Respiratory and rigid body motion compensation in cardiac perfusion SPECT

P. Hendrik Pretorius, PhD
Department of Radiology, University of Massachusetts Medical School

Grant funding: R01-EB001457

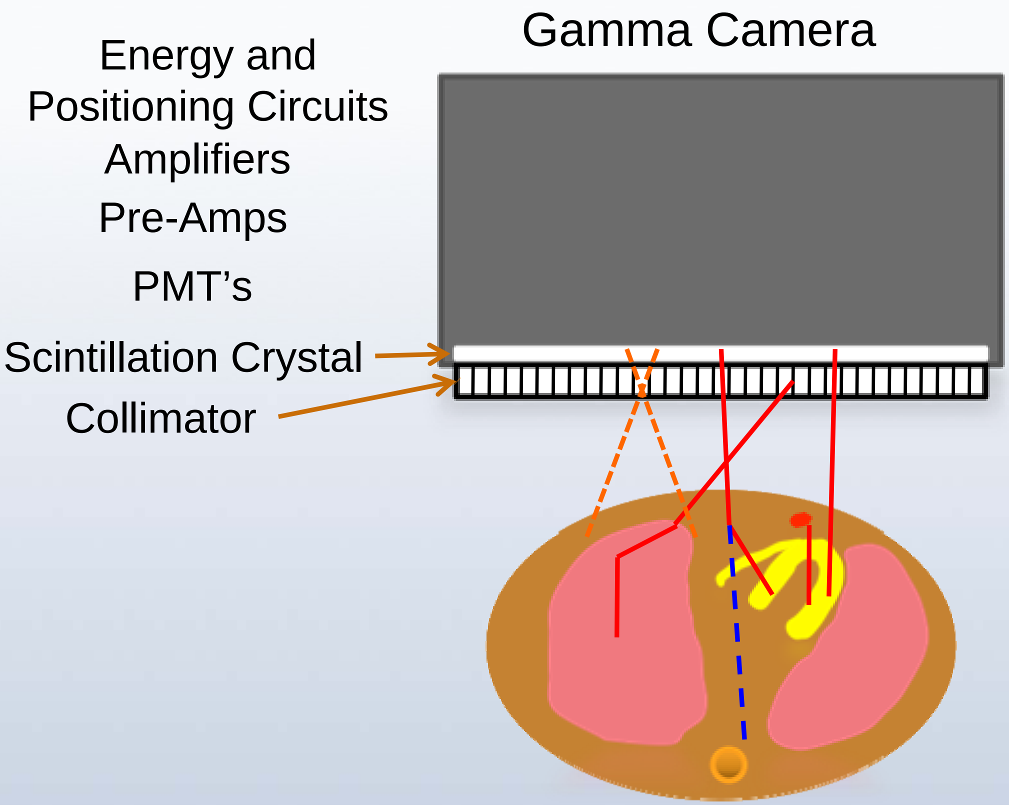
Contributors

- Michael A. King, PhD
- Karen L. Johnson, NMT
- Joyeeta M. Mukherjee, PhD
- Joyoni Dey, PhD
- Arda Konik, PhD
- Bing Feng, PhD, Philips Medical Systems, Philippe Bruyant, PhD, Richard Beach, PhD, Ron Walvick.

Goal

- The integration of motion compensation: respiratory motion estimation is added and corrected in unison with rigid body motion.
- In this presentation I report on the validation of our acquisition and processing implementation through acquisitions of the Data Spectrum anthropomorphic phantom with the Iowa heart insert, and investigation of clinical efficacy and robustness in cardiac perfusion patients

The Physics Challenge



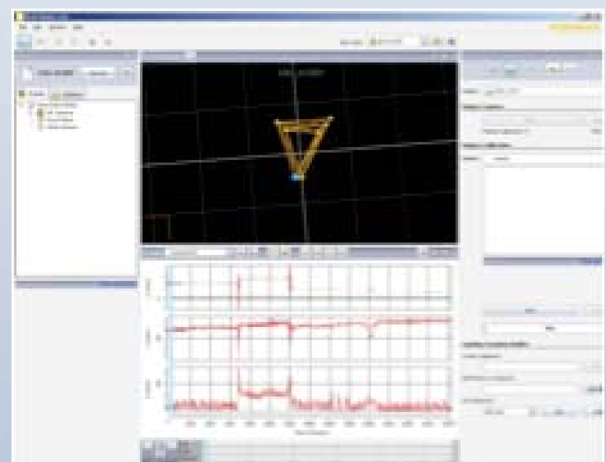
Attenuation
Compton Scatter
Distance dependent resolution
Motion
Mess with the quantitative and spatial accuracy of the data

SPECT

List and Frame mode acquisitions

Brightview (Philips, Cleveland, OH)

VTS: employing near infrared cameras from Vicon Motion Systems Inc. (Lake Forest, CA)

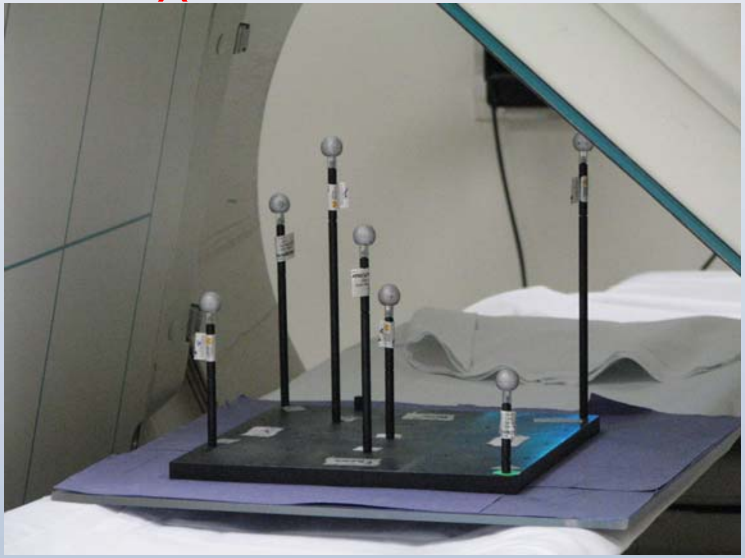


VTS: Calibration

1.

2.

3.



1. Waving wand with 3 retro-reflective spheres in known geometry, Vicon software select a camera as origin
2. Drive origin into SPECT space using L-Frame with 3 retro-reflective spheres in known geometry
3. Acquire 7 retro-reflective sphere-phantom with embedded Co-57 point sources to accurately align geometries

Rigid Body and Respiratory Motion Processing

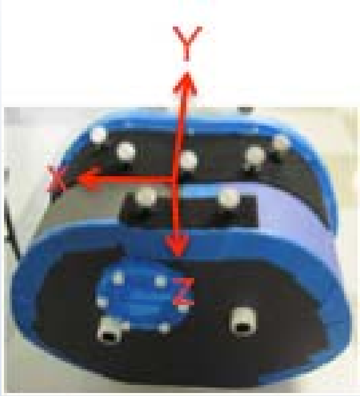
- Bin SPECT list mode data into either:
  - 100 millisecond (msec) projection bins for respiratory motion estimation, or
  - k projection bins (~6 sec) for sub-projection motion estimation.
- Synchronize VTS and SPECT using a square wave signal inserted into the list mode data.
- Down sample VTS (100 msec) and remove measurements occurring during gantry rotation.
- Separate respiratory and rigid body motion signals.
- Estimate motion for rigid body component for sub-, and full projections (chest markers).
- Determine local maximums and minimums of respiratory signal of the abdominal markers and using a gray scale histogram technique to discard ~5% on both sides (minimum and maximum).
- Bin 100 msec SPECT projection bins into N odd amplitude projection bins, with bin size determined from previous step.

Phantom Acquisition Protocol Rigid Body Motion Evaluation

- The heart and liver were filled with Tc-99m concentrations of 2:1
- Acquire a baseline frame mode SPECT, followed by a list mode SPECT with and without induced motion
- Use the clinical acquisition parameters, acquiring through 204 degrees, in 3 degree steps
- Beacon transmission (Philips, Cleveland, OH) done after baseline

Rigid Body Motion Introduced

- Transmission/Emission mismatch and rotation around the X-axis.



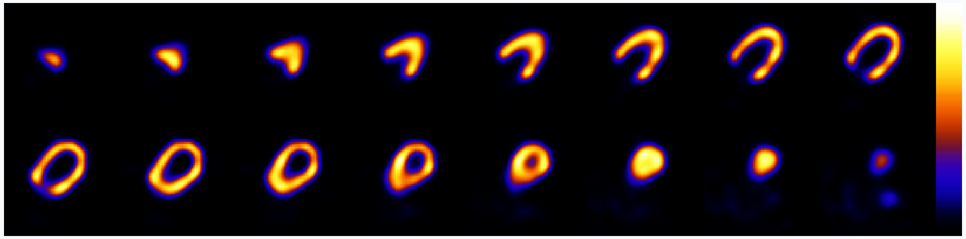
- Translation in Z.
- Rotation around the Y-axis.
- Rotation around the X-axis.
- 3 Complete acquisitions without motion, but in different rotational states (0, 9.3, 17.7 degrees in X). Mix and match to create different 'within projection motion' acquisitions.

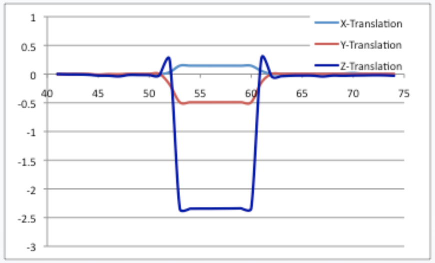
Processing

- Estimate rigid body motion (3DOF, 6DOF) using full- and sub-projections.
- Reconstruct using 5 iterations of OSEM, 17 subsets, 4 projections per subset, 4 sequential sub-projections when necessary.
- Same as above, without sub-projections.
- Evaluate:
  - visually,
  - location shift in center of heart counts, and
  - polar map quantification.

Within Projection Motion: Two-Steps

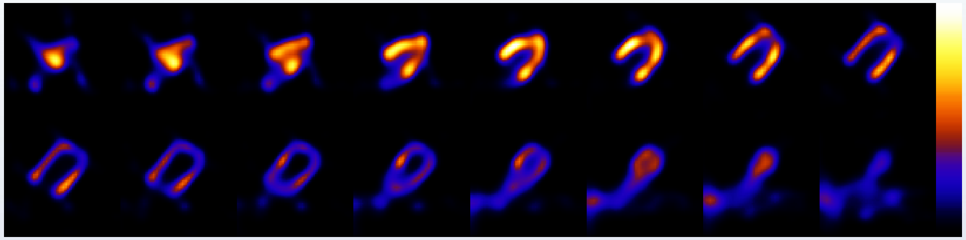
Baseline



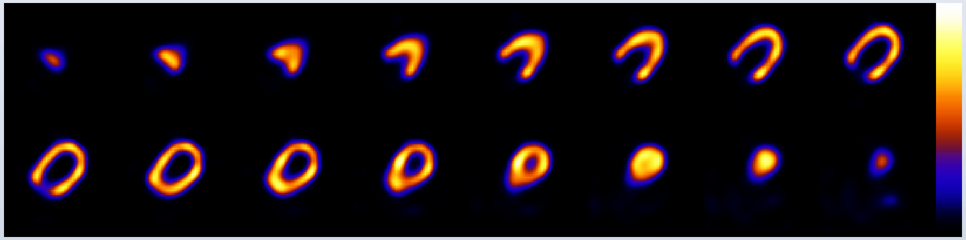


proj involved
~6.0%

No Motion
Compensation

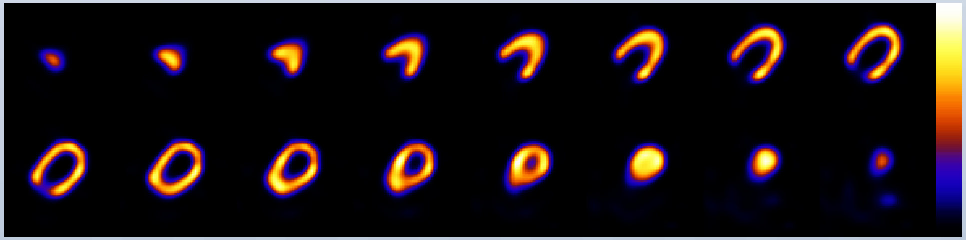


Full Projections



Sub-optimal filtering done to enhance differences:
3D Gaussian, sigma=0.5

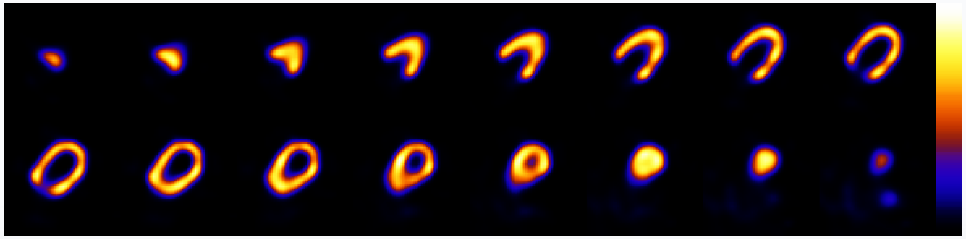
Sub Projections
when necessary

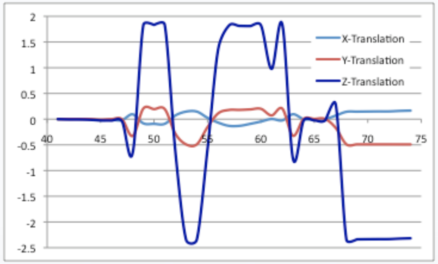


Exact same slices displayed

Within Projection Motion: Six-Steps

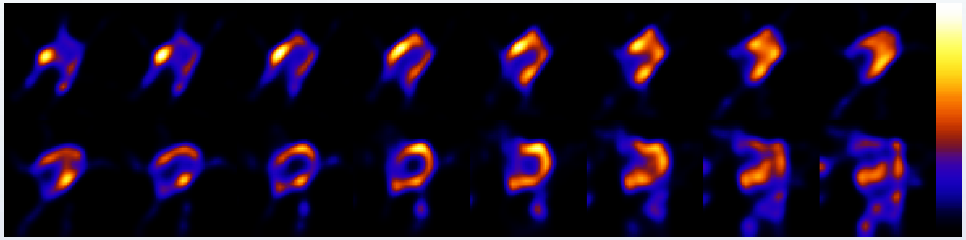
Baseline



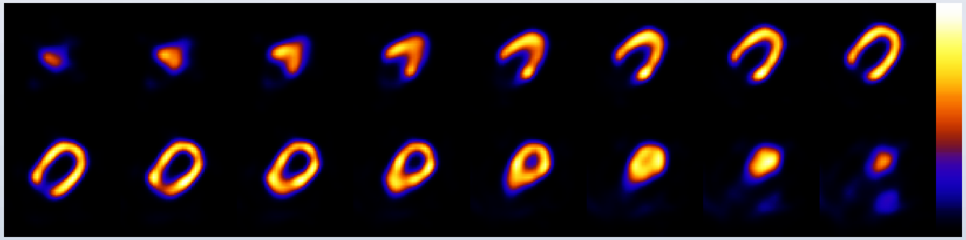


proj involved ~18%

No Motion Compensation

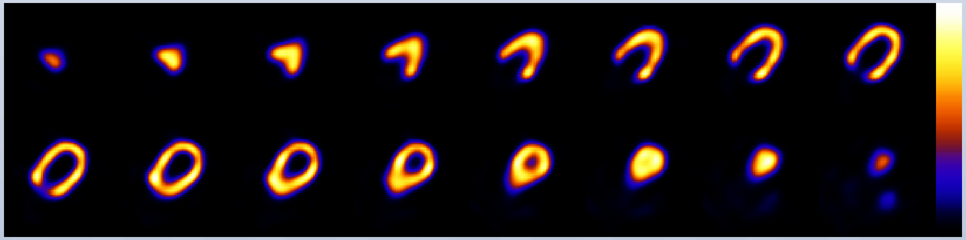


Full Projections



Sub-optimal filtering done to enhance differences: 3D Gaussian, sigma=0.5

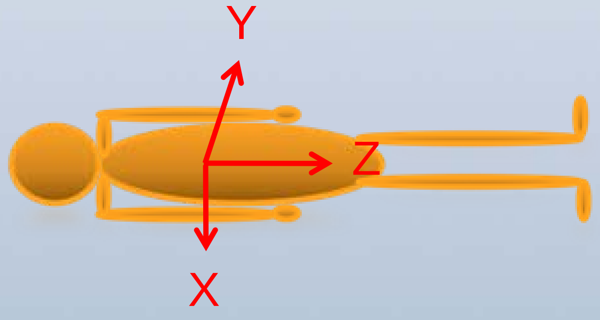
Sub Projections when necessary



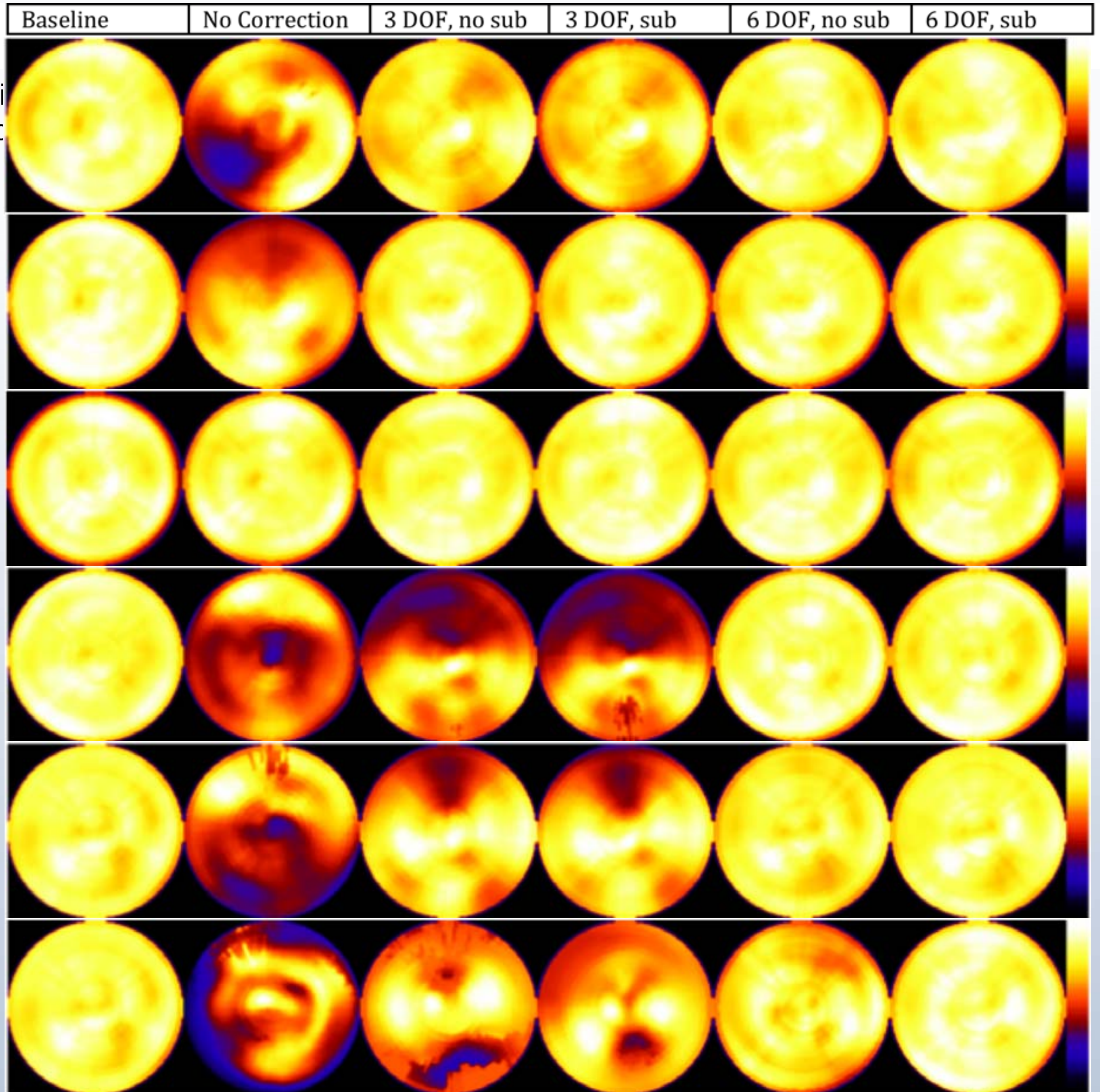
Exact same slices displayed

Location Shift in Center of Heart Counts Compared to Baseline

Motion scenario	No Correction (cm)			3 DOF (cm)			6 DOF (cm)		
	x	y	z	x	y	z	x	y	z
Transmission/Emission mismatch, x-rotation	-0.79	-1.90	-4.54	-0.50	-0.99	2.46	0.04	-0.10	-0.21
Z-translation	0.22	-0.15	-1.05	0.02	-0.11	-0.22	0.03	-0.10	-0.24
Y-rotation	-0.42	-0.04	0.07	0.10	-0.08	-0.32	0.09	-0.00	-0.28
X-rotation	-0.32	0.79	0.15	0.11	0.29	-0.90	0.00	-0.02	-0.32
6% projections corrupted	-0.39	0.52	0.63	-0.01	0.20	-0.42	0.01	0.01	-0.06
18% projections corrupted	0.05	0.78	1.08	0.14	0.45	-0.32	-0.01	0.04	-0.05



Polar Map Evaluation



Transmission/Emissi n mismatch, x-rotatic	X: 0.5 cm Y: 1.5 cm Z: 3.5 cm	X: 14.0 deg Y: -5.5 deg
Z-Translation	Z: 1.3 cm	X: 1.0 deg Y: 0.4 deg
Y-Rotation	X: 0.6 cm Z: 0.8 cm	Y: 7.5 deg
X-Rotation	Y: 2.4 cm Z: 2.9 cm	X: 14.5 deg Z: -1.3 deg
6% of projections Corrupted	Y: 0.5 cm Z:- 2.3 cm	X: 9.5 deg Z: -0.9 deg
18% of projections Corrupted	Z: 1.7 cm to – 2.1 cm	X: -11 deg to 8.5 deg

Concluding Remarks, Rigid Body Motion Compensation

- 6DOF compensation for rigid body motion using SVD is robust.
- 3DOF compensation fails when significant rotational motion is present.
- Sub-projection reconstruction improve imaging when a significant percentage of projections are involved.

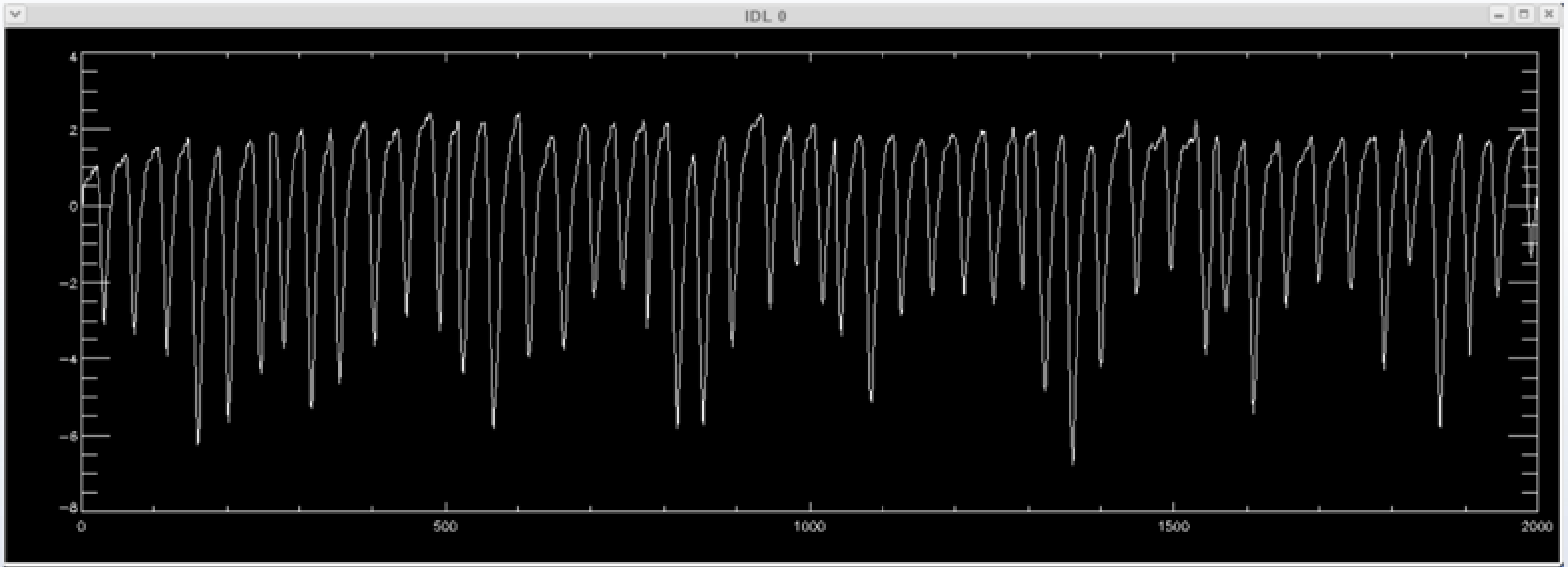
Rigid Body and Respiratory Motion Processing

- Bin SPECT list mode data into either:
  - 100 millisecond (msec) projection bins for respiratory motion estimation, or
  - k projection bins (~6 sec) for sub-projection motion estimation.
- Synchronize VTS and SPECT using a square wave signal inserted into the list mode data.
- Down sample VTS (100 msec) and remove measurements occurring during gantry rotation.
- Separate respiratory and rigid body motion signals.
- Estimate motion for rigid body component for sub-, and full projections (chest markers).
- Determine local maximums and minimums of respiratory signal of the abdominal markers and using a gray scale histogram technique to discard ~5% on both sides (minimum and maximum).
- Bin 100 msec SPECT projection bins into N odd amplitude projection bins, with bin size determined from previous step.

Respiratory Signal

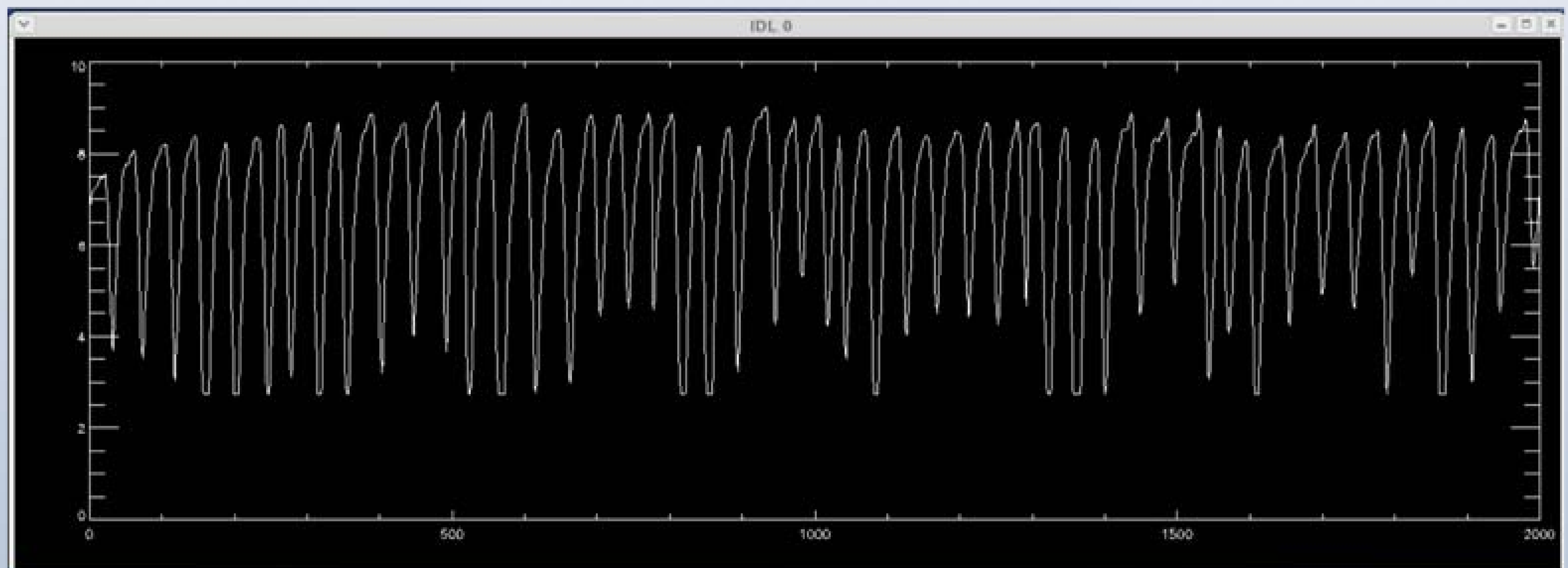
End Expiration

End Inspiration

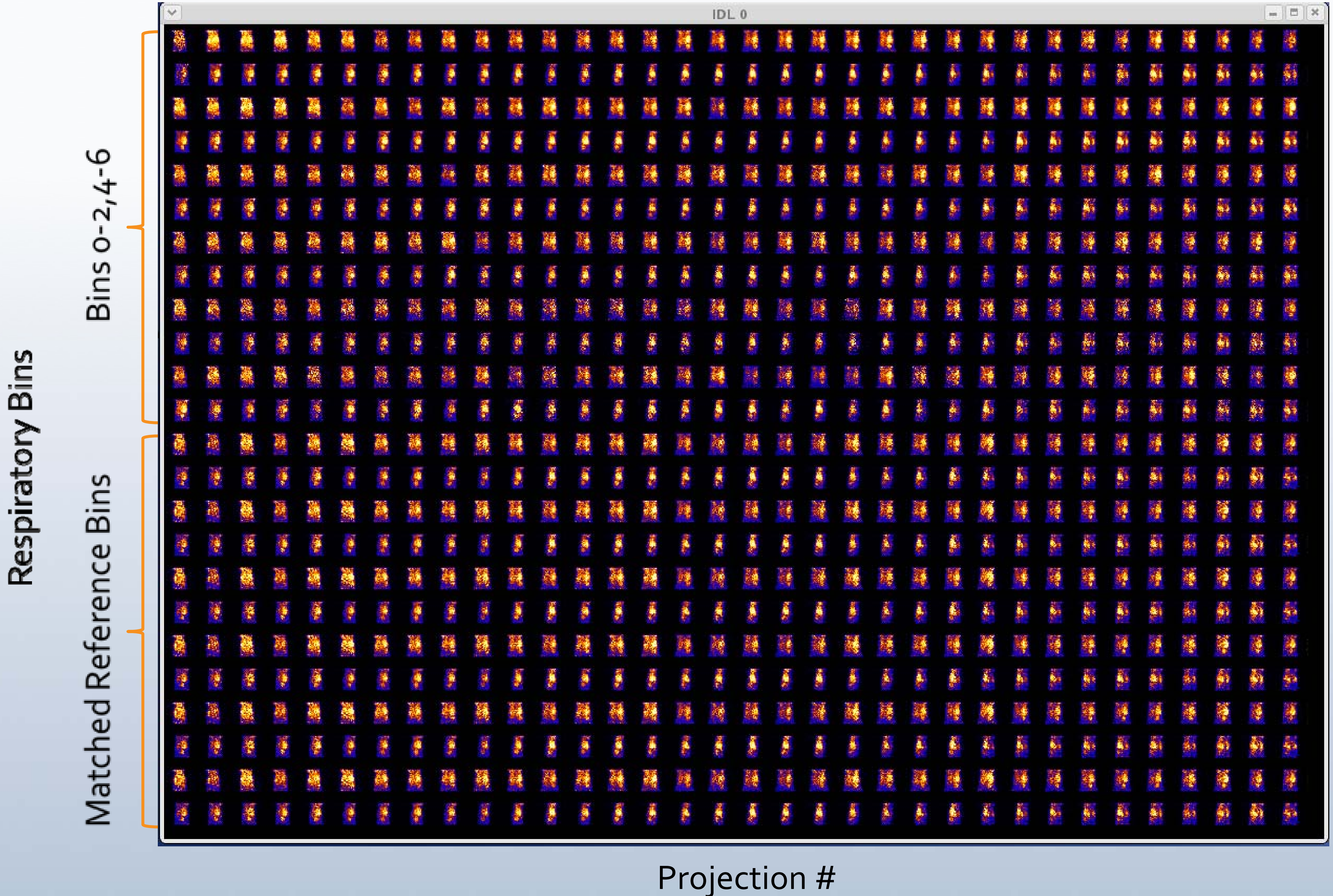


End Expiration

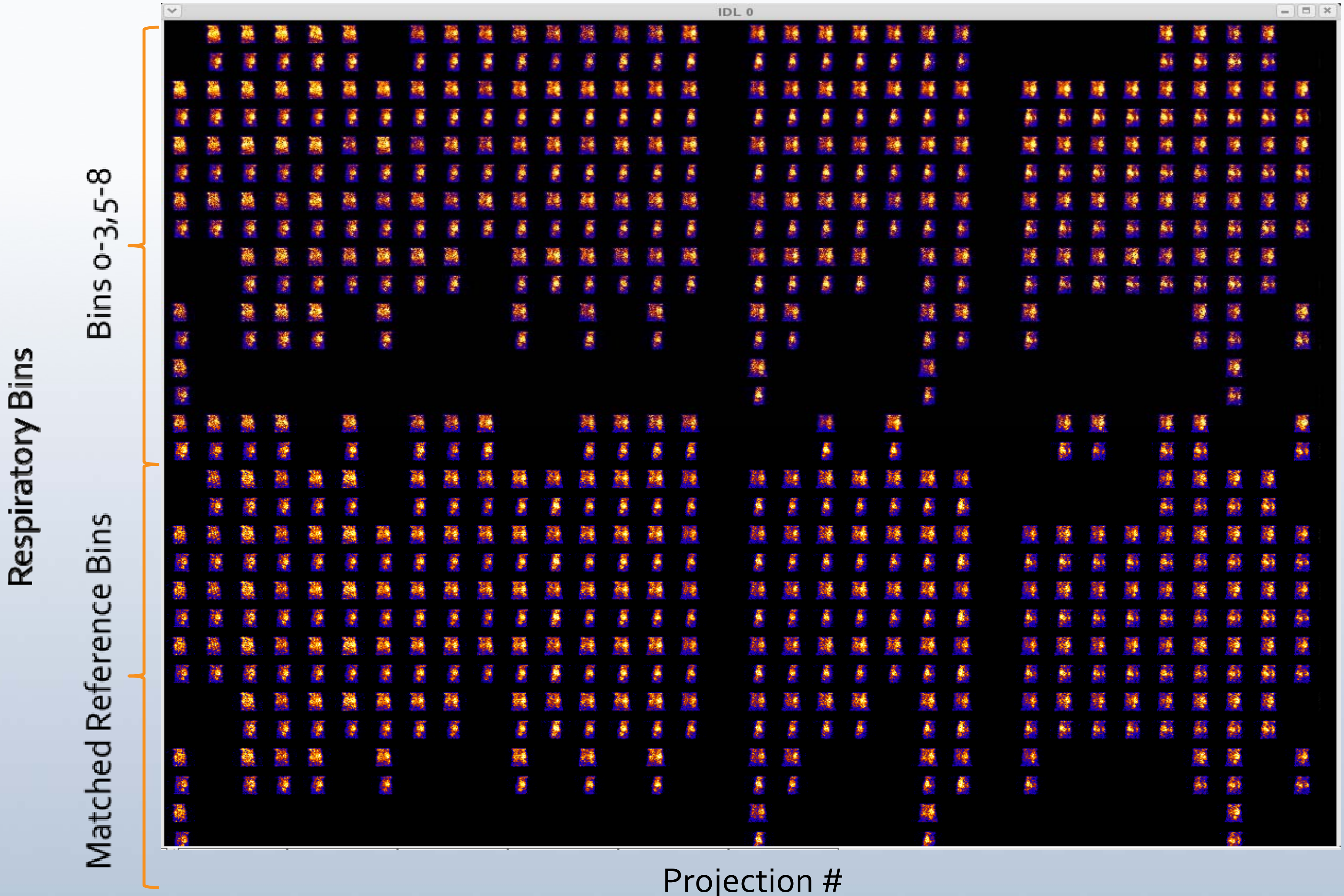
End Inspiration



Respiratory Binned SPECT (Example 1)



Respiratory Binned SPECT (Example 2)



Respiratory Motion Estimation and Reconstruction

- Select and scale data for estimation using a percentage of an ideal number of respiratory frames per projection angle.
- Reconstruct with rigid body motion compensation using OSEM with 17 projection/subset.
- Apply mask to the reference reconstructed bin and crop data.
- Estimate 6DOF using an intensity based method.
- Combine rigid body and respiratory motion.
- Sequentially reconstruct respiratory amplitude bins using the total counts in each full projection angle to calculate weights for combining bins appropriately

Dey et. al., Med. Phys. 37,6453-6465, 2010

Anthropomorphic Phantom Acquisition

- The heart and liver was filled with a 2:1 concentration of Tc-99m and two sets of SPECT data of the phantom were acquired.

- Each set of SPECT data consisted of a rest-perfusion baseline frame-mode emission acquisition, a Beacon (Philips, Cleveland, OH) transmission acquisition, and a list-mode emission acquisition.

- Respiratory motion was simulated during the list-mode acquisitions using the Quasar (Modus Medical Devices Inc. ON, Canada).

- Rigid-body motion was introduced in one of the two list-mode acquisitions by rotating the phantom around the x-axis and translating the phantom in x, y, and z. The same clinical acquisition protocol as described before was used.

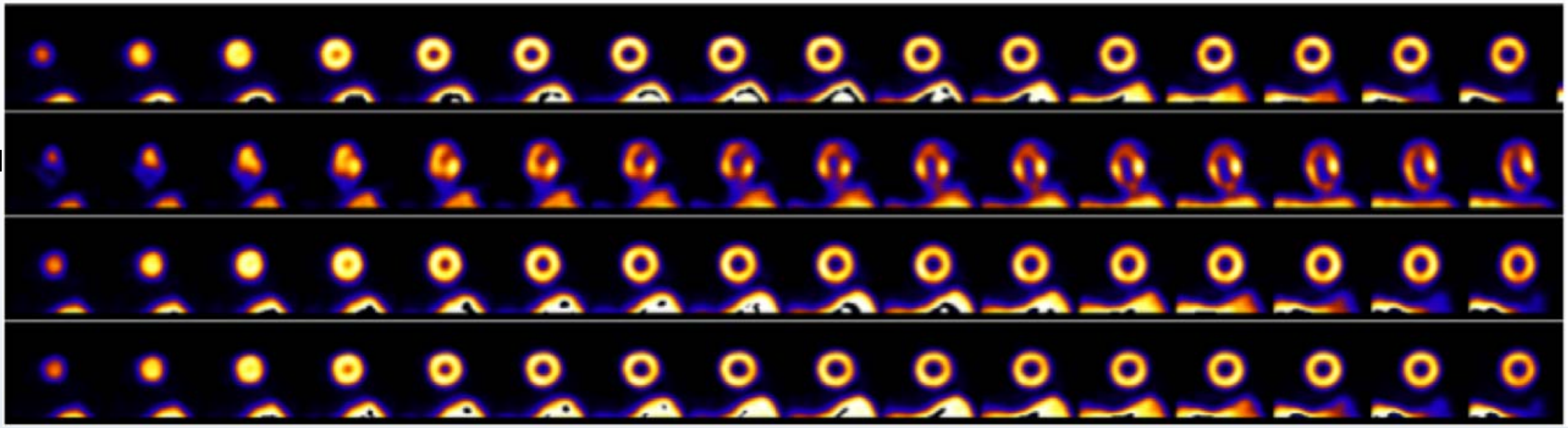
Anthropomorphic Phantom Results

Baseline

Uncorrected

Rigid body

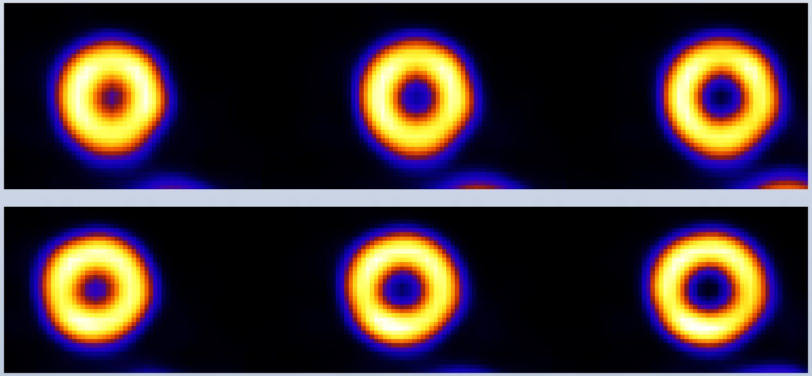
Rigid body
+
Respiratory



1. 1.6 cm respiratory motion, estimated as 1.43 cm.
2. Maximum x, y, z displacement of 1.0 cm, 1.2 cm, and -0.7 cm respectively.
3. ~8.4 and ~2.2 degrees of rotation about the x and y axes respectively.

Rigid body

Rigid body
+
Respiratory

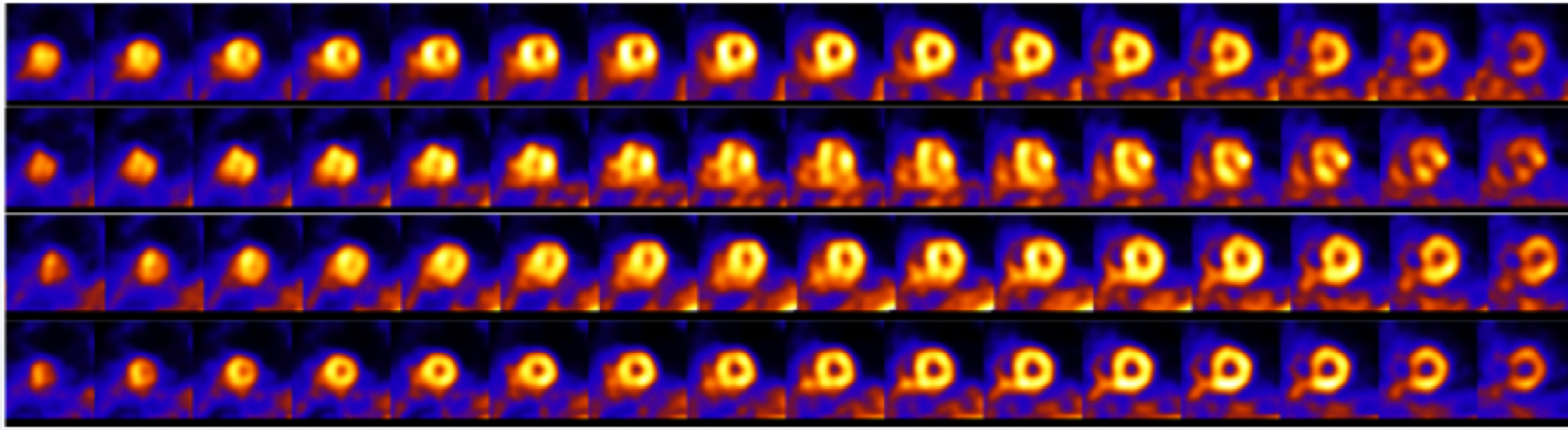


Patient Acquisitions

- Patient volunteers with written consent (n=25) were asked to execute some predefined body motion during a list-mode second rest perfusion acquisition, as part of their regular rest perfusion portion of a stress-rest perfusion exam.
- The regular rest perfusion studies were used as a baseline to compare rigid body motion compensation against.
- The majority of these patients underwent a same day stress-rest Tl-201 exam (n=24) (One same day stress-rest Tc-99m Mibi).
- The acquisition was done using the standard clinical protocol with 68 projections acquired through 204 degrees employing two heads of the IRIX scintillation camera with 3-degree steps during emission acquisition with pixel size of 0.4669 cm and a 128x128 matrix. Transmission acquisitions were acquired through 264 degrees in 6-degree steps.

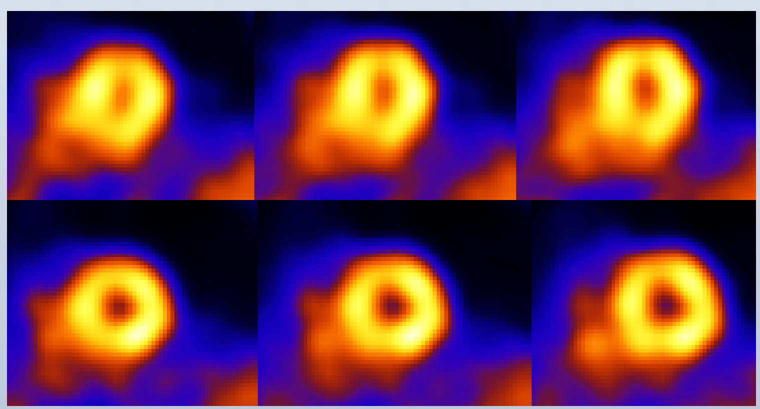
Patient Results (Example 1)

Baseline
Uncorrected
Rigid body
Rigid body + Respiratory



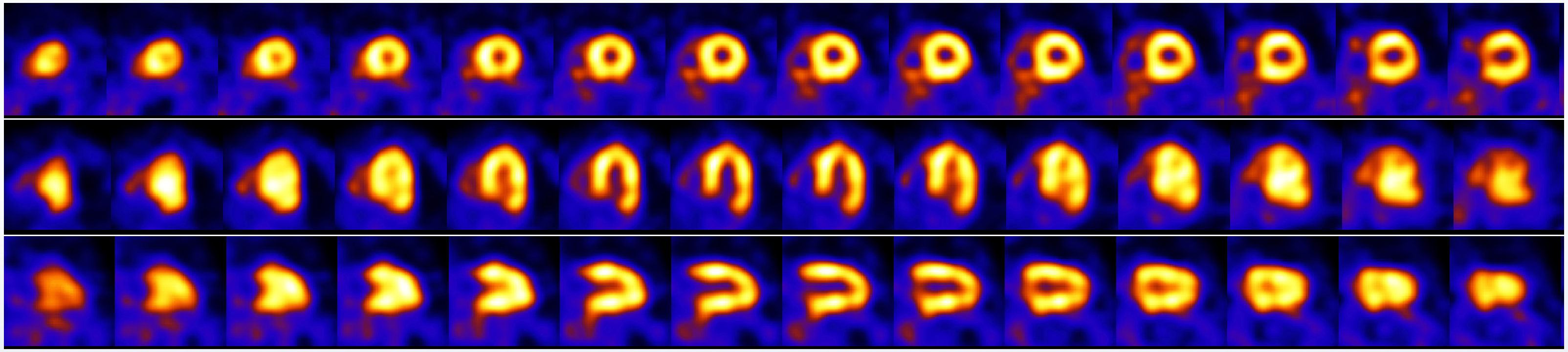
1. Male patient volunteer.
2. Estimated 1.9 cm respiratory motion.
3. Maximum x, y, z displacement of -1.4 cm, 1.4 cm, and 3.5 cm respectively.
4. ~7.2 and ~5.1 degrees of rotation about the x and y axes respectively.

Rigid body
Rigid body + Respiratory

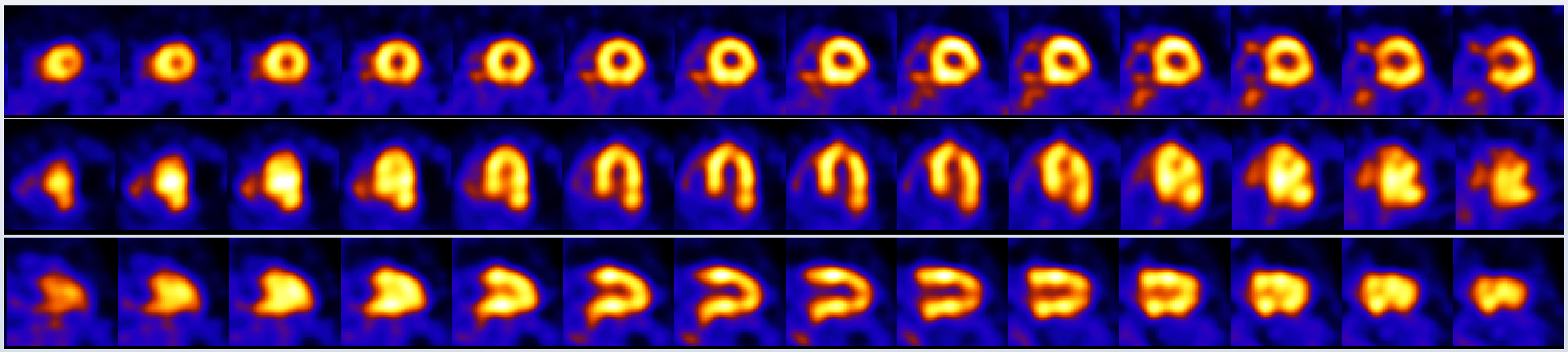


Patient Results (Example 2)

Rigid body

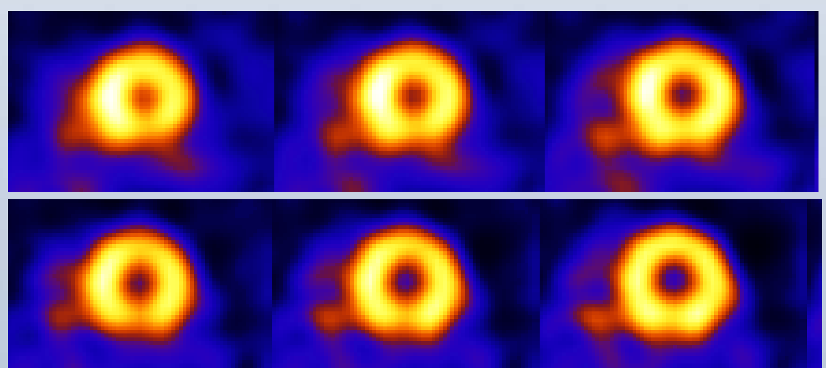


Rigid body
+
Respiratory



Rigid body

Rigid body
+
Respiratory



3.0 cm Z, 0.8 cm respiratory motion

Concluding Remarks, Combined Compensation

- It is evident that combined rigid body and respiratory motion compensation improves the visual impression.
- For some of the patient volunteers the combined compensation seems better than the first rest baseline.
- As expected, the respiratory motion estimates vary greatly between patients, with a minimum of ~0.4 cm and a maximum of 1.9 cm.
- In 4 of the 25 patients, respiratory motion estimation and compensation degraded the visual impression. All these were identified as having some visualization issue with the retro-reflective abdominal markers.