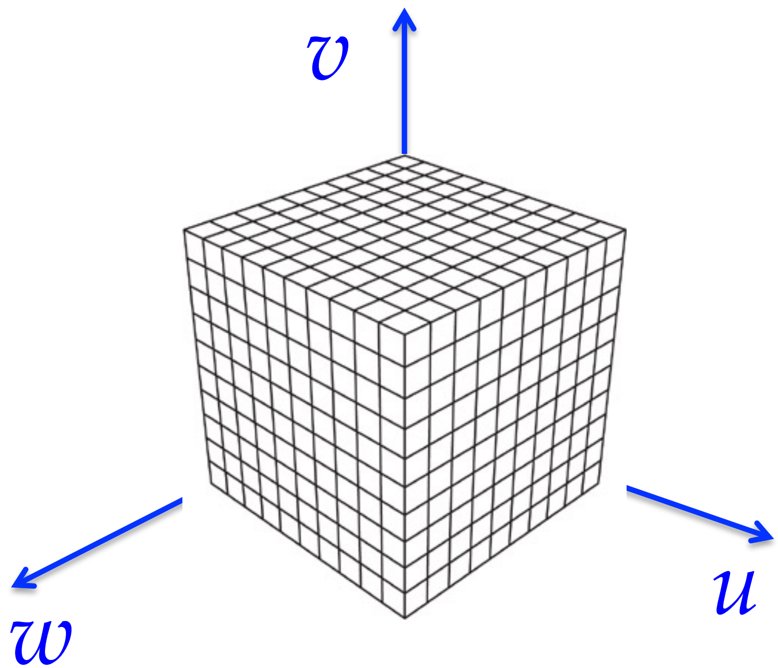


Image Reconstruction Methods

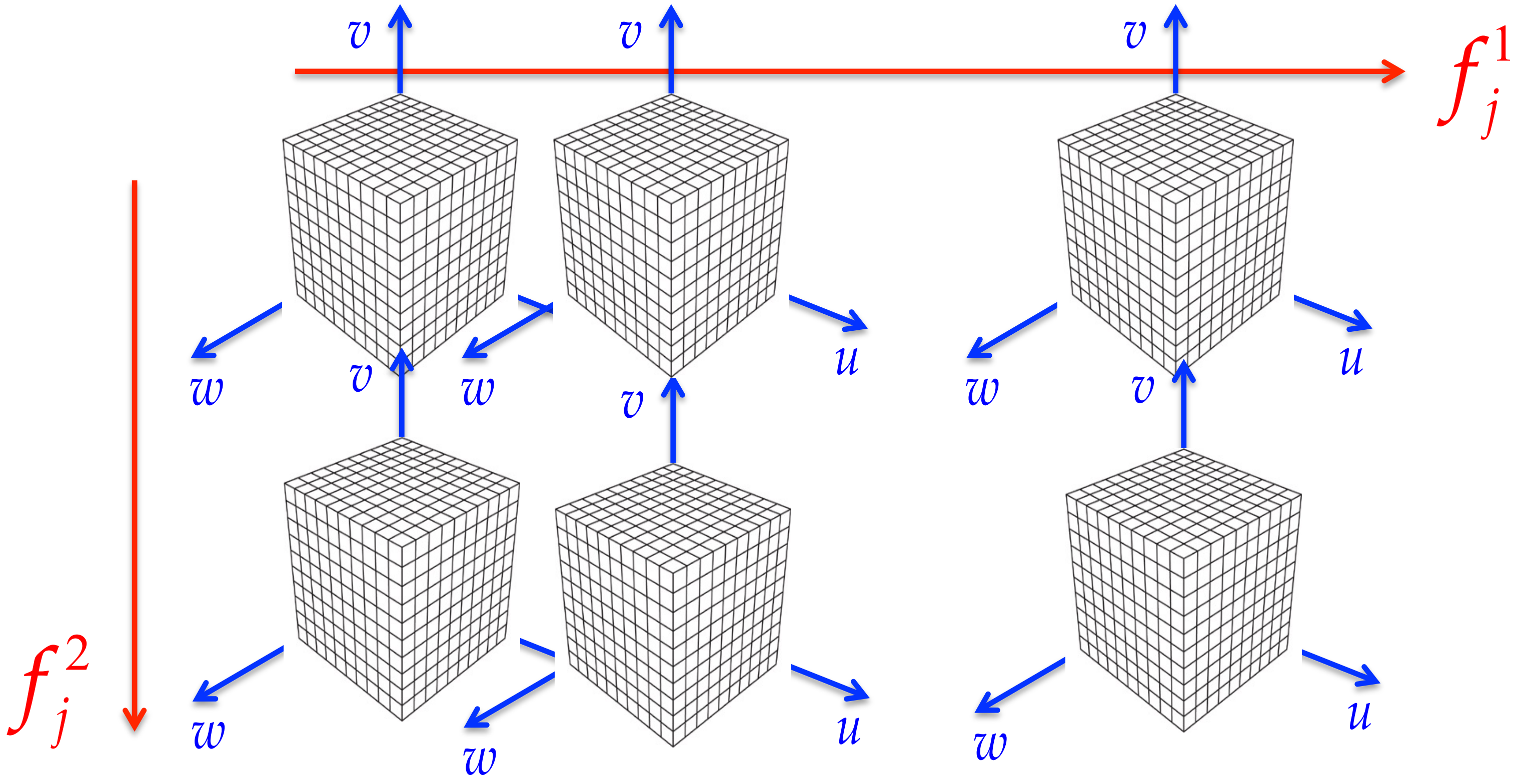
- Conventional listmode OSEM
  - 195×195×527 image array of 3.42 mm voxel
  - 10 subsets and 10 iterations
  - w/ and w/o Gaussian post-smoothing
- Kernel-based listmode OSEM
  - 195×195×527 image array of 3.42 mm voxel
  - 10 subsets and 10 iterations
- Scatter mean estimated from a separate Monte Carlo simulation and smoothed by spatial averaging

Introducing Kernel Representation



Intensity in voxel *j*: $x_j = \Gamma(\underbrace{u_j, v_j, w_j}_{\text{Spatial Location}})$

Adding Functional Attributes



$$x_j = \Gamma(z_j), \quad z_j = [\underbrace{u_j, v_j, w_j}_{\text{Spatial Location}}, \underbrace{f_j^1, f_j^2, f_j^3, \ldots}_{\text{Functional attributes}}]^T$$

Reconstructed Composite Images (Functional Attributes for Kernel Method)

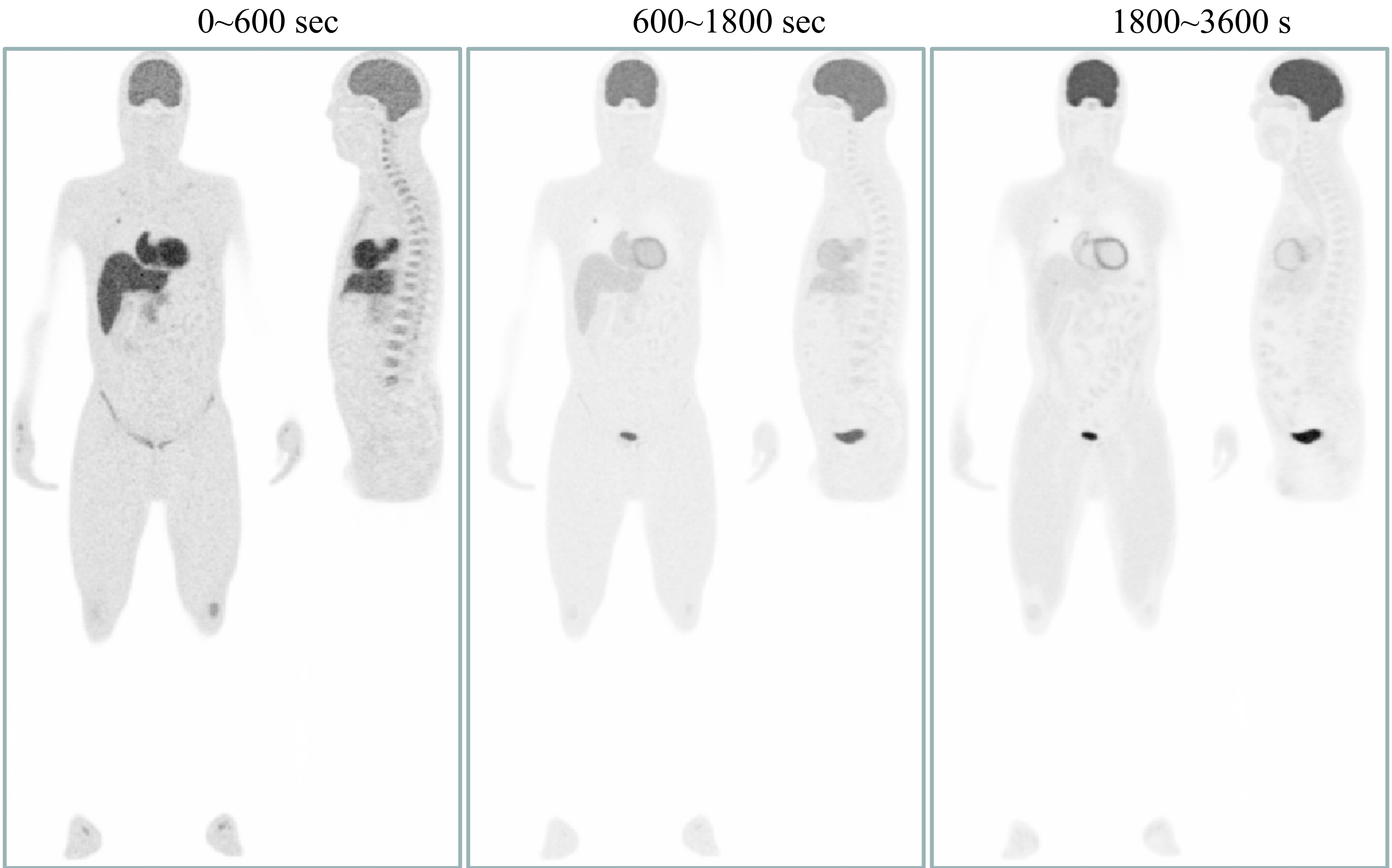


Image Representation using Kernels

- Linear assumption in high-D feature space $\{\phi(z_j)\}$

$$\Gamma(z) = \boldsymbol{c}^T \phi(z), \quad \boldsymbol{c} = \sum_{j=1}^{N} a_j \phi(z_j)$$

- Kernel-based image representation

$$\Gamma(z) = \sum_{j=1}^{N} a_j \kappa(z_j, z), \quad \kappa(z_j, z) = < \phi(z_j), \phi(z) >$$

- Kernel example: Gaussian kernel

$$\kappa(z_j, z_k) = \exp\left(-\left\|z_j - z_k\right\|^2 \Big/ 2\sigma^2\right)$$

Image Reconstruction in Kernel Space

Image Model

$$x = Ka$$

Projection Model

$$\bar{y} = Px + r$$

Noise Model

$$Y_i \sim \mathrm{Poisson}[\bar{y}_i]$$

Projection Model

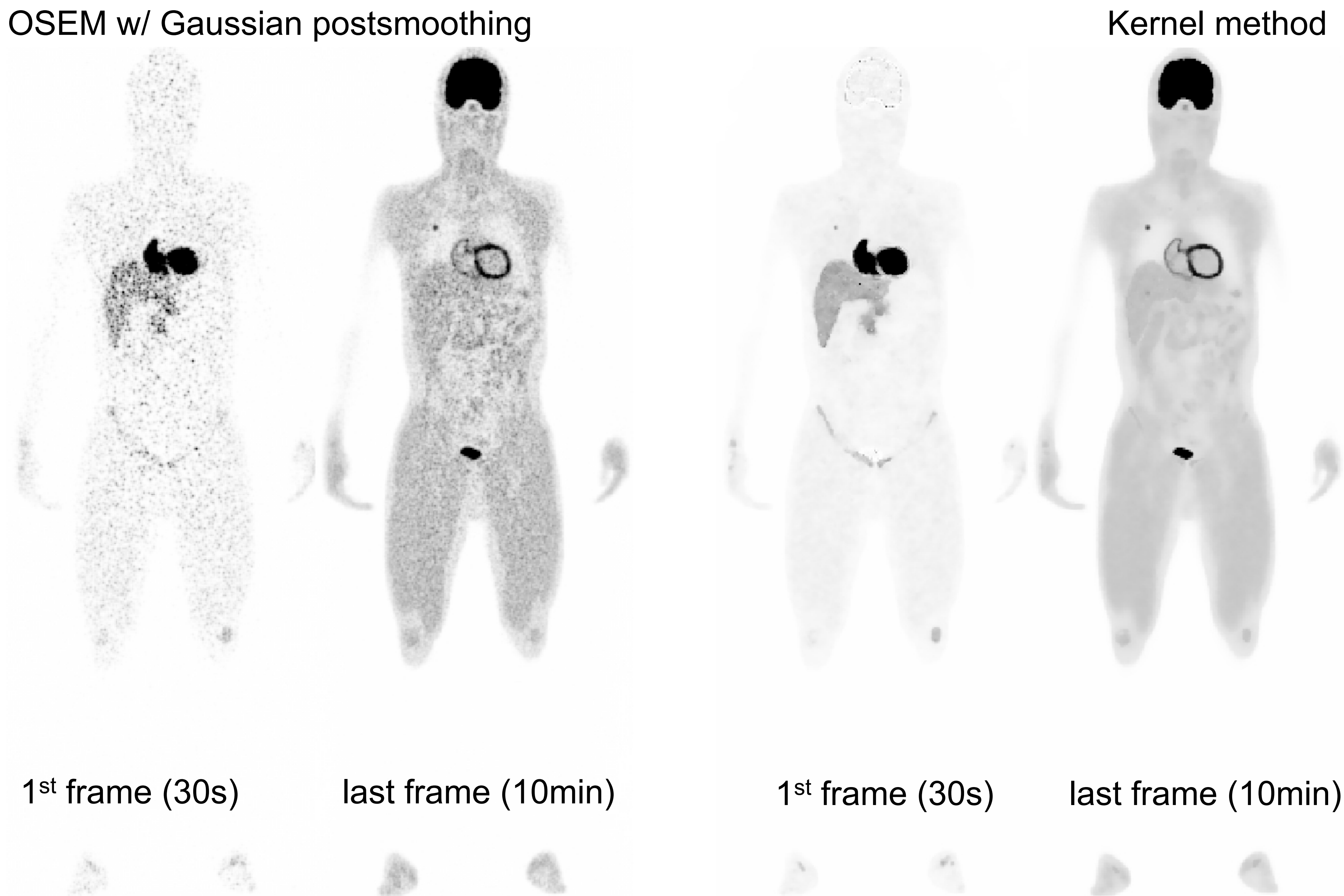
$$\bar{y} = PKa + r$$

$$\hat{a} = \arg\max_{a} \sum_i y_i \log \bar{y}_i - \bar{y}_i$$

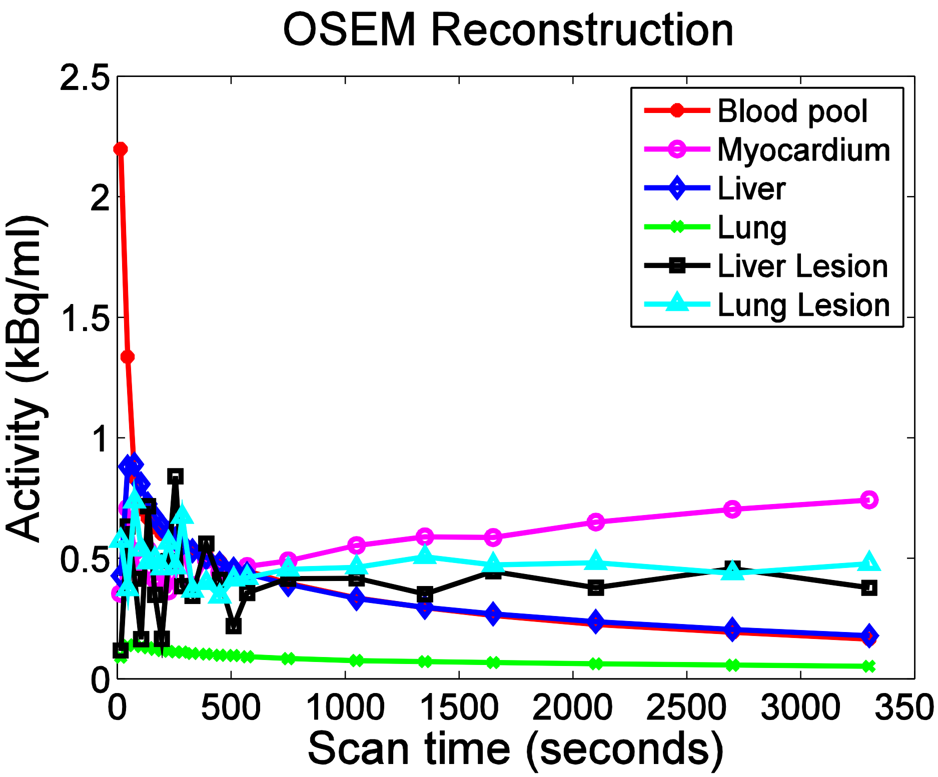
$$\hat{x} = K\hat{a}$$

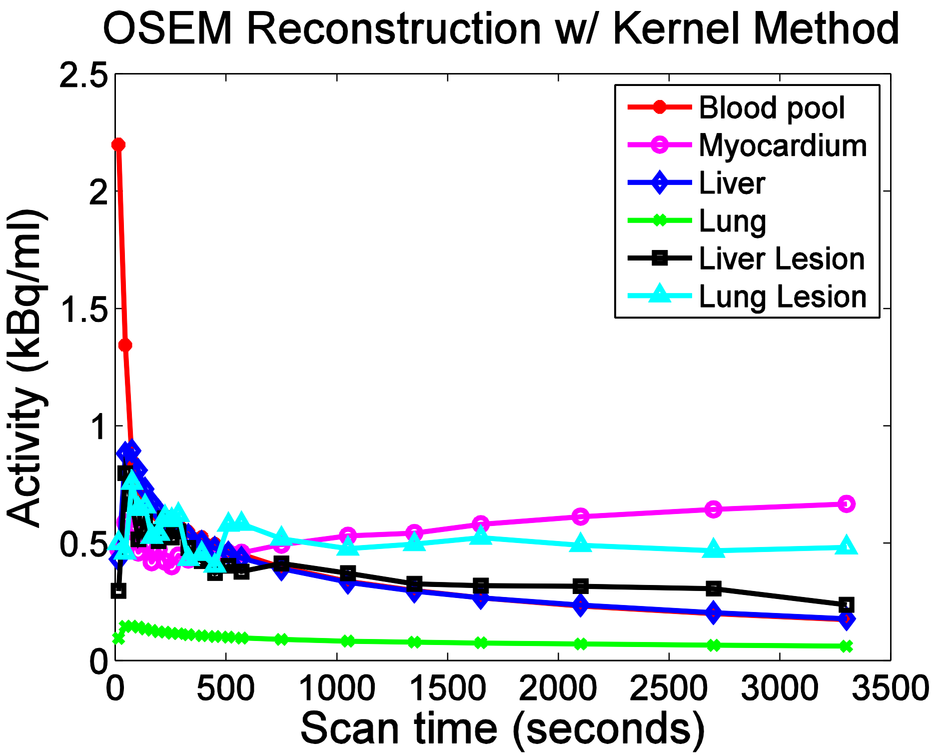
Special case: $K = I, a = x$ (conventional method)

Reconstructed Images



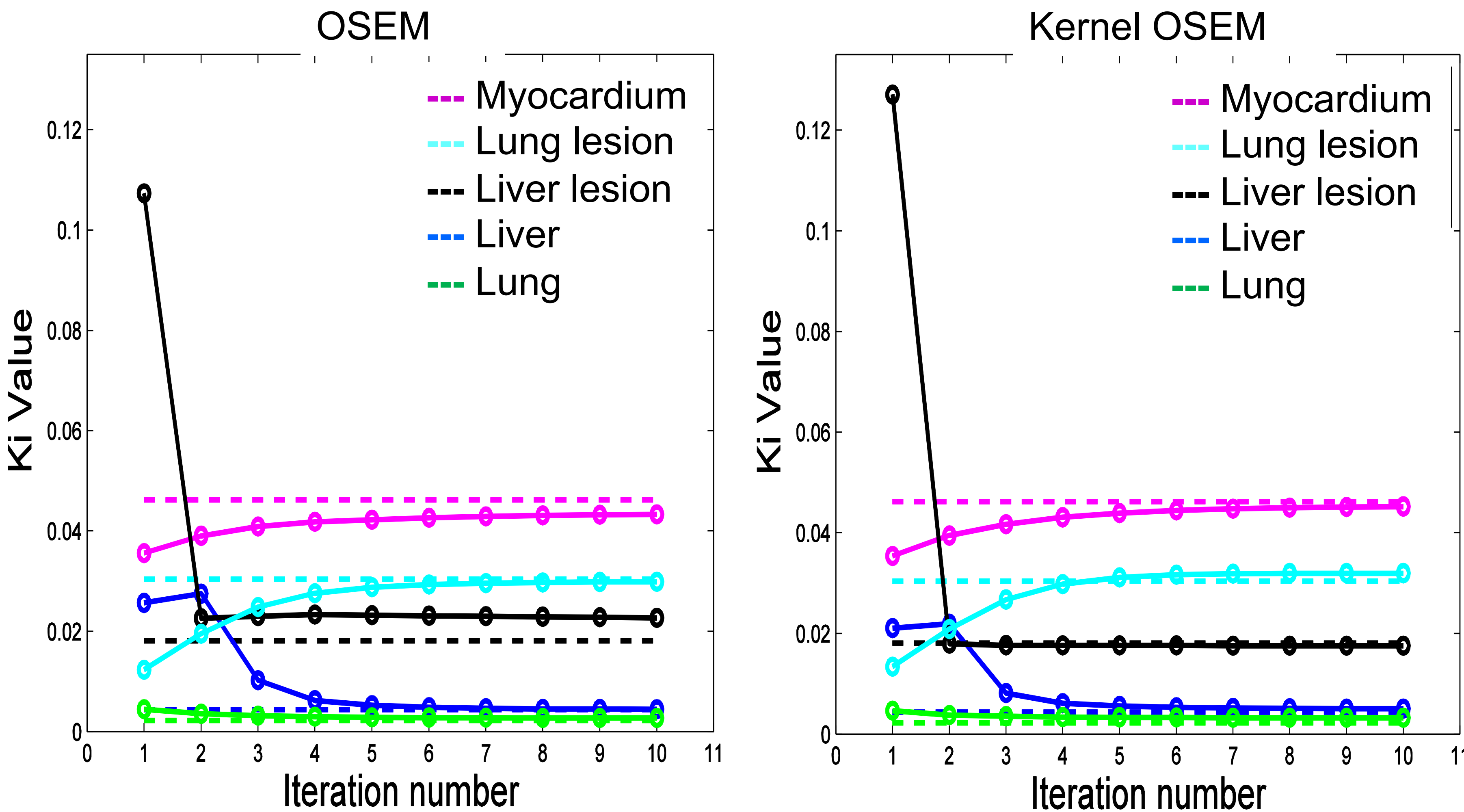
Reconstructed Time-Activity Curves





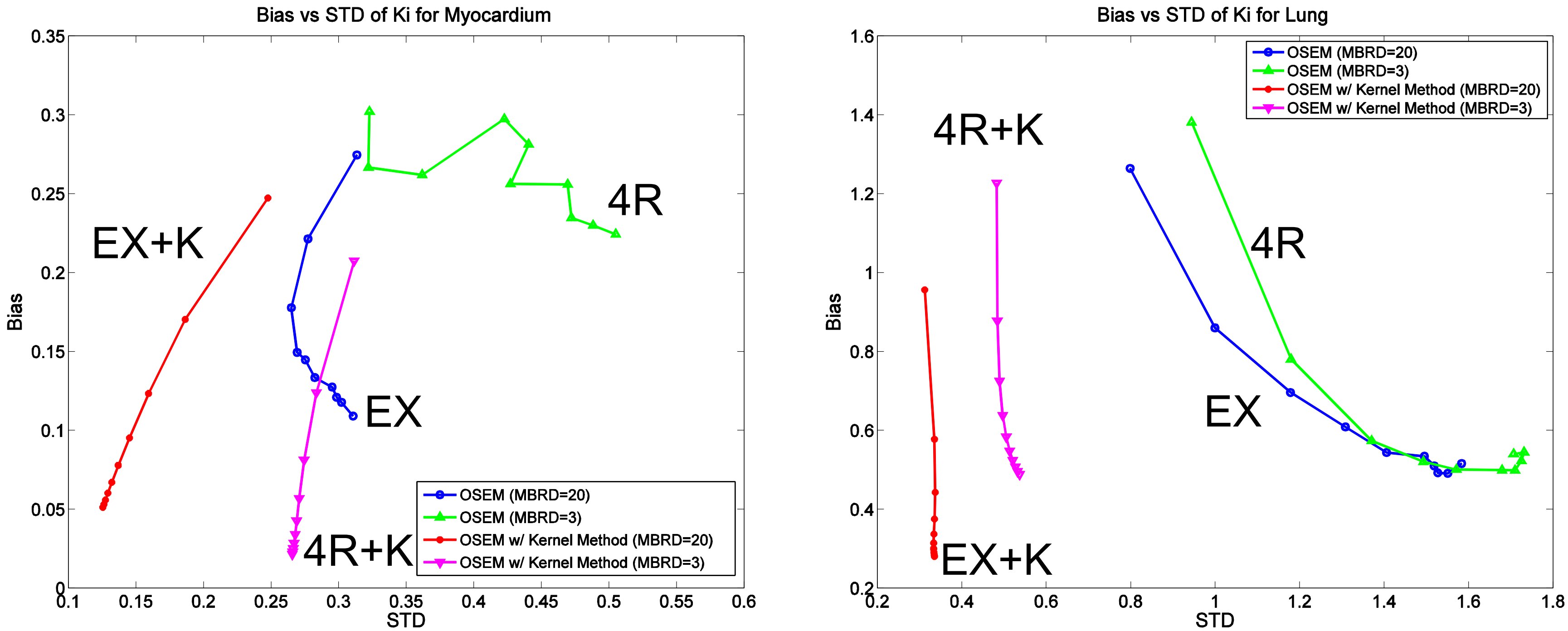
- TACs from the kernel method is less noisy at earlier frames (shorter duration)

Comparison of Estimated Ki Values



Dashed lines indicate the true Ki values

Voxel-wise Bias vs. Standard Deviation



- We also simulated single-organ dynamic imaging using current 4-block ring scanner (22-cm AFOV) (“4R”)
- The best performance (lowest bias and std) is achieved by combining the EXPLORER with kernel reconstruction (“EX+K”)

Conclusions

- Combining the EXPLORER with the new kernel-based image reconstruction we obtained high-quality PET images and time activity curves using only ~**1/40** of standard injected activity
- The simulation study show that micro-dose total-body dynamic PET imaging is feasible with the EXPLORER
- The development of the EXPLORER and new image reconstruction method can open up vast new opportunities for PET applications

Acknowledgements

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