Phantom Evaluation of C-SPECT Performance for Myocardial Perfusion Imaging

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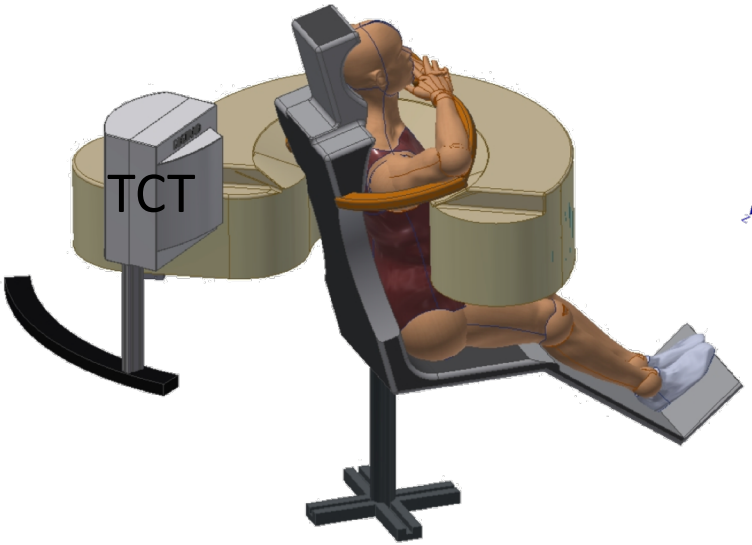
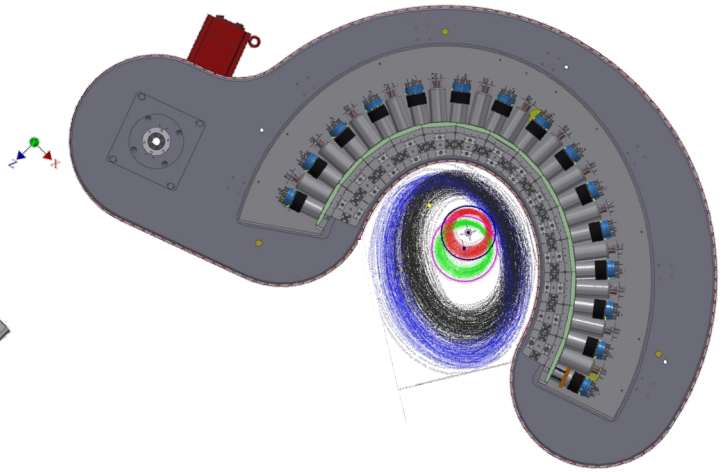
C-SPECT Concept

- Dedicated cardiac SPECT imager.
- Obtains complete sampling over the heart without patient or scanner motion: dynamic imaging.





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- Dedicated cardiac SPECT imager.
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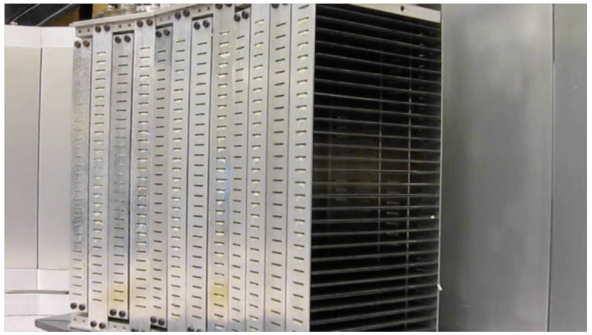
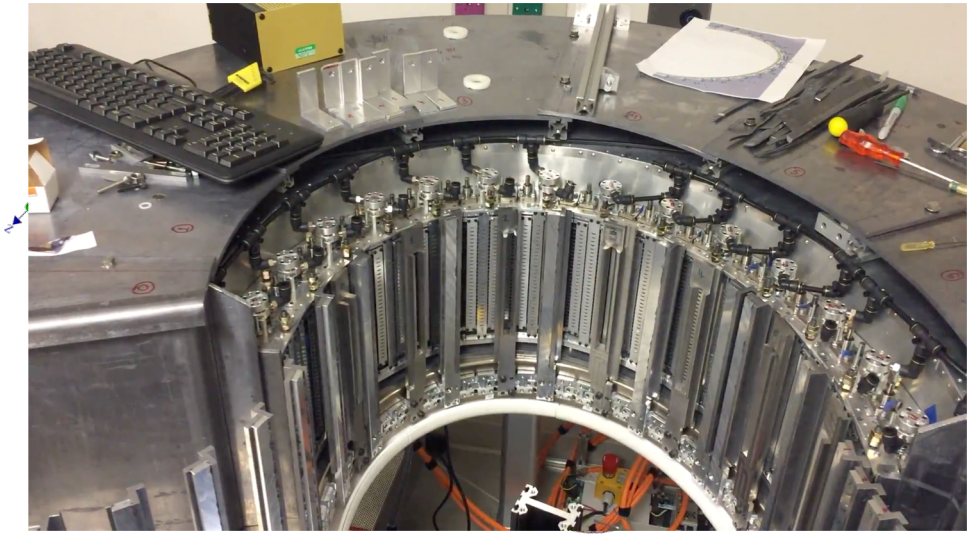
- Adaptive: different resolution-sensitivity-FOV tradeoff points based on slit-slat collimation.
- Can perform large FOV or cardio-focal imaging.





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C-SPECT Concept

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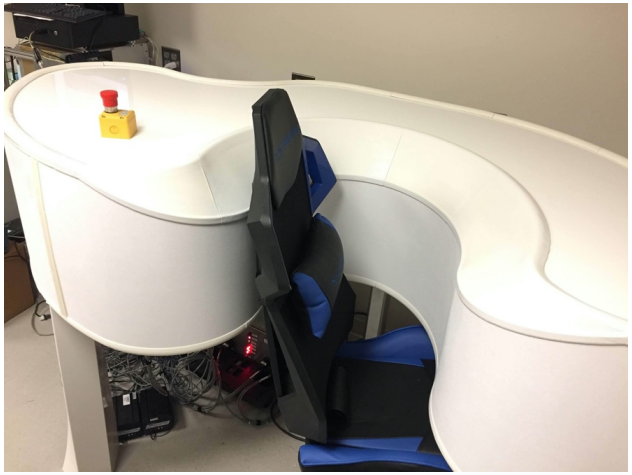
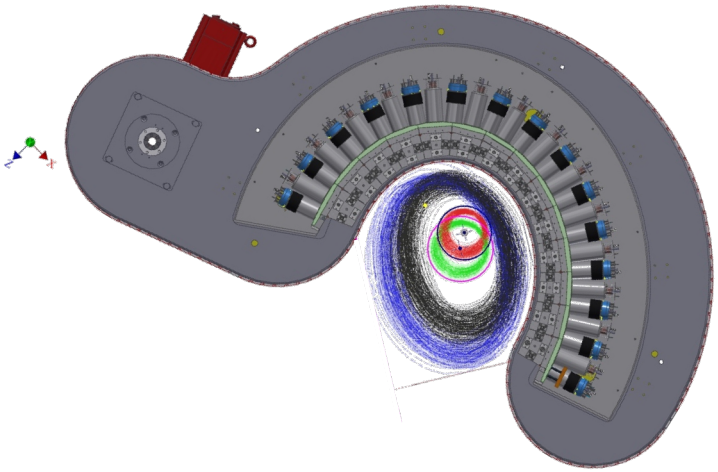
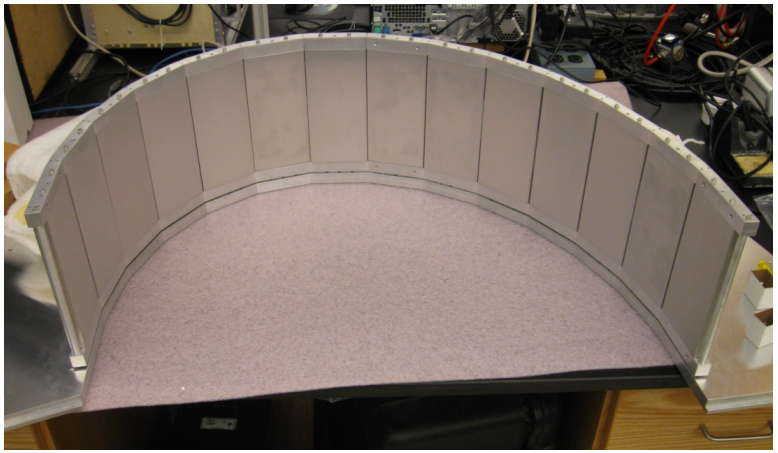
- Adaptive: different resolution-sensitivity-FOV tradeoff points based on slit-slat collimation.
- Can perform large FOV or cardio-focal imaging.
- Optimized for performance based on a set of clinical cardiac SPECT patients.
- Integrated transmission source

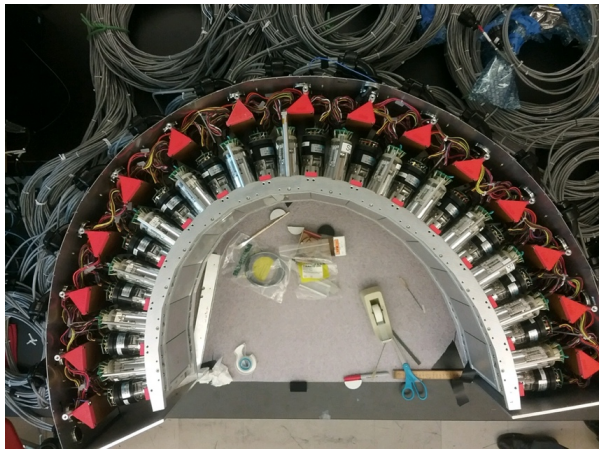




Detector System I

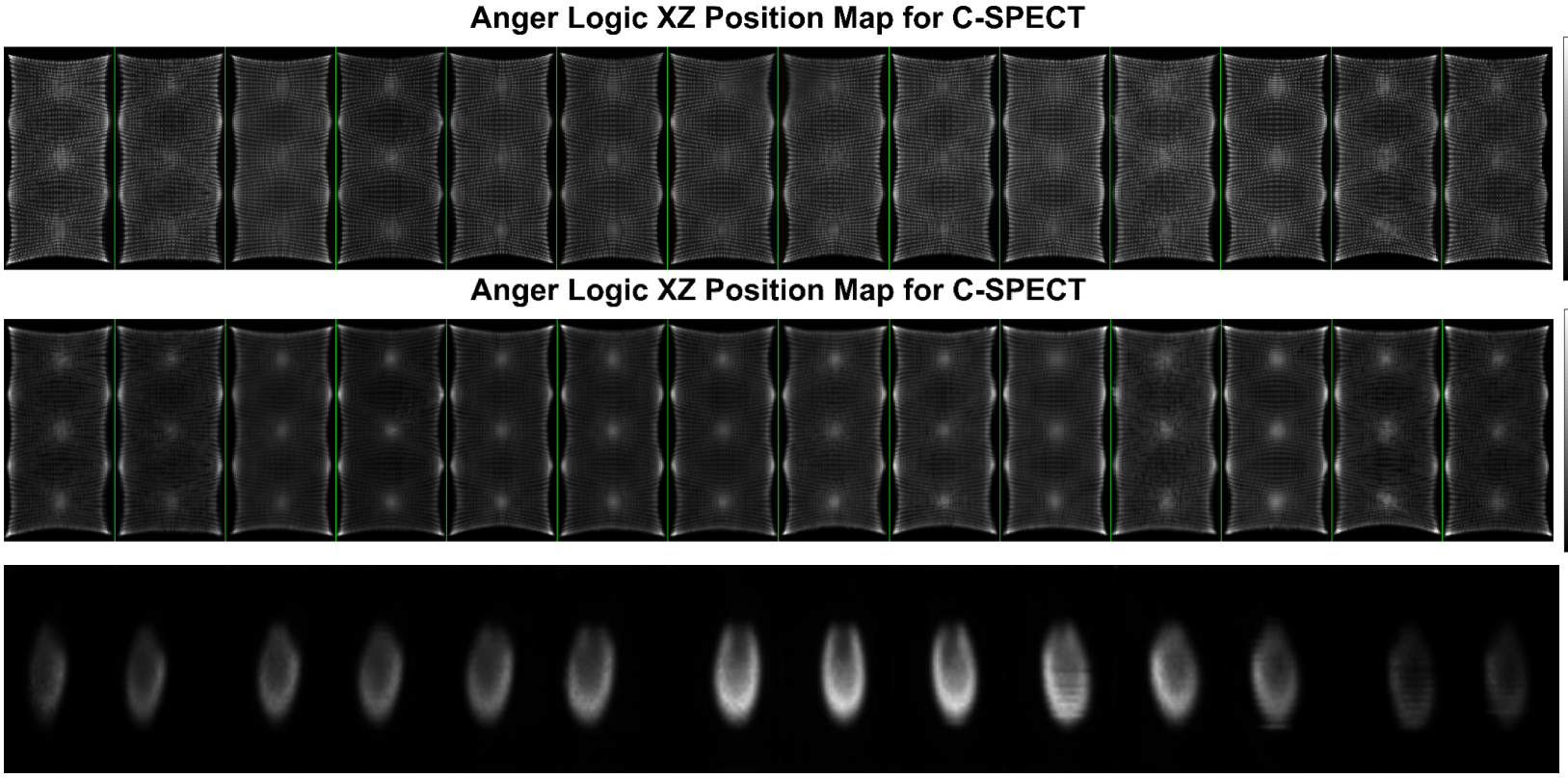
- 14 Modules of Pixelated NaI(Tl) with 2.5 x 3.0 (axial) mm pitch
- 5 central PMTs per module, with 4 on each transverse edge
- Edge PMTs are shared across modules





Detector System II

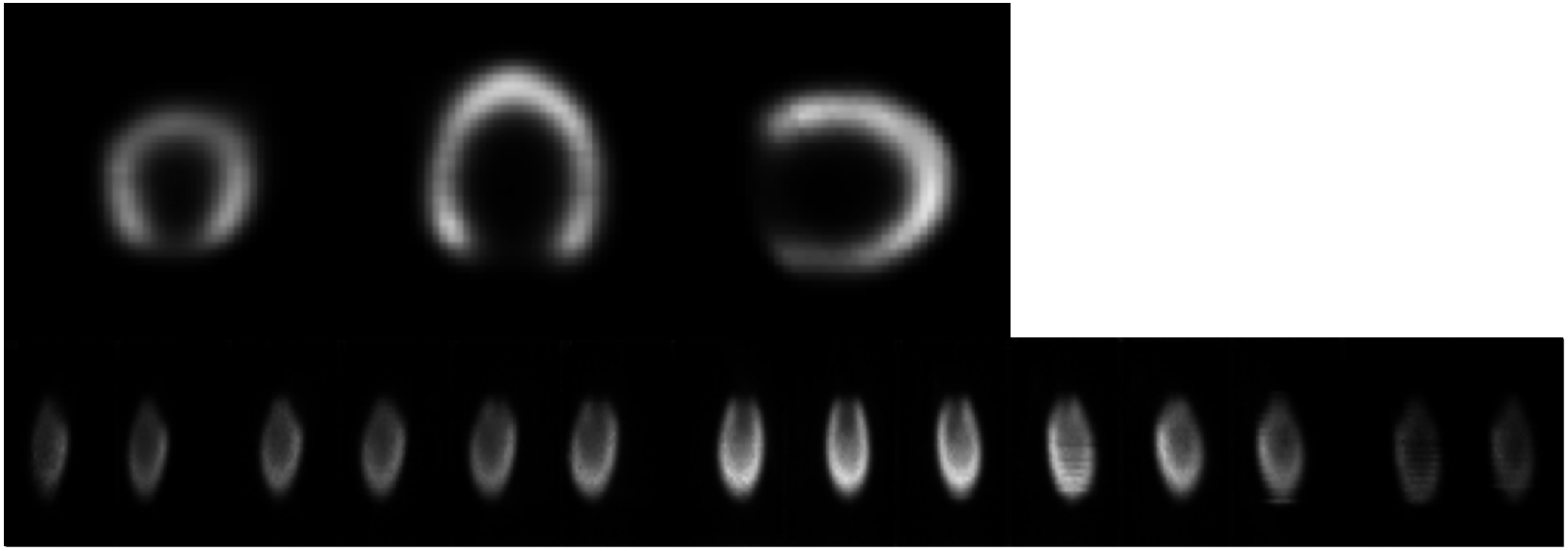
^{22}Na used for pixel ID due to higher light output



Beating Heart Phantom

Purpose of This Study

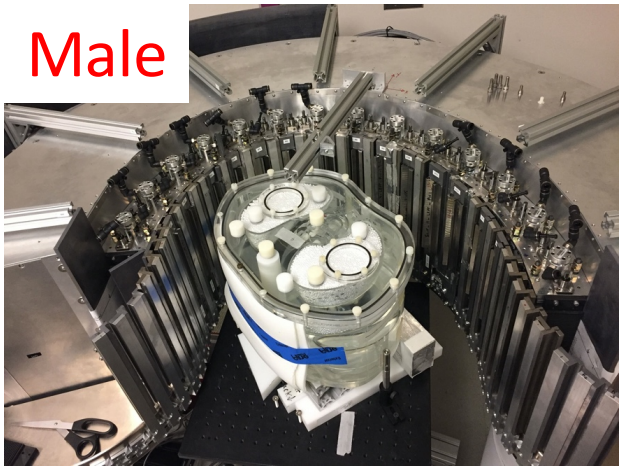
- Quantitative evaluation of C-SPECT performance for static imaging
- We will use the area under the Receiver Operating Characteristic (ROC) curve as our metric

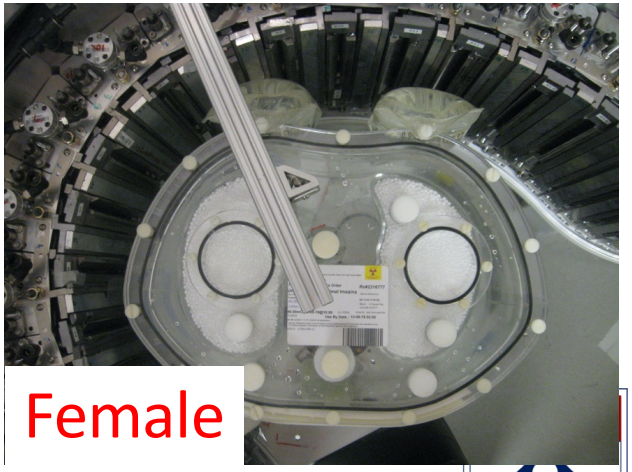


Data Acquisition I

- Anthropomorphic phantom (Data Spectrum) in male and female configurations.
- Acquired with no cardiac insert.
- Lung:Background:Liver = 0.77:1.0:3.4.
- Breast emission data were acquired separately utilizing two 500 ml saline bags.

Male

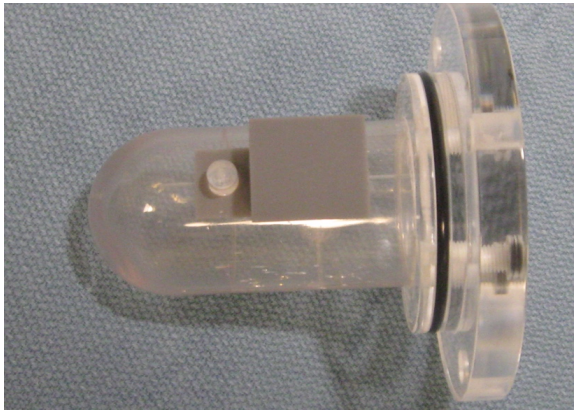


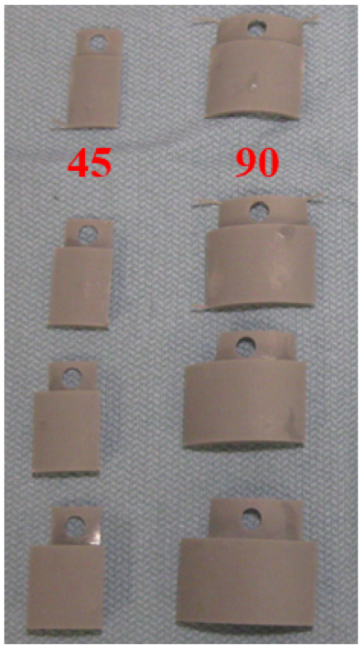


Female

Data Acquisition II

- Myocardium insert acquired in the cold torso phantom with water for attenuation and scatter
- Acquired with no defect
- Acquired with defects of different sizes and locations
  - Anterior, lateral, inferior, and septal
  - 45° and 90° azimuthal extent
  - 50%, 75%, and 100% wall thickness





Data Processing and Reconstruction

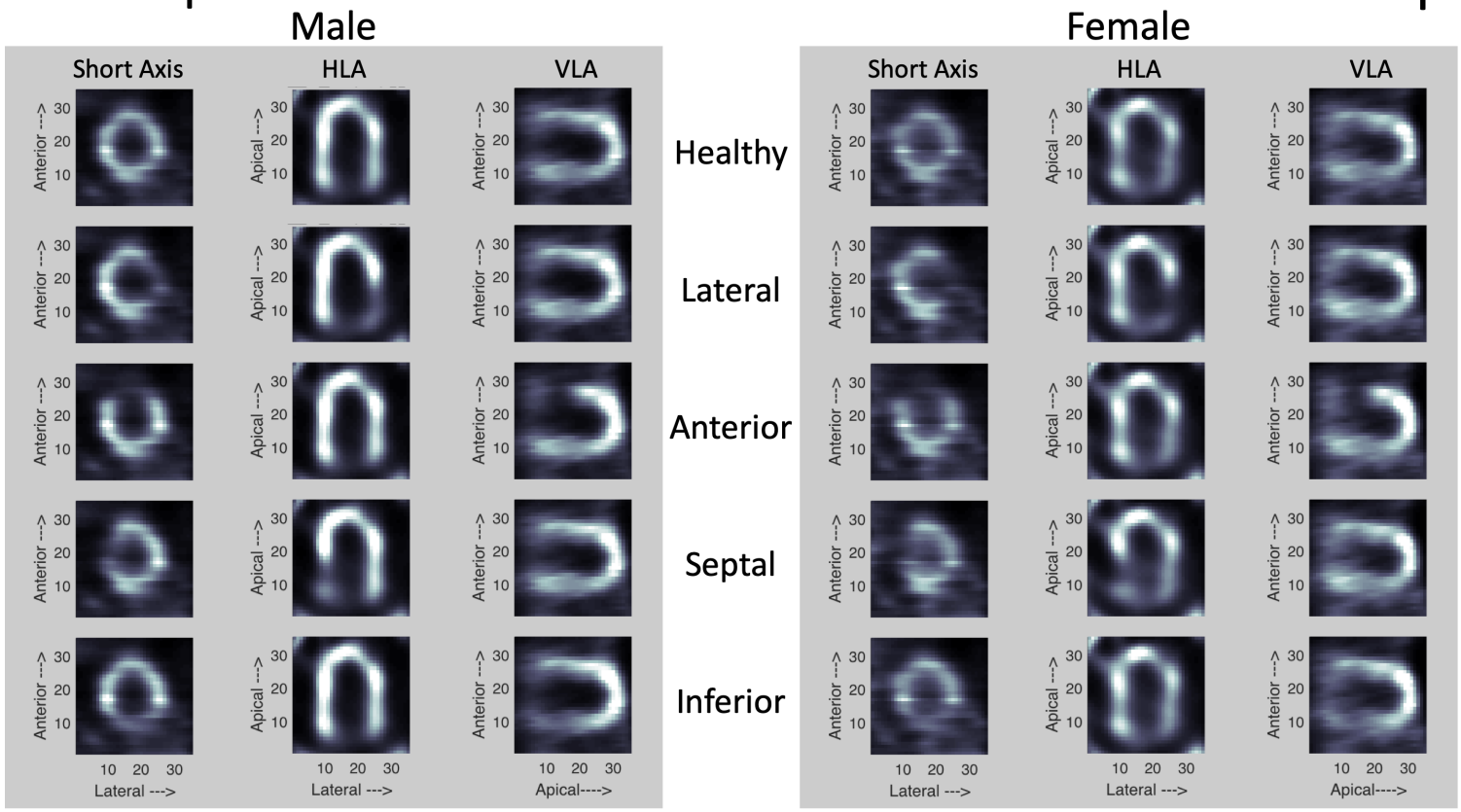
- High-count data sets were created by mixing data from each torso configuration with each of the 25 cardiac configurations such that the myocardial concentration was 6.9x background.
- Breast-emission data was scaled to be background level.
- Ensembles were created by sampling the high-count data from each torso configuration (male and female) with each of the 25 cardiac configurations and sampling to create 2-, 5-, and 10-minute acquisitions with 10 sets for each lesion configuration and 40 sets for each healthy configuration.
- All reconstructions used 25 iterations with Triple Energy Window (TEW) scatter correction, but no attenuation correction.
- The Receiver Operating Characteristic (ROC) Curve was generated and the area under the curve was determined.

Data Set Sizes

	Bkg. Scan	Healthy Myocardium	Breast	High-Count Healthy	2 Min Scan	5 Min Scan	10 Min Scan
Male	219 M	101 M		245 M	2.9 M	7.2 M	14.4 M
Female	166 M	97 M	171 M	209 M	2.9 M	7.3 M	14.5

For the 10-minute male sets, each photon was used about 2.4x.
For the 10-minute female sets, each photon was used about 2.8x.

Example Reconstructions for 2-Minute Acquisitions



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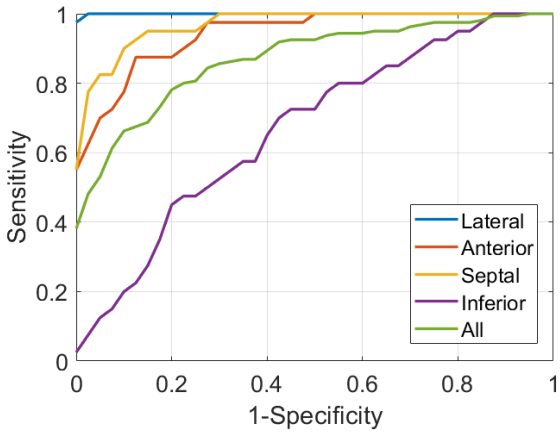
ROC Curve Generation

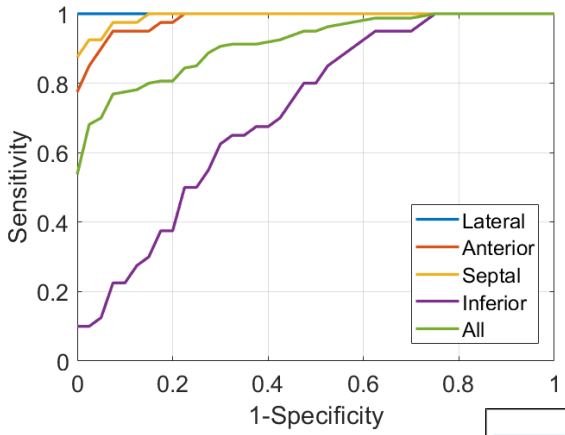
- For each lesion ensemble, there is a corresponding healthy ensemble
- We apply an overall myocardial ROI to each data set to extract the voxels within the ROIs.
- The voxels values are converted to normalized standard deviations for each set. That is, they are self-normalizing.
- Two variables are considered:
  - *Ts*: the threshold below which a voxel is considered to be part of the cold lesion.
  - *Tv*: the volume threshold (i.e., # of voxels) for a data set to be labeled positive.
- These variables were varied to find the maximum sensitivity (% true positives) at a given specificity (% true negatives).

ROC Curves (Male, 2 minutes)

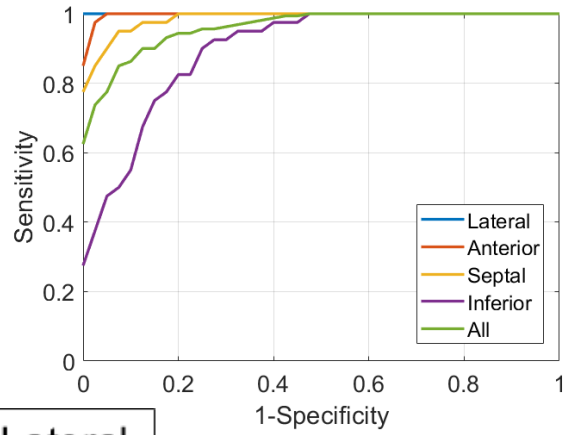
50% transmural, 45°



75% transmural, 45°



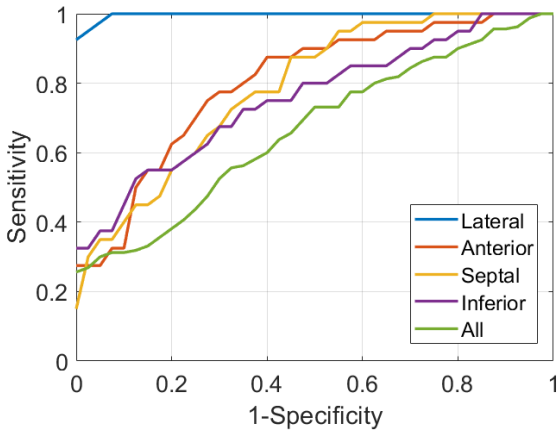
100% transmural, 45°



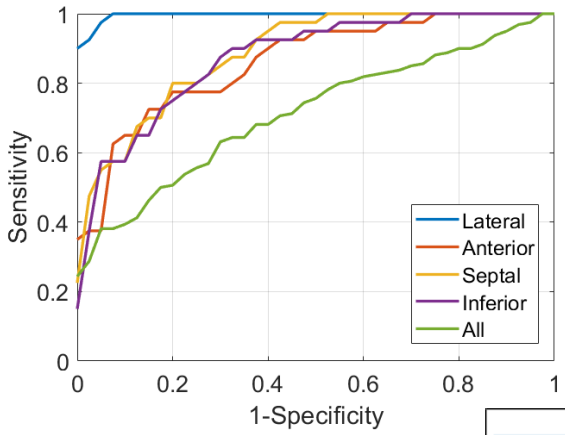
Similar shapes between the curves, but the area increases with increasing lesion extent.

ROC Curves (Female, 2 minutes)

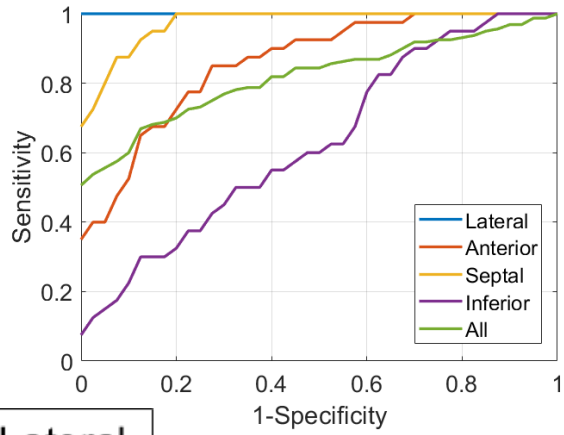
50% transmural, 45°



75% transmural, 45°

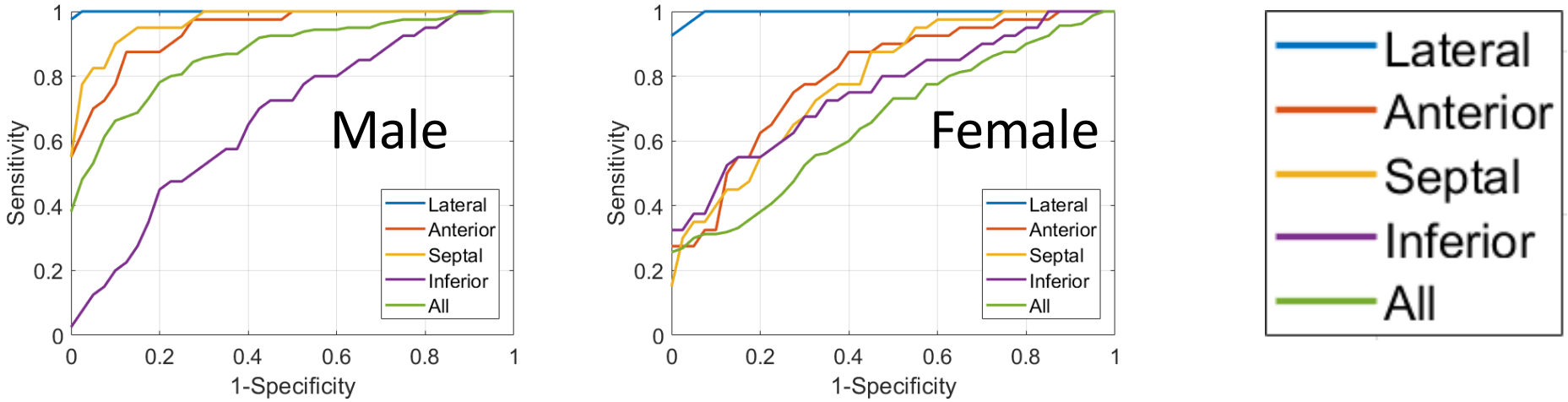


100% transmural, 45°



Similar shapes between the curves, but the area increases with increasing lesion extent.

ROC Curves (2 minutes, 50% transmural, 45°)



- In both cases, the lateral is relatively easy to identify.
- The inferior case, which is typically the most challenging in men, is similar between the two phantoms.
- The anterior and septal cases in the female phantom are degraded compared to the corresponding curves in the male phantom.

Areas Under the ROC Curves

10-Minute Scans

Male

Extent	50%		75%		100%	
Width	**45°**	**90°**	**45°**	**90°**	**45°**	**90°**
Lateral	1.00	1.00	1.00	1.00	1.00	1.00
Anterior	1.00	1.00	1.00	1.00	1.00	1.00
Septal	1.00	1.00	1.00	1.00	1.00	1.00
Inferior	0.82	1.00	0.91	1.00	1.00	1.00
All	0.92	1.00	0.98	1.00	1.00	1.00

Female

Extent	50%		75%		100%	
Width	**45°**	**90°**	**45°**	**90°**	**45°**	**90°**
Lateral	1.00	1.00	1.00	1.00	1.00	1.00
Anterior	0.93	1.00	1.00	1.00	0.99	1.00
Septal	0.97	1.00	0.99	1.00	1.00	1.00
Inferior	0.65	0.99	0.98	1.00	0.72	1.00
All	0.68	0.99	0.73	1.00	0.87	1.00

All boxes less than 90% are highlighted.

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Areas Under the ROC Curves

5-Minute Scans

Male

Extent	50%		75%		100%	
Width	**45°**	**90°**	**45°**	**90°**	**45°**	**90°**
Lateral	1.00	1.00	1.00	1.00	1.00	1.00
Anterior	1.00	1.00	1.00	1.00	1.00	1.00
Septal	1.00	1.00	1.00	1.00	1.00	1.00
Inferior	0.65	0.96	0.92	1.00	1.00	1.00
All	0.88	0.99	0.98	1.00	1.00	1.00

Female

Extent	50%		75%		100%	
Width	**45°**	**90°**	**45°**	**90°**	**45°**	**90°**
Lateral	1.00	1.00	1.00	1.00	1.00	1.00
Anterior	0.76	1.00	0.98	1.00	0.98	0.97
Septal	0.94	1.00	0.97	1.00	1.00	1.00
Inferior	0.64	0.91	0.86	1.00	0.75	1.00
All	0.62	0.95	0.74	1.00	0.82	0.97

All boxes less than 90% are highlighted.

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Areas Under the ROC Curves

2-Minute Scans

Male

Extent	50%		75%		100%	
Width	**45º**	**90º**	**45º**	**90º**	**45º**	**90º**
Lateral	1.00	1.00	1.00	1.00	1.00	1.00
Anterior	0.94	1.00	0.98	1.00	1.00	1.00
Septal	0.97	1.00	0.99	1.00	0.99	0.99
Inferior	0.67	0.84	0.72	1.00	0.90	1.00
All	0.87	0.96	0.92	1.00	0.96	0.99

Female

Extent	50%		75%		100%	
Width	**45º**	**90º**	**45º**	**90º**	**45º**	**90º**
Lateral	1.00	1.00	1.00	1.00	1.00	1.00
Anterior	0.80	1.00	0.86	1.00	0.86	0.96
Septal	0.79	1.00	0.89	0.99	0.97	1.00
Inferior	0.76	0.93	0.87	0.92	0.63	1.00
All	0.66	0.95	0.71	0.98	0.82	0.94

All boxes less than 90% are highlighted.

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Discussion

- The reconstructed images show the ability to resolve lesions in all four quadrants even though the 3D printed lesions were smaller than those typically used.
- Numerical evaluation with a simple observer shows that with a 10-minute scan both male and female phantoms have AUC close to 100% except for the inferior wall and the small lesion.
- With a 2-minute scan, the AUC in the inferior wall degrades for males. All female lesion locations degrade except for lateral. In is notable that C-SPECT seems to be more sensitive to azimuthal size than transmural extent.
- In the context of this study, the female phantom is more attenuating than the male since the same torso was used with additional breast attenuation. In the clinic, the female patients' torsos would be relatively smaller.

Conclusions

- C-SPECT can successfully identify cardiac lesions in a range of locations in as little as a few minutes with well over 90% AUC for the male phantom and the smallest lesion (50% transmural and 45° azimuthal) except in the inferior wall. In the inferior wall, the AUC is sensitive to transmural and azimuthal extent.
- In the female phantom, the AUC performance is degraded in the anterior, septal, and inferior walls compared to the male phantom for 2-minute scans. The AUC appears to be more sensitive to azimuthal than transmural extent.

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