QIBA SPECT Biomarker Committee Data Acquisition and Processing

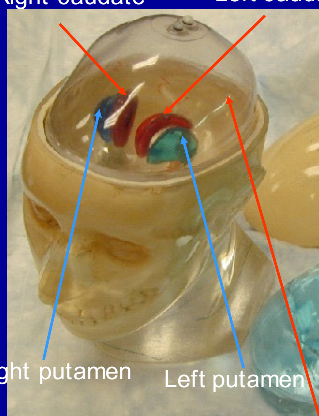
2 February 2016

If you want me to give you a two-hour presentation, I am ready today. If you want only a five-minute speech, it will take me two weeks to prepare."
M. Twain

Conjectures(?)

- 1. Optimal parameters for visual interpretation are usually different than for reconstruction.
- 2. For objects larger than the resolution more iterations are better (in terms of MSE) and low-pass filtering is not a good thing to do.
- 3. When the physics is modeled correctly accuracy and precision are determined largely by the collimator/object rather than the radionuclide.
- 4. VOI definition and differences in partial volume effects between patients (or in the same patient over time if the object changes) are the most important sources of uncertainty in measurements. These can be larger than noise effects unless you get to very low count levels. This is true for objects that are on the order of the size of the resolution or larger. Partial volume effects depend on the resolution, size and shape of the object, and activity in surrounding structures. Differences in these contributes to uncertainty across patients and in the same patient over time.

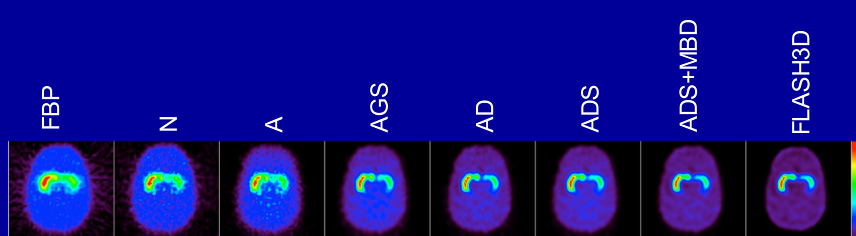
Striatal Phantom (unpublished)



- Siemens Symbia (3/8”)
- LEHR Collimator
- CT attenuation maps
- Manually defined VOIs CT Images
- Bkg VOI: elliptical VOI in cerebellum region away from boundaries
- Relative activity concentrations:
  - Bkg: 1
  - Left Caudate: 3
  - Left Putamen: 3
  - Right Caudate: 7
  - Right Putamen: 7

Courtesy of Yong Du

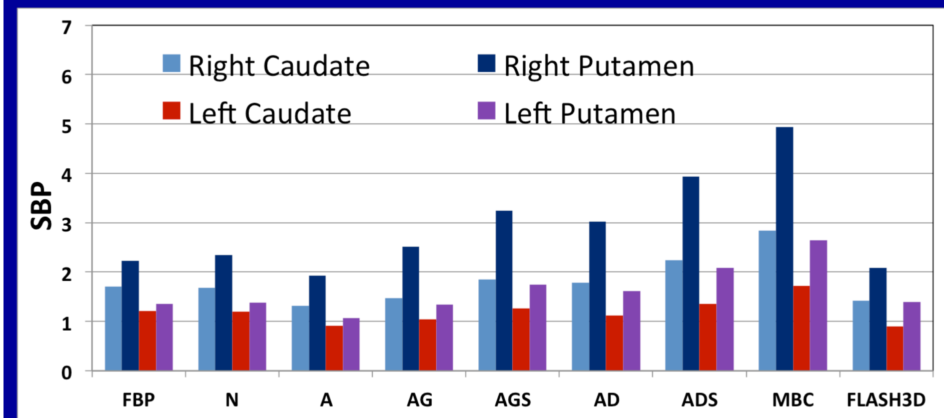
Striatal Phantom (unpublished)



FBP=Filtered Backprojection w/no compensation
A=Attenuation Compensation
G=Geometric response compensation
D=Full detector response compensation (including penetration and scatter)
S=Model-based scatter compensation
MBD=Model-based downscatter compensation

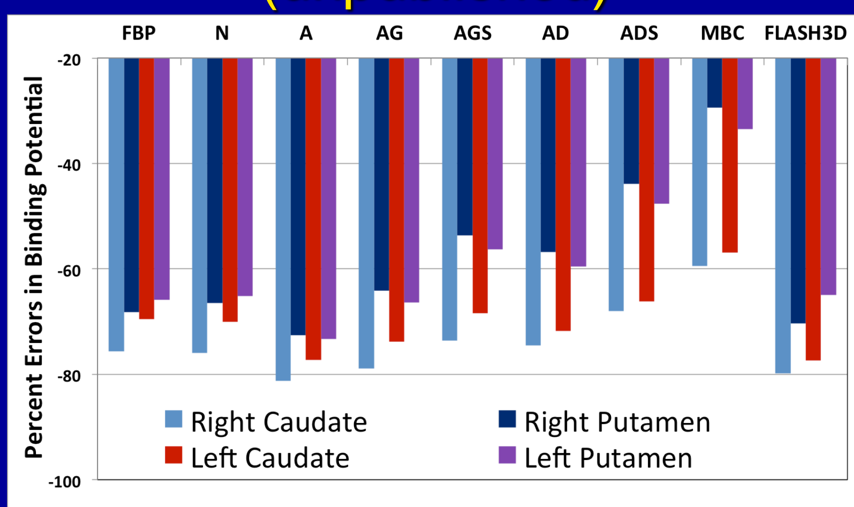
Courtesy of Yong Du, Ph.D.

Striatal Phantom (unpublished)



Courtesy of Yong Du, Ph.D.

Striatal Phantom (unpublished)



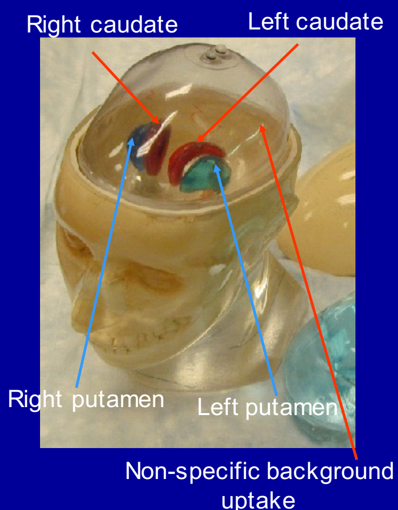
Courtesy of Yong Du, Ph.D.

Conclusions

- Modeling more physics gives better accuracy
- Relative quantification does not cancel out all errors
- Large residual errors from partial volume effects
- PVEs depend on object size

Accuracy of Activity Quantitation: I-123 Brain SPECT

RSD Striatal Phantom

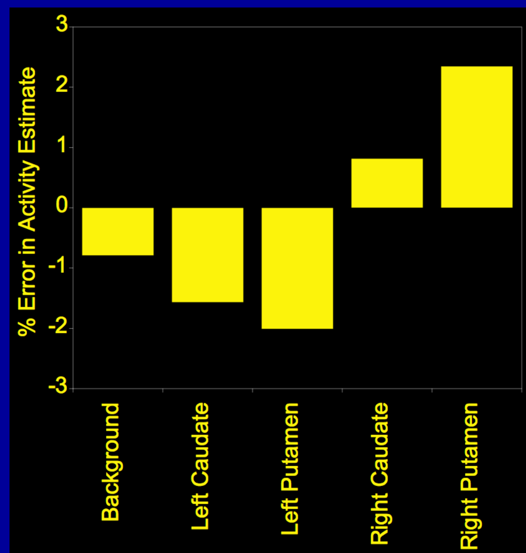


- GE Millennium VG/Hawkeye (5/8" thick crystal)
- LEHR Collimator
- 128 views/360°, 128*128 projection w/ 0.24 cm pixels
- CT attenuation maps
- Manually defined VOIs using registered MR Images
- Activity concentrations:
  - Bkg: 110 kBq/ml
  - Left Caudate: 212 kBq/ml
  - Left Putamen: 154 kBq/ml
  - Right Caudate: 1770 kBq/ml
  - Right Putamen: 222 kBq/ml

Y. Du, B.M.W. Tsui, and E.C. Frey, "Model-based compensation for quantitative I-123 brain SPECT imaging," *Phys Med Biol*, 51(5): 1269-1282, 2006

Accuracy of Activity Quantitation: I-123 Brain SPECT

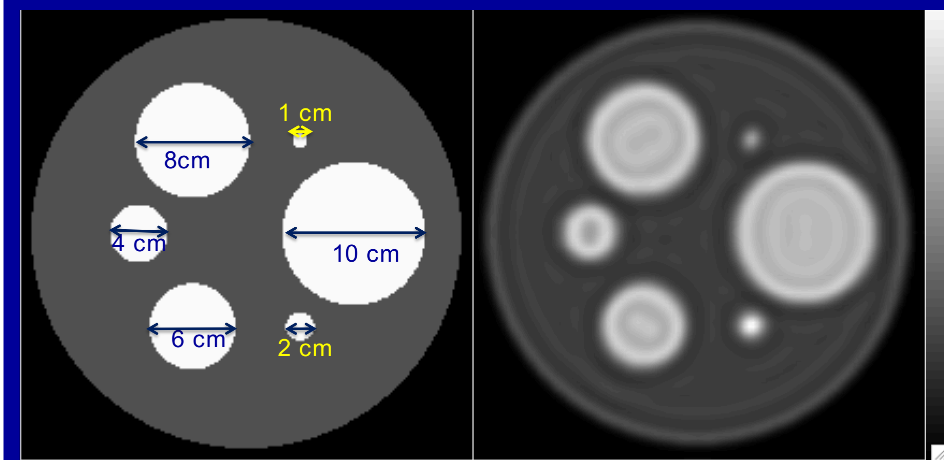
OS-EM w/
Attenuation
Scatter &
CDRF Compensation
Post-Reconstruction
pGTM PVC



Conclusions

- If the true VOIs are known and activity inside VOIs is uniform, partial volume compensation can give very high accuracy

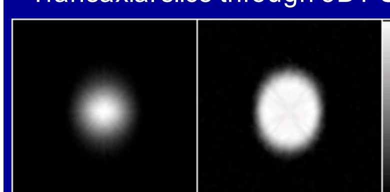
DRF Compensation Ringing



17 cm Radius of Rotation, HEGP Collimator, 128 projections over 360°
1600 updates (50 iterations, 32 subsets), DRF compensation

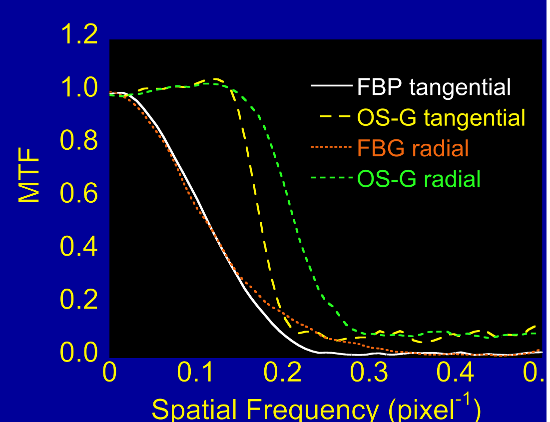
Effect of DRF on Reconstructed MTF

Transaxial slice through 3D PSF



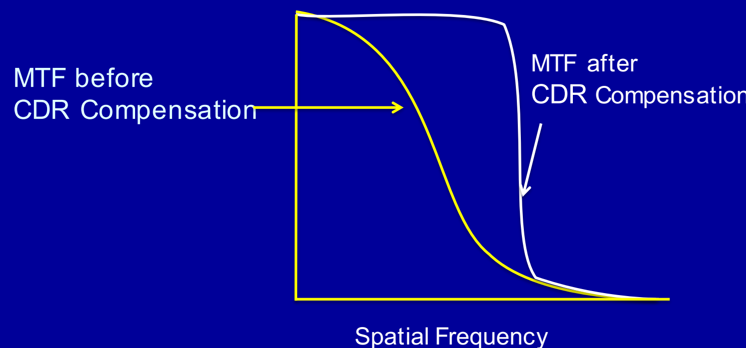
FBP
Ramp, Nyquist

OSEM w/DRFC



Profiles through MTFs

Understanding DRF Compensation Ringing

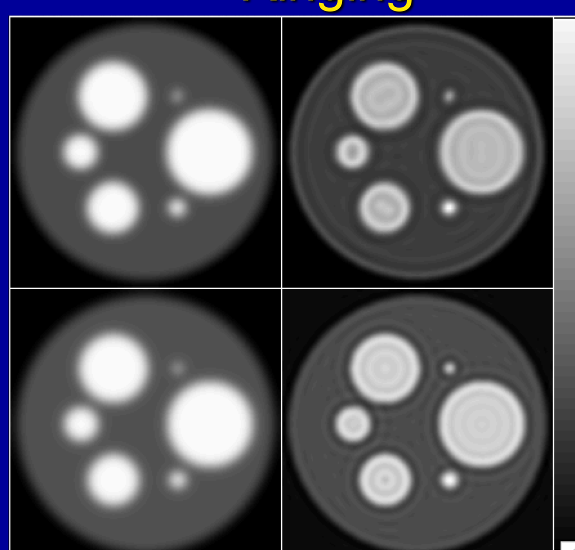


- DRF acts like Gaussian filter
- DRFC acts like filter with sharp cutoff (e.g., Butterworth with high order)

Understanding DRF Compensation Ringing

FBP
Ramp,
Nyquist

OSEM, DRFC
1600 Updates

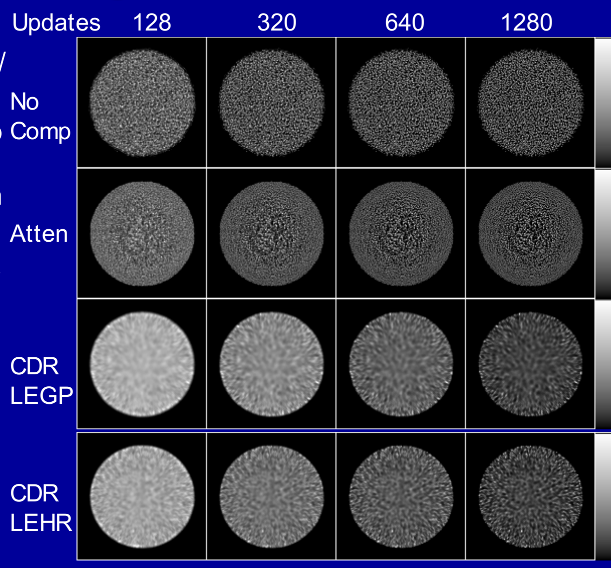


Phantom
Gaussian
FWHM=
1.5 cm

Phantom
Butterworth
Order=16
Cutoff=0.1

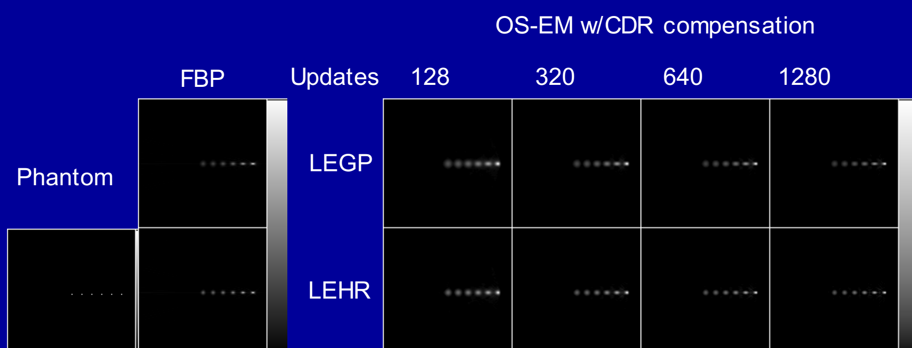
Effect of Compensation on Image Noise

- Noise increases w/ iteration
- Attenuation Comp has larger noise where attenuation is greatest
- CDR comp results in “lumpy” noise and ‘ringing’
- Texture of noise w/CDR comp
  - varies spatially
  - depends on collimator

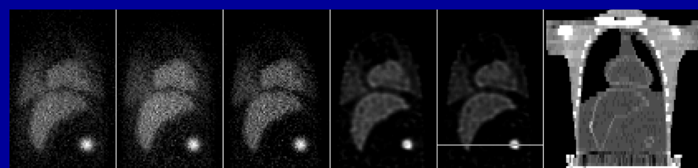


Efficacy of CDR Compensation

- Resolution improves with iteration but remains limited: cannot totally recover resolution
- Resolution remains spatially varying
- Resolution for LEHR better than for LEGP



In-111 RSD Phantom



NC=No Compensation
A=Attenuation Compensation
AD=Attenuation and CDR Comp
AS=Attenuation and Scatter Compensation
ADS=Attenuation, CDR and Scatter Comp

GE Millenium VG w/Hawkeye SPECT/CT system, MEGP Collimator

B. He, Y. Du, X. Song, W.P. Segars and E.C. Frey, "A Monte Carlo and physical phantom evaluation of quantitative In-111 SPECT," Phys Med Biol, 50(2005): 4169-4185, 2005.

Accuracy of Activity Quantitation: RSD Phantom and In-111

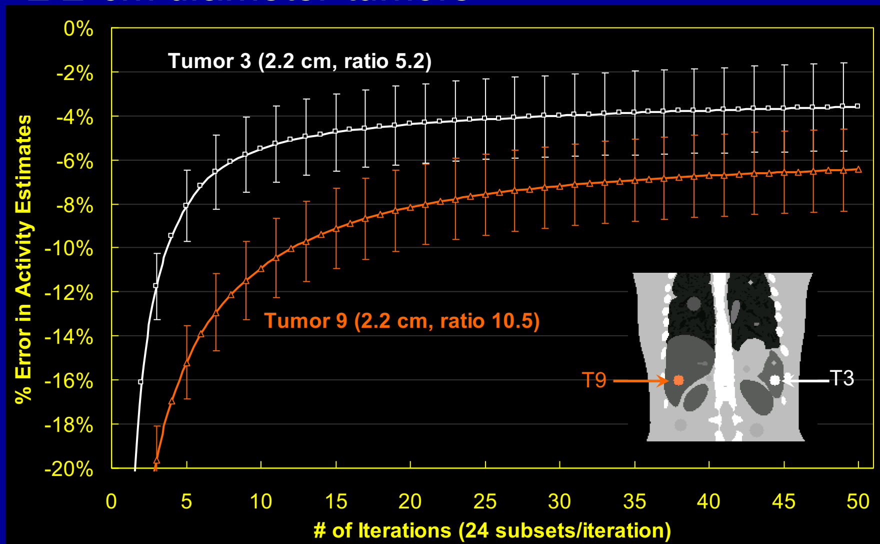
% Error in total activity estimation: (true-estimate)/true x 100%

Organ	No Comp	Atten Comp	Atn+ Scat Comp	Atn + CDR + Scat Comp	Atn + CDR + Scat + PVC
Heart	-77.60%	24.63%	-11.76%	-3.72%	-2.11%
Lungs	-62.78%	31.39%	-0.96%	4.23%	6.45%
Liver	-74.38%	29.22%	-7.47%	2.71%	4.14%
20.6 cc sphere	-78.88%	-14.85%	-29.81%	-3.36%	-1.97%
5.6 cc sphere	-88.24%	-51.53%	-56.75%	-21.55%	-11.95%

PVC using pGTM method

Quantification of Small Objects

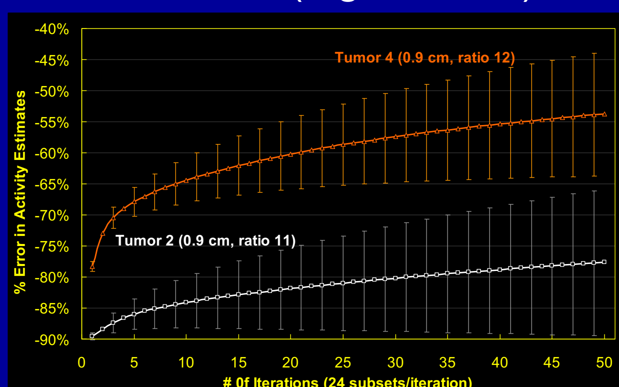
- 2.2 cm diameter tumors



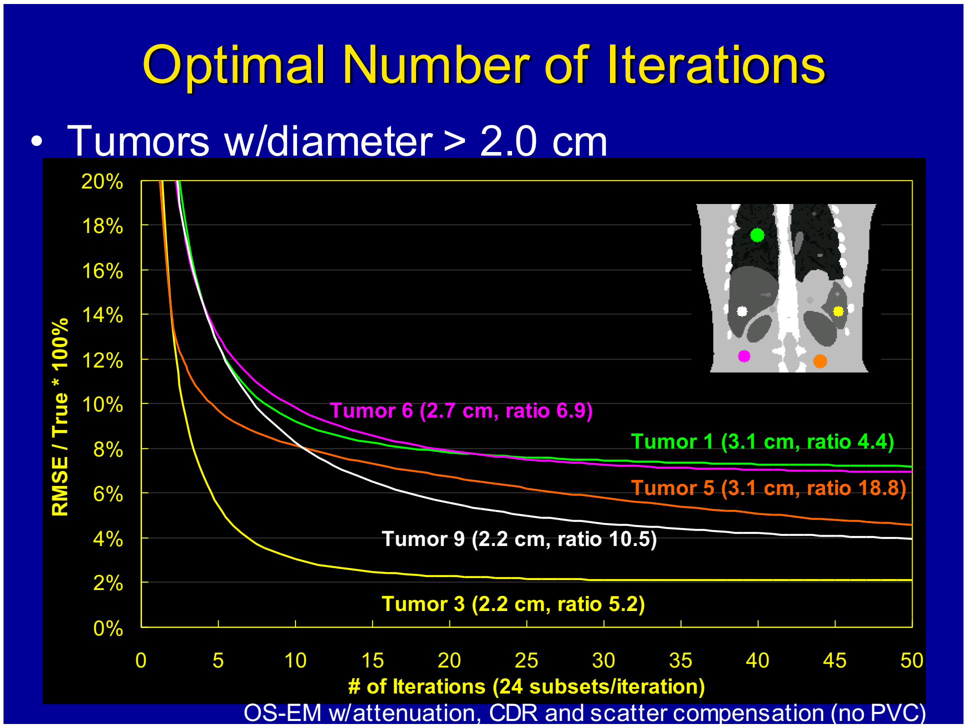
OS-EM w/attenuation, CDR and scatter compensation (no PVC)

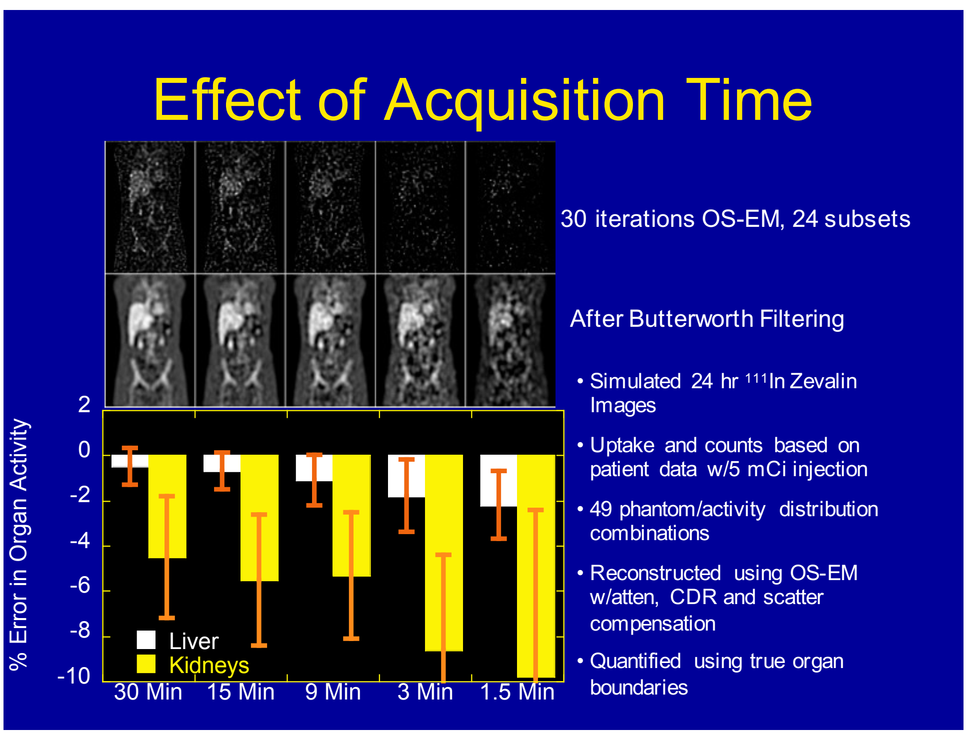
Quantification of Very Small Objects

- Estimation of Activity in objects much smaller than the resolution (e.g. a voxel) is not reliably



In-111, MEGP collimator
OS-EM w/ Atten, CDR, and Scatter Compensation


Optimal Number of Iterations
• Tumors w/diameter > 2.0 cm
RMSE / True * 100%
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
5
10
15
20
25
30
35
40
45
50
# of Iterations (24 subsets/iteration)
Tumor 6 (2.7 cm, ratio 6.9)
Tumor 1 (3.1 cm, ratio 4.4)
Tumor 5 (3.1 cm, ratio 18.8)
Tumor 9 (2.2 cm, ratio 10.5)
Tumor 3 (2.2 cm, ratio 5.2)
OS-EM w/attenuation, CDR and scatter compensation (no PVC)


Effect of Acquisition Time
30 iterations OS-EM, 24 subsets
After Butterworth Filtering
% Error in Organ Activity
2
0
-2
-4
-6
-8
-10
Liver
Kidneys
30 Min
15 Min
9 Min
3 Min
1.5 Min
• Simulated 24 hr ¹¹¹In Zevalin Images
• Uptake and counts based on patient data w/5 mCi injection
• 49 phantom/activity distribution combinations
• Reconstructed using OS-EM w/atten, CDR and scatter compensation
• Quantified using true organ boundaries

I-131 Physical Phantom

Philips Precedence SPECT/CT system with HEGP collimator

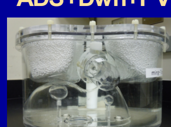
	Heart Chamber	Myocardium	Large Sphere	Small Sphere	Background
Volume (*ml*)	59.7	115.3	17.5 (r =1.61 cm)	5.7 (r =1.11 cm)	9580
Activity(*mCi*)	0.562	0.471	0.136	0.044	8.15
Activity concentration (*mCi/μl*)	9.38	4.08	7.77	7.72	0.851

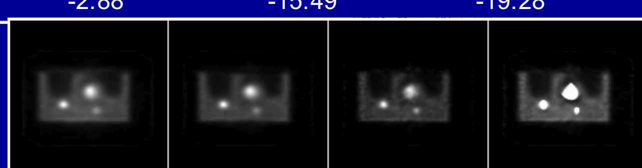
- **128 projection views**
- **Acquisition time: 40s / view**

I-131 Physical Phantom

Percent errors of activity estimates for Anthropomorphic torso phantom

(%)	**Heart**	**Large sphere (r = 1.61 cm 17.5 ml)**	**Small sphere (r = 1.11 cm 5.7 ml)**
AGS	-15.21	-26.12	-32.72
ADS	4.75	-17.63	-25.77
ADS+Dwn+	-5.20	-21.10	-31.17
ADS+Dwn+PVC*	-2.88	-15.49	-19.28



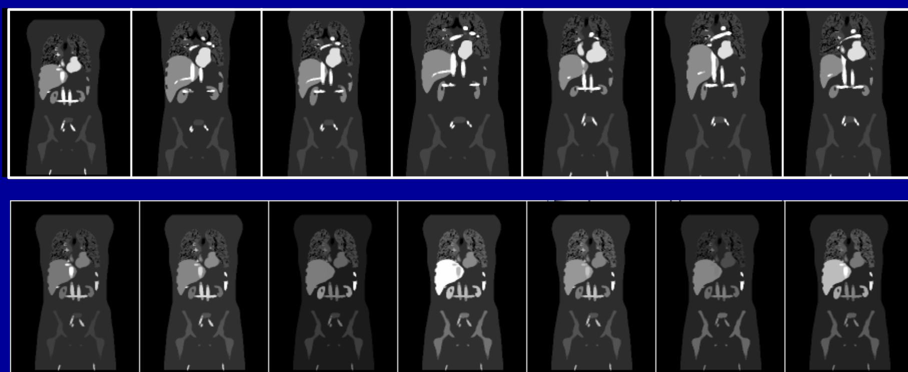


AGS **ADS** **ADS + Dwn** **ADS+Dwn+PVE**

50 iterations
24 subsets/iteration

+DWN=model-based downscatter compensation
*PVC=reconstruction-based PVC compensation

I-131 MC Simulation Study

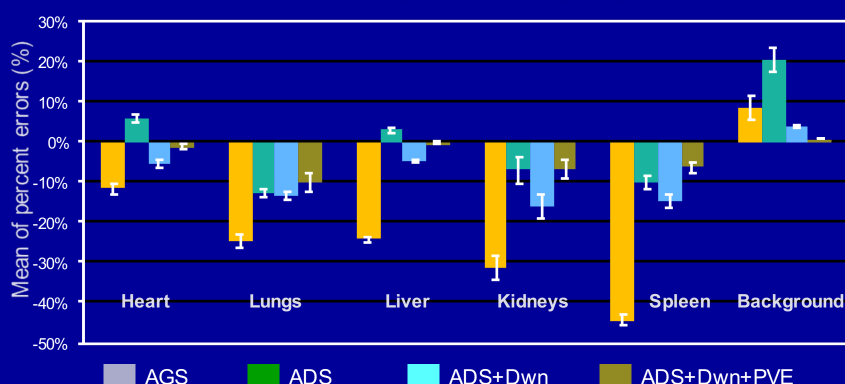


3D NCAT phantom population (49 phantoms) to model various patient anatomies and organ uptakes

50 Noise realizations for each phantom/uptake combination

I-131 MC Simulation Study

Effects of Compensation Methods and Poisson Noise



Mean of % Error and % STD over all noise realizations averaged over phantom population for each organ and for each compensation method.

% Error = (Estimate - True) / True

% STD = STD / True

50 iterations
24 subsets/iteration

Y-90 Physical Phantom Experiment

- Physical phantom experiment
  - Elliptical phantom with 3 spheres
  - Philips Precedence SPECT/CT: HEGP
  - Acquisition time per view: 45 s/view
  - Crystal thickness: 9.525 mm
  - 128 projection views over 360°
  - Matrix size per view: 128*128
  - Pixel size: 4.664 mm

X. Rong, Y. Du, M. Ljungberg, E. Rault, S. Vandenberghe, and E.C. Frey, "Development and evaluation of an improved quantitative (90)Y bremsstrahlung SPECT method," *Med Phys*, 39(5): 2346-58, 2012, PMC 3338590.

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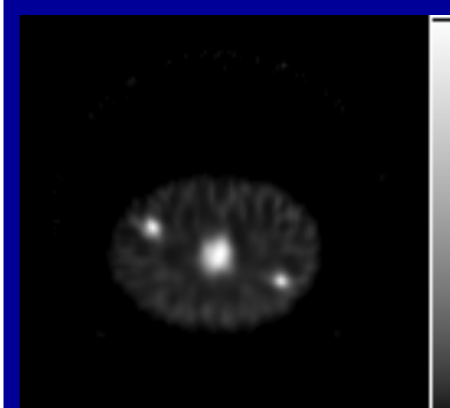
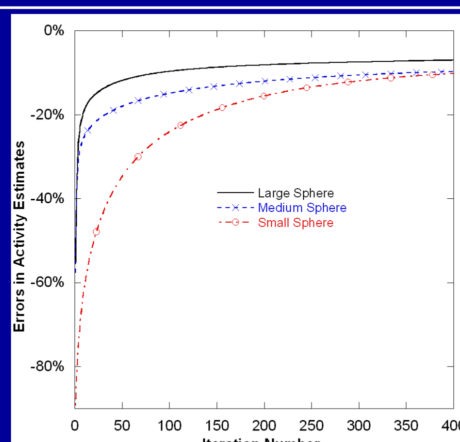
Experimental Results





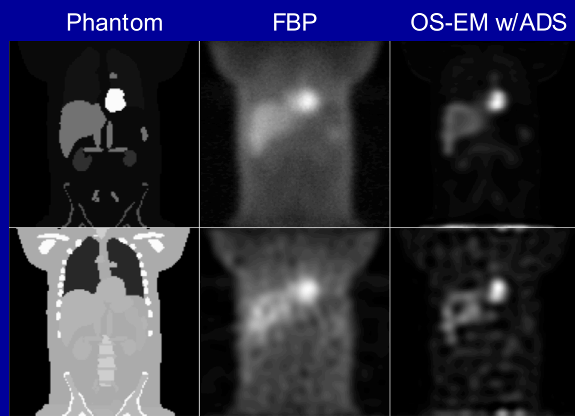
Sphere size	89.6 cc r=5.5 cm	19.0 cc R=3.3 cm	2.0 cc R=1.5 cm
Error	-7.0%	-9.7%	-10.2%

Error = (EstimatedActivity – TrueActivity) / TrueActivity × 100%

28

28

Y-90 Simulation



Organ	Lung	Spleen	Kidneys	Liver	Heart
No Noise	15.8%	-15.1%	-8.2%	-6.9%	-12.1%
W/Noise	16.7%	-16.9%	-3.0%	-6.2%	-11.4%

Other Sources of Information

- Frey EC, Humm JL, Ljungberg M. Accuracy and Precision of Radioactivity Quantification in Nuclear Medicine Images. Semin Nucl Med. 2012;42(3):208-18.
- IAEA HUMAN HEALTH REPORTS No.9 Quantitative Nuclear Medicine Imaging: Concepts, Requirements and Methods (in Press)