Automated Phantom Analysis for Gamma Cameras - An Efficient, Accessible, Consistent, and Sensitive Method for Quality Control

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Disclosures and Disclaimers

Funding for this project was provided by Atirix Medical Systems

- Atirix sells the QC-Track® system for imaging QC
- All analysis was performed in QC-Track®

Contributors:

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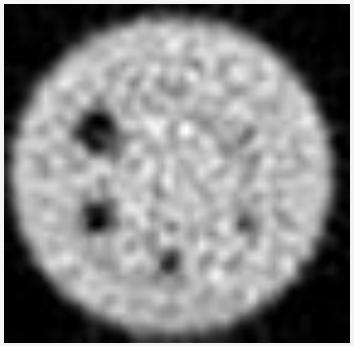
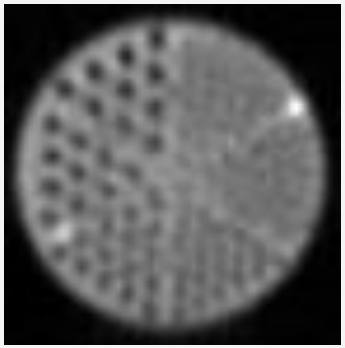
Why strive for excellence in Quality Control?

- Maintain high quality images
  - Better diagnostic capabilities
  - Better patient care
- Higher sensitivity to system degradation
  - Catch system failures early
  - Reduce imaging downtime
- ACR/TJC/State Regulation compliance
- Trend towards stricter QC requirements for all modalities
  - Stay ahead of the curve

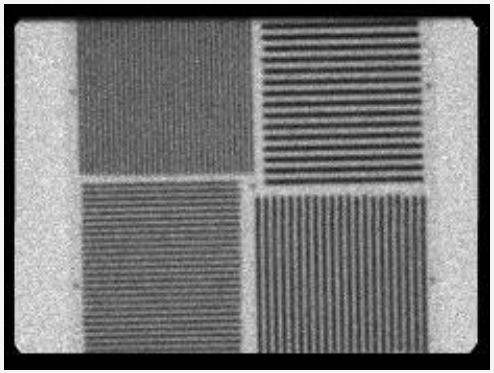
Clinical Nuc Med QC Methods

- Most hospitals and clinics
  - Visual assessment of image quality
  - Discrete levels of assessment
  - Subject to individual bias and inconsistencies



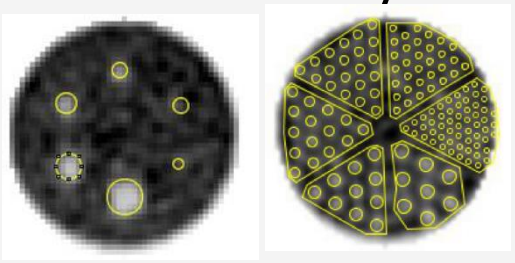


- Research/academic environments
  - Quantitative analysis in ImageJ, MATLAB, or in-house software
  - Larger image acquisition matrix (longer scan time, more disk space) sometimes required

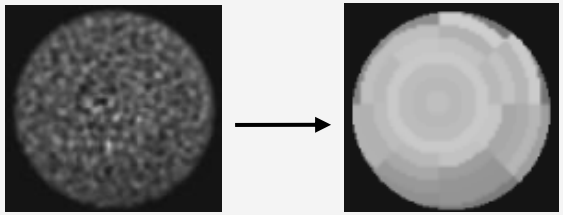


Existing methods for Quantitative Phantom Analysis

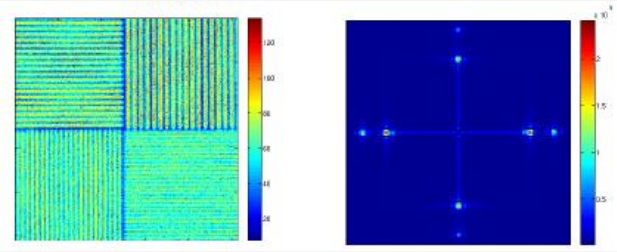
- Hirtl et. al. – ImageJ plugin
  - Spheres and rods (contrast)
  - Uniformity (Hough transform)
- Madsen
  - Uniformity analysis (annular sampling)
- Nijs et. al. – MATLAB scripts
  - Bar phantom (Fourier analysis)
- DiFilippo
  - ROC curve (rods), SNR, noise texture



Hirtl. et al. Med Phys. 44 (5), May 2017



Madsen. Med Phys. 24 (11), Nov 1997



De Nijs et. al. J Phys. Conf. Ser. 317 (1) , Sept 2011

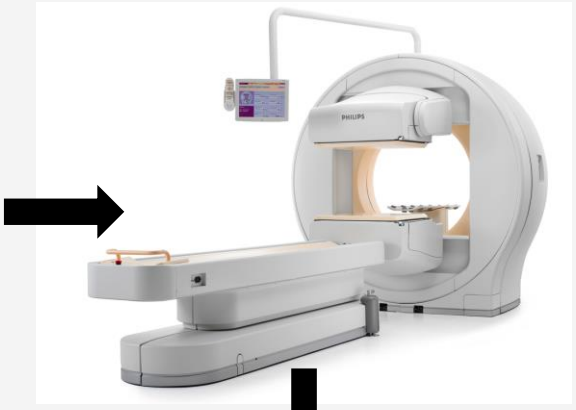
Main drawbacks: computationally expensive and complex methods, ImageJ/MATLAB workflow unlikely in clinical setting

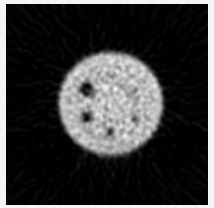
Objective

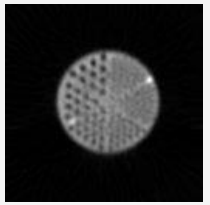
- Provide method that exceeds visual analysis
- Sensitive and objective
  - Simple computations
- Focus on areas where automation is limited clinically
  - ACR/Jaszczak Phantom
  - Bar phantoms
- Easily accessible to clinics (technologists)
- Incorporate into QC-Track, a centralized database for QC
- Simple QC workflow = less downtime

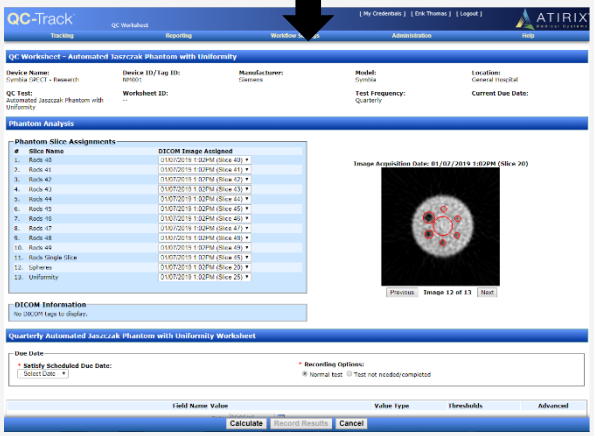
Clinical Workflow

- Acquire Images using Standard QC protocols
- ‘For presentation’ images uploaded to QC-Track via DICOM send
  - ROIs drawn and calculations performed automatically
- Results stored in a database on a local (on-site) network server
- For research purposes, results were exported from QC-Track and analyzed in Excel





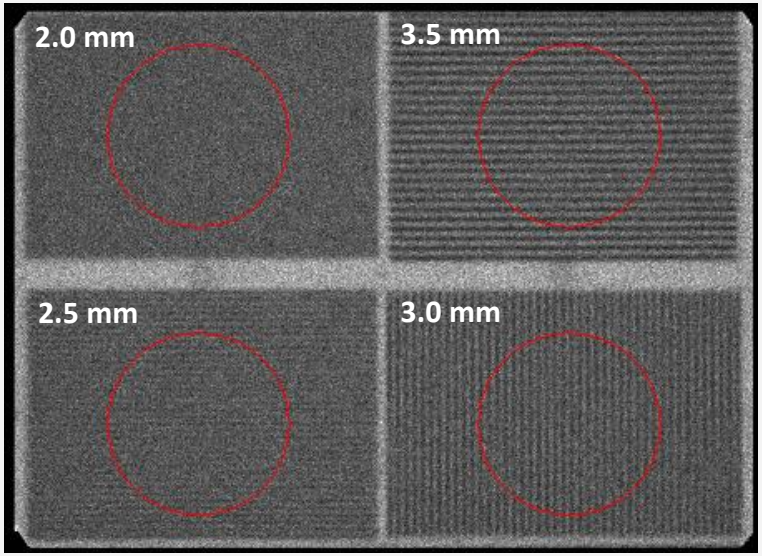




Four-Quadrant Bar Phantom

- Goal: assess the spatial resolution of a planar gamma camera scan by determining “smallest spacing without aliasing”

- Automated Method:
  - Software places circular ROIs in each quadrant based on phantom center
  - Calculates standard-deviation based modulation transfer function (MTF) as described by Hander et. al.

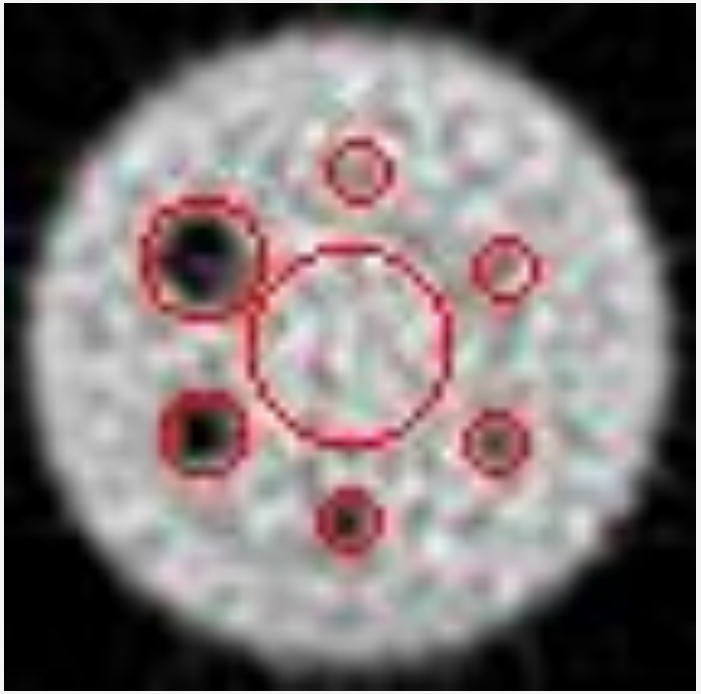


Hander TA et. al. An improved method for rapid objective measurement of gamma camera resolution. Med Phys. 2000; 27:2688:2692.

Jaszczak Phantom Spheres Section

- Goal: assess the contrast of a SPECT scan by determining "limiting observable sphere"

- Automated Method:
  - Software places circular ROIs around each sphere
  - Calculates contrast-to-noise ratio (CNR) for each sphere

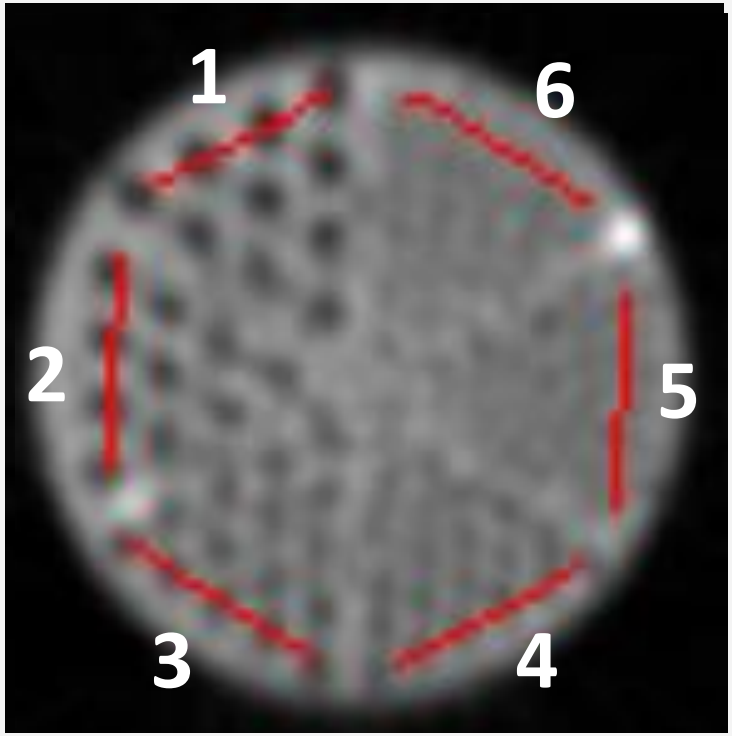


Method adapted from AAPM Report 52: Quantitation of SPECT Performance. Med Phys. 22 (4), April 1995

Jaszczak Phantom Rods Section

- Goal: assess the spatial resolution of a SPECT scan by determining "limiting set of rods"

- Automated Method:
  - Software automatically places line ROIs on each rods section
  - Calculates basic modulation using pixel values within line ROI



Jaszczak Phantom Uniformity Section

- Goal: assess the uniformity of a SPECT scan

- Automated Method:
  - Compare mean counts in top, right, bottom, and left ROIs to mean counts within center ROI
  - Similar to Daily GE Water phantom and CATPHAN Module 486 (CT)

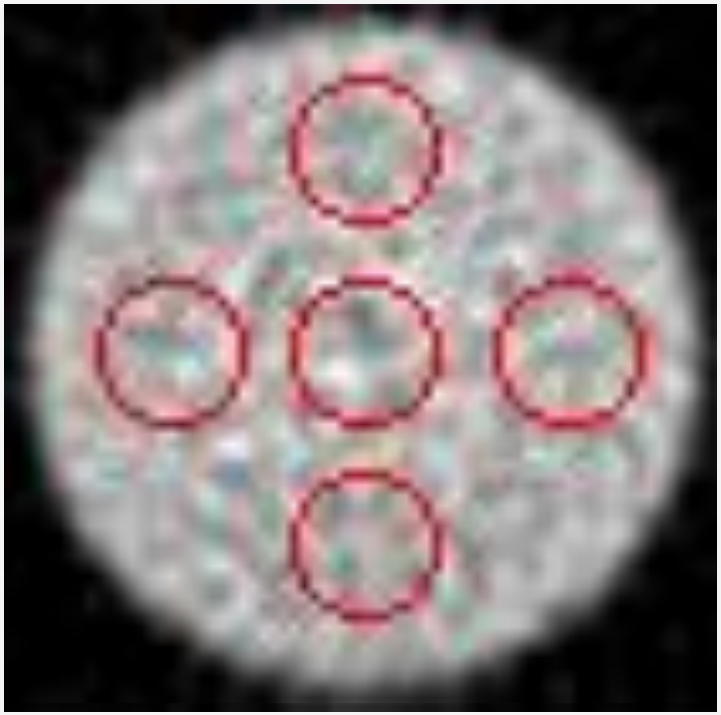
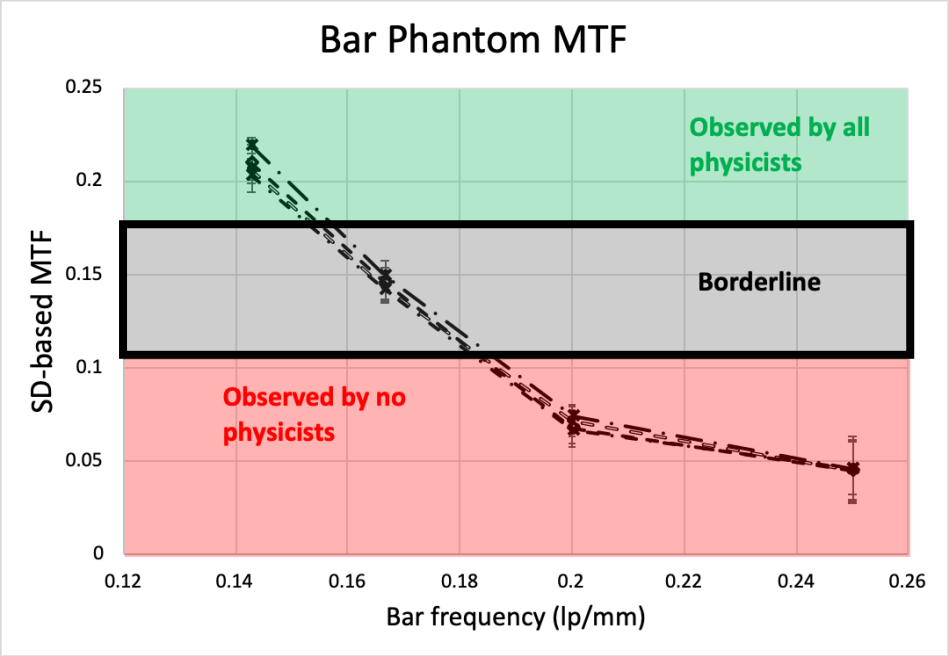


Image Acquisition and Study Details

- Imaging units
  - 3 SPECT units
    - 1 Older model
  - 1 SPECT/CT unit
- Images
  - Analyzed previously captured images to build phantoms and worksheets within QC-Track
  - After clinical implementation, acquired data over 6-7 months using standard ACR, vendor, or physicist protocols
  - Bar phantom – weekly (200+ images over 4 imaging units)
  - Jaszczak phantom – quarterly (8+ images over 4 imaging units)

Four-Quadrant Bar Phantom Results

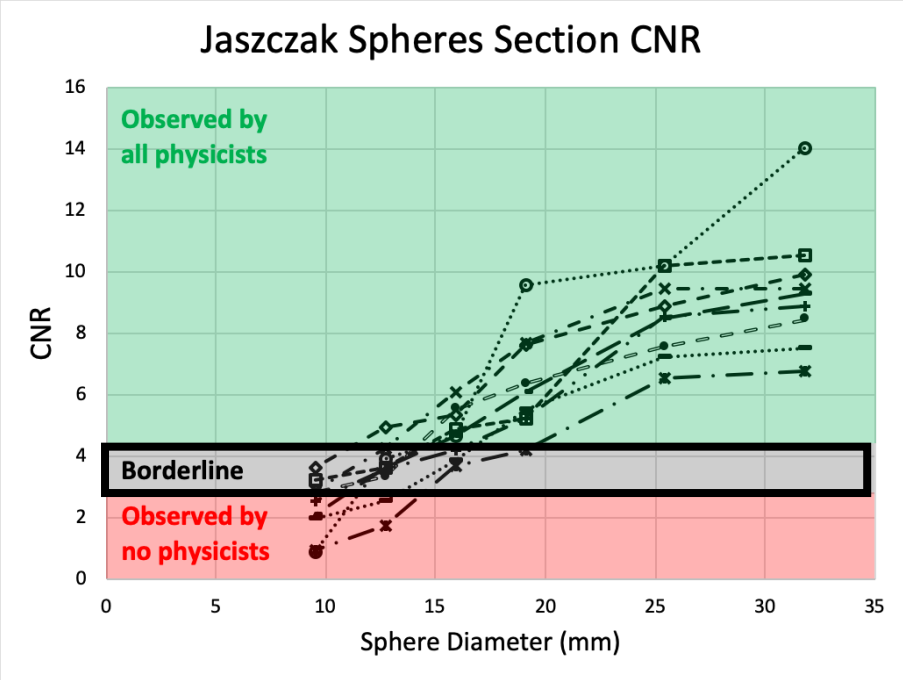
- Analysis of roughly 40 acquisitions each over 4 scanners
- MTF values for each bar width show consistency over many acquisitions
- Physicists visual assessment showed disagreement
  - borderline region between 0.1-0.18 MTF
- Interpolation of curve allows for more continuous assessment of image quality



Jaszczak Phantom Spheres Section Results

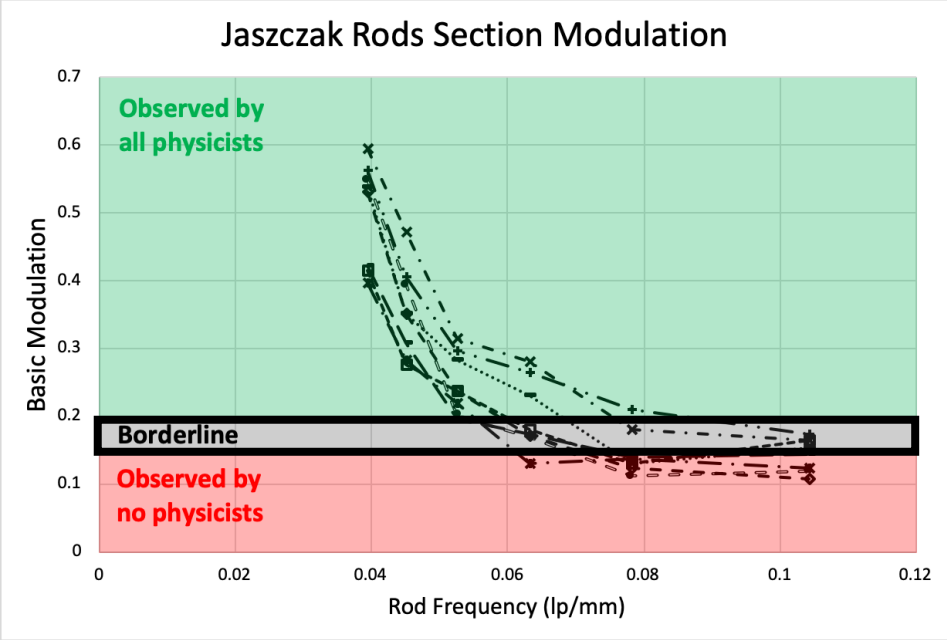
- CNR analysis over 9 tomographic reconstructions of Jaszczak phantom
- In general, CNR increases with sphere size
- Results more variable due to image variability
- Physicist visibility correlates well with previous guidelines (CNR > 3-5 for visible objects)*

*Cherry. et al. Phys in Nuc Med, 4e. p244, 2012

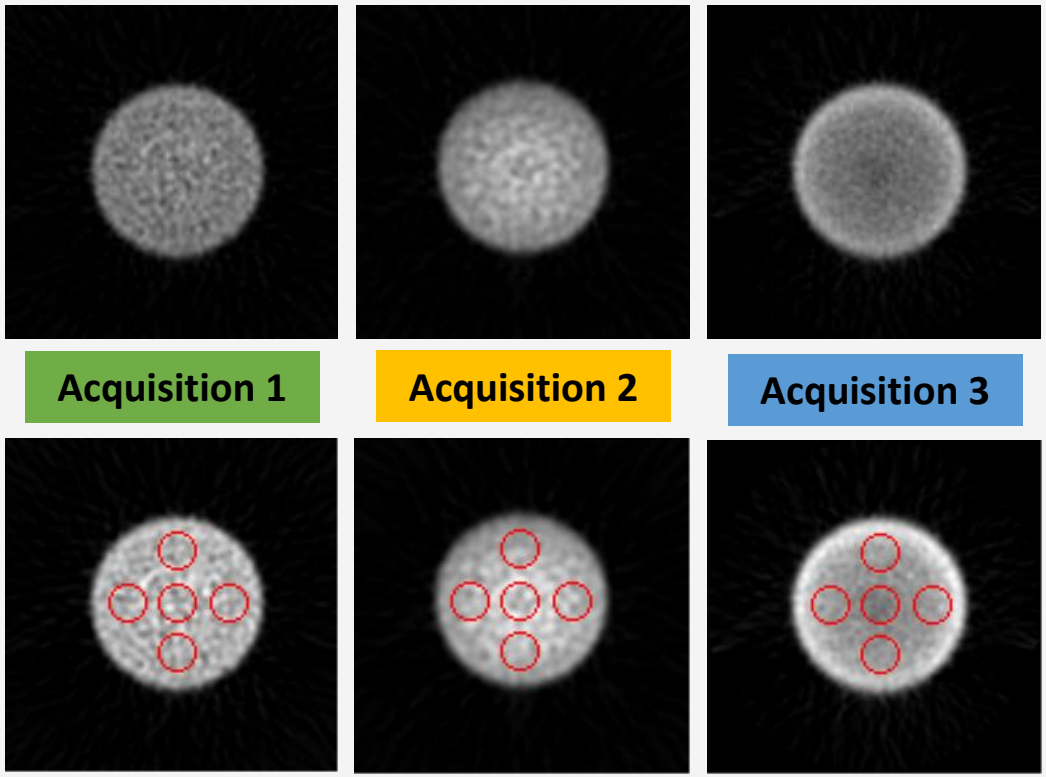


Jaszczak Phantom Rods Section Results

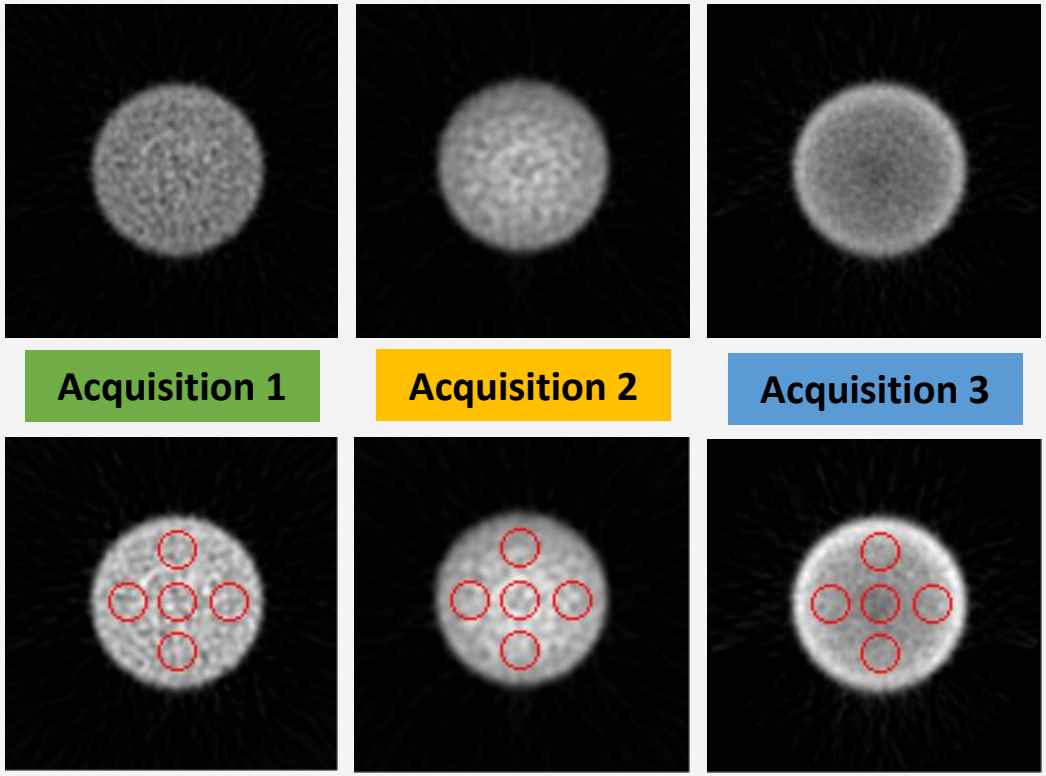
- Modulation analysis over 10 slices each of 9 acquisitions of the Jaszczak phantom
- Modulation curve shape
  - Decreasing until higher frequencies (noise level)
- Physicist visual read shows distinct areas where visual assessment suffices but also borderline regions where biases come into play



Jaszczak Phantom Uniformity Section



Jaszczak Phantom Uniformity Section



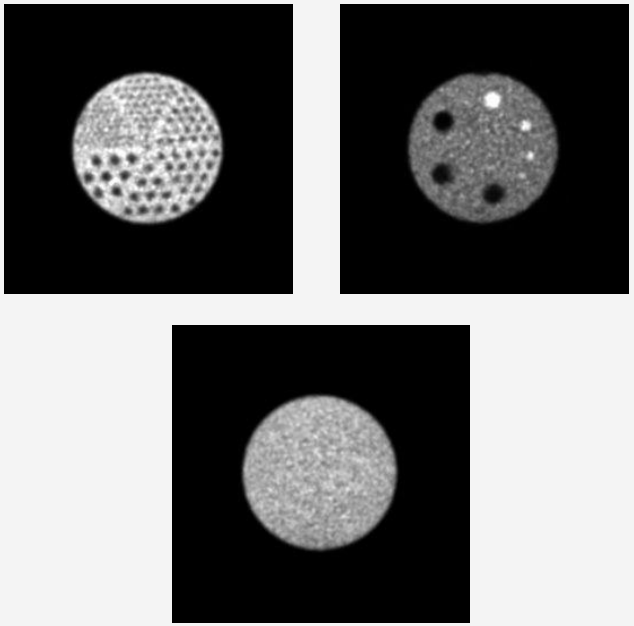
Acquisition	Greatest % deviation
1	-5.88 %
2	-15.1 %
3	27.5 %

Conclusions

- Our framework can be used in clinical settings
  - Simple yet quantitative
  - Accessible to technologists
  - Easy to incorporate into workflow
- Automated method can be used to detect QC situations that may be overlooked during visual analysis
  - Allows more sensitive tracking of image quality parameters with quantitative thresholding

Future Work

- Analysis of PET phantoms
  - Rods
  - Specific uptake value and contrast detectability
  - Uniformity
- Incorporate noise texture analysis for more robust uniformity assessment



Thank you!

Extra Slides (1/6) – Full Acquisition Parameters

Acquisition Parameters- Planar Bar Phantom	
Isotope	Co-57
Total Counts	5,000,000
Energy Window	+/-20% centered on 122 keV
Collimator	Low Energy High Resolution (LEHR)
Matrix Size	256x256
Zoom Factor	1

Acquisition Parameters- Jaszczak Phantom	
Isotope	Tc-99m
Injected Activity	10-15 mCi
Energy Window	+/-15% centered on 140 keV
Collimator	Low Energy High Resolution (LEHR)
Matrix Size	128x128
Zoom Factor	1.45
Acquisition	180° rotation, non-circular orbit
Number of Views	64
Time per View	~13 sec
Reconstructed Slice Thickness	3 mm
Reconstruction Algorithm	Filtered back projection
Attenuation Correction	Chang- 0.15 attenuation coefficient

Extra Slides (2/6) – Bar Phantom Analysis

ROI Size and Placement: 131.9 mm diameter circle ROI placed centrally within each bars section using geometric considerations.

$$\mathrm{MTF} = \frac{\pi\sqrt{2}}{4 \cdot A(f_b, w_p)} \cdot \frac{\sqrt{\sigma_{ROI}^2 - \mu_{ROI}}}{\mu_{ROI}}$$

$$A(f_b, w_p) = \frac{\sin(\pi \cdot f_b \cdot w_p)}{\pi \cdot f_b \cdot w_p}$$

$$f_b = \frac{1}{2 \cdot (\text{bar width})}$$

Pixel size correction factor

$$w_p = \text{pixel size}$$

Bar Width (mm)	Bar Frequency (lp/mm)
3.5	0.143
3.0	0.167
2.5	0.20
2.0	0.25

Hander TA et al. (2000). An improved method for rapid objective measurement of gamma camera resolution. Medical physics. 27. 2688-2692.

Extra Slides (3/6) – Jaszczak Phantom Spheres Analysis

ROI Placement: Circle ROI, slightly larger than sphere, placed centrally over each sphere using manufacturer's geometric specifications.

$$\mathrm{CNR} = \frac{|\mu_{\mathrm{center}} - \min_{\mathrm{sphere}}|}{\sigma_{\mathrm{center}}}$$

Adapted from:

AAPM Report 52: Quantitation of SPECT Performance. Medical physics. 22 (4), April 1995

Sphere diameter (mm)	ROI Diameter (mm)
31.8	42.8
25.4	29.7
19.1	23.0
15.9	19.7
12.7	19.7
9.5	19.7

Extra Slides (4/6) – Jaszczak Phantom Rods Analysis

ROI Placement: Line ROI 72mm in length placed centrally over outer set of rods in each section using manufacturer's geometric specifications.

$$\text{Modulation} = \frac{|\max_{\text{ROI}} - \min_{\text{ROI}}|}{\max_{\text{ROI}} + \min_{\text{ROI}}}$$

Rod diameter (mm)	Rod Frequency (lp/mm)
12.7	0.039
11.1	0.045
9.5	0.053
7.9	0.063
6.4	0.078
4.8	0.104

Extra Slides (5/6) – Jaszczak Phantom Uniformity

ROI Placement: Circle ROI, 50mm diameter, placed in center of phantom and at distance of 65mm from center in 4 directions (0°, 90°, 180°, 270°)

$$\%\ \text{Deviation}_{\text{ROI,i}} = \frac{\mu_{\text{ROI,i}} - \mu_{\text{ROI,center}}}{\mu_{\text{ROI,i}} + \mu_{\text{ROI,center}}} \times 100$$

Extra Slides (6/6) – Full References

- Hirtl, A. , Bergmann, H. , Knäusl, B. , Beyer, T. , Figl, M. and Hummel, J. (2017). Technical Note: Fully-automated analysis of Jaszczak phantom measurements as part of routine SPECT quality control. Medical physics. 44. 1638-1645. doi:10.1002/mp.12150
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