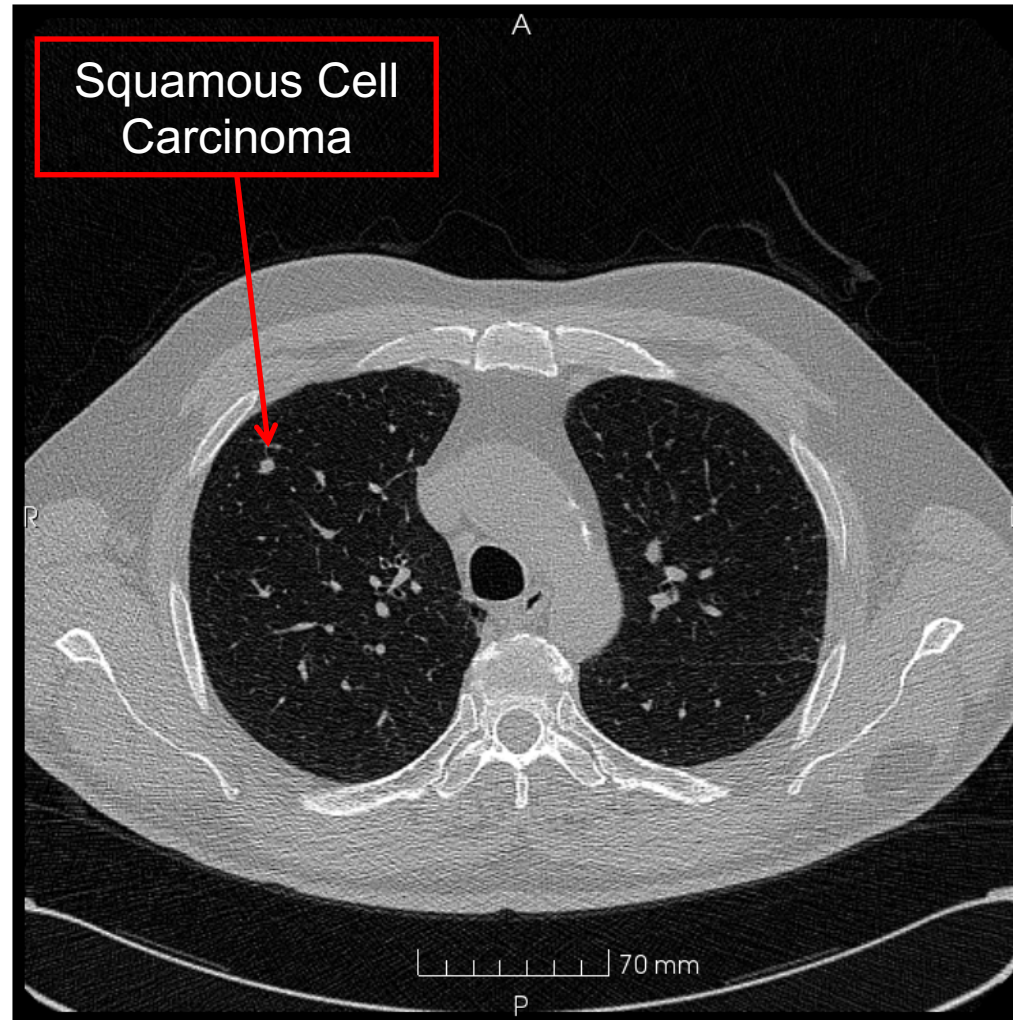


# **Towards an International Image Quality Monitoring Framework for Quantitative Imaging: Plan for Global Sharing and Progress**

Ricardo S. Avila  
rick.avila@accumetra.com

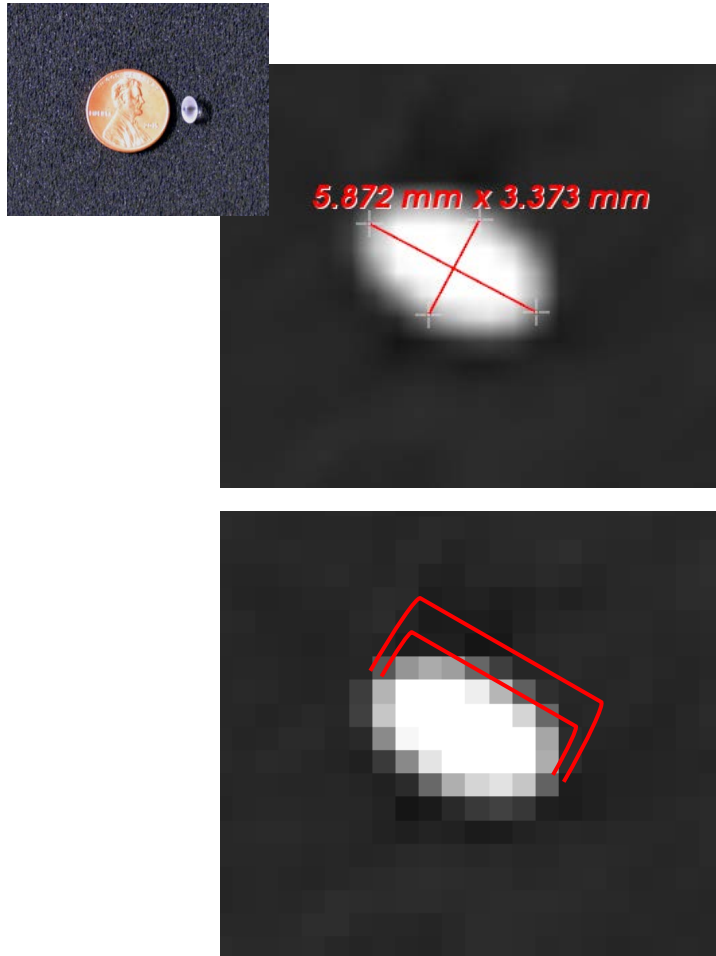
November 5, 2018

# Follow-Up Measurement of Small Lung Nodules



[Dr. Javier Zulueta, University of Navarra]

# Small Lung Nodule Measurement



**For a 6.0 x 3.6 x 3.6 mm Lung Nodule:**

We are working with axial CT images with a maximum nodule diameter of between 6 and 9 pixels

**+1mm Max Diameter Increase**

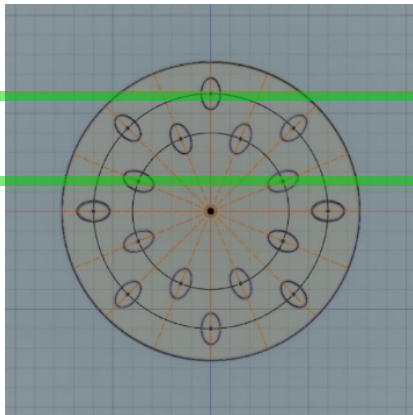
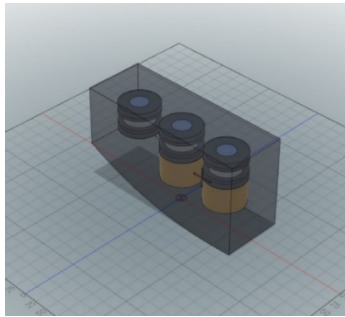
Nodule Diameter	Diameter Change %	Volume Change %
6.0	17%	59%
7.0	14%	49%
8.0	13%	42%
9.0	11%	37%
10.0	10%	33%

**If This Is TRULY a +1.0 mm Max Diameter Increase Over 6 Months, This Is a > 250% Volume Increase Over A Year**

**(640% for 3m)**

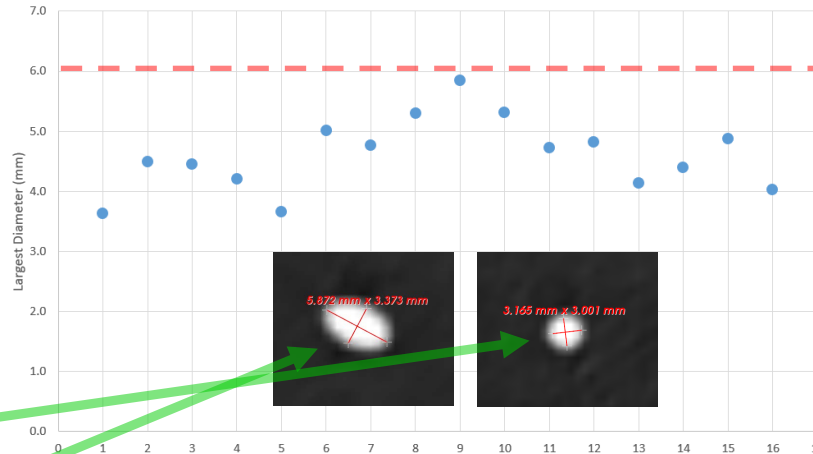
**Numerous CT Image Quality Issues Can Bias This Measurement**  
**Use of Precise and Quality Controlled Quantitative Image Measurement Tools Is Critical**

# Small Lung Nodules



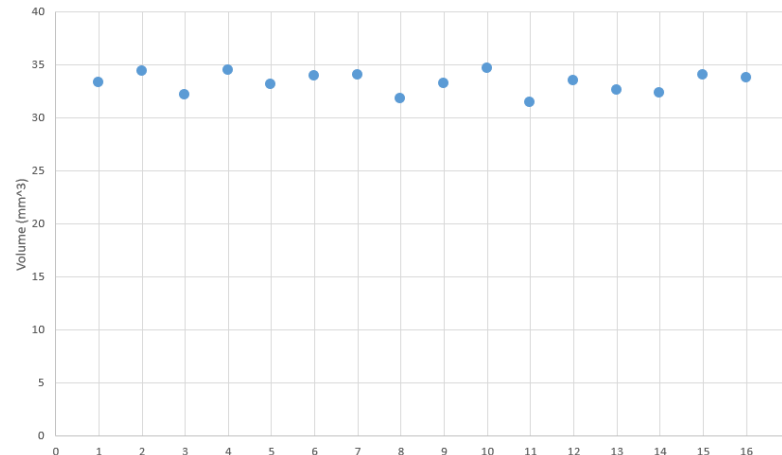
Coronal Image

6.0 x 3.6 Ellipsoid Diameter Measurements



**Axial Diameter**  
Mean: 4.60 mm  
SD: 0.61 mm  
CV: 13%

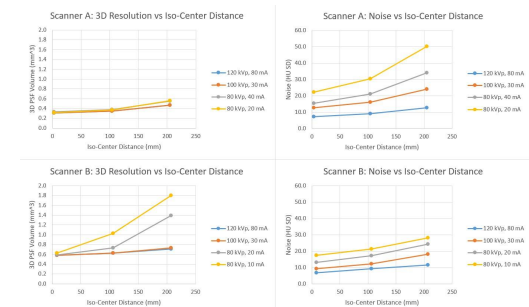
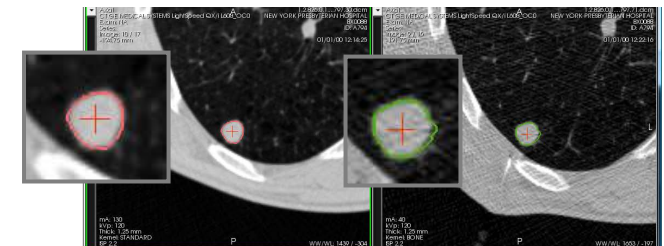
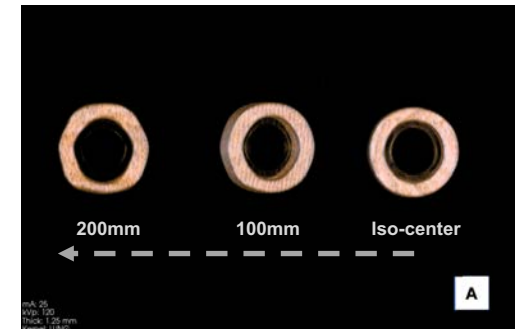
6.0 x 3.6 Ellipsoid Volume Measurements



**Volume**  
Mean: 33.33 mm  
SD: 0.98 mm  
CV: 3%

# Quality of Lung Nodule Measurements: What Have We Learned Over The Last 15 years?

- While studies have shown great results, major quality issues persist & impact small (6-10mm) lung nodule measurements:
  - CT Image quality can greatly degrade in the periphery
  - 3D spatial warping can give the appearance of  $\pm 40\%$   $\Delta$
  - Some recon kernels can bias HU values by  $> 50$  HU
  - Lowering dose can result in resolution losses of  $> 200\%$
  - Many institutions continue to use thick slices
  - Difficult to determine if a segmentation is “good enough”
  - ...
- CT imaging technology is constantly changing
  - Scanner geometries and detectors
  - “Standard” reconstruction kernels
  - Iterative reconstruction algorithms
  - New AI-based measurement methods
  - Measurement equipment is being replaced/repared and protocols are changing across lung nodule follow-ups
  - ...



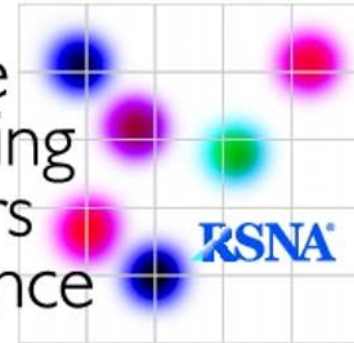
**We need to constantly measure and monitor CT detection and measurement equipment**

# Solution: QIBA CT Small Lung Nodule Profile + Conformance Phantom & Online Software



QIBA Profile: Lung Nodule Assessment in CT Screening Profile - 2017

Quantitative  
Imaging  
Biomarkers  
Alliance



2

3

4

5

6

7

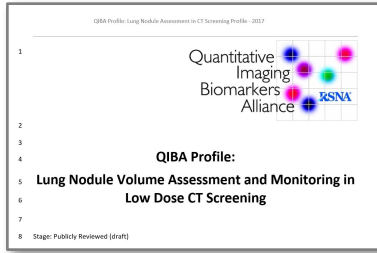
8

## QIBA Profile: Lung Nodule Volume Assessment and Monitoring in Low Dose CT Screening

Stage: Publicly Reviewed (draft)

# CTLX1 Phantom

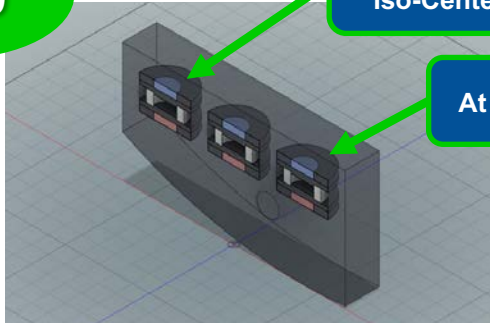
The First Image Quality Phantom To Measure The Full CT Scanner Field of View



200 mm from Iso-Center

At Iso-Center

\$250



This Ellipsoid Represents The Smallest Size Lung Nodule That a CT Lung Cancer Screening Site Needs To Be Able To Reliably Measure

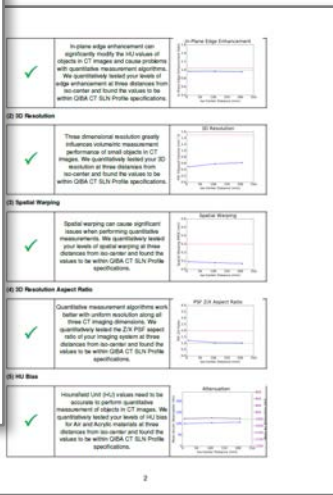
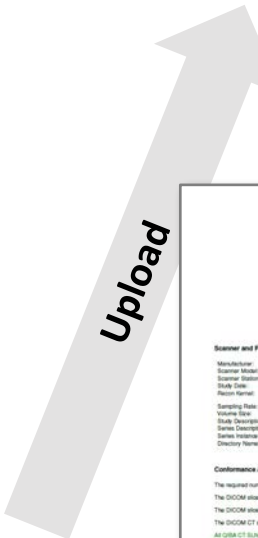
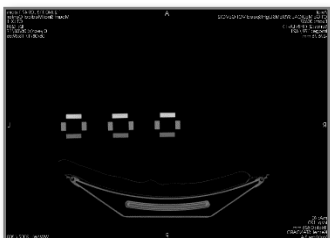
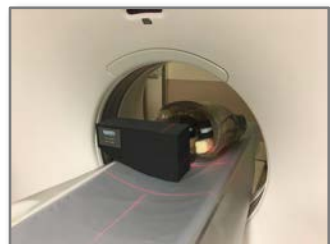
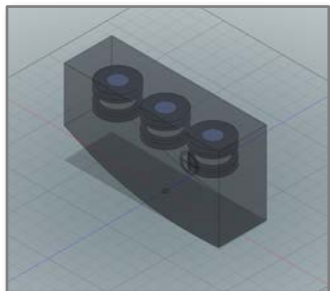
- **Fundamental CT Image Properties**

- 3D Resolution:
  - 3D PSF Ellipsoid Volume  $\leq 1.5\text{mm}^3$
- 3D Resolution Aspect:
  - PSF Z/X  $\leq 2.0$
- Linearity Bias:
  - Air and Acrylic Bias  $< 35$  HU
- Image Noise:
  - Acrylic Noise  $\leq 50$  HU SD
- Kernel Edge Enhancement:
  - Air to Delrin Enhancement  $\leq 5\%$
- 3D Spatial Warping:
  - Delrin Cylinder RMSE  $\leq 0.3$  mm

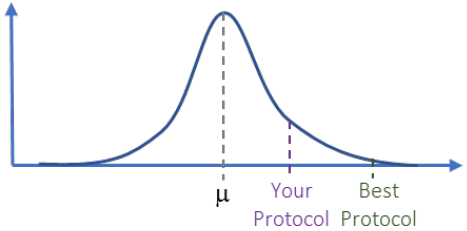
- **Lung Nodule Volume Change Performance**

- Verifies That Image Quality Meets or Exceeds The QIBA CT Lung Nodule Profile Volume Change Measurement Recommendations

# RSNA/QIBA Conformance Certification Pilot Project Using Cloud-Based Computing Services



**Check Each  
Time Scanner  
or Protocol  
Changes and  
Once Per Year**



**Guidance**  
Webpages & FAQs

**Optimize**



# International CT Image Quality Monitoring

## Thanks to the Prevent Cancer Foundation

65 CTLX1 Phantoms Shipped As Of 11/3/2018

> 240 CTLX1  
Scans Received





# RSNA/QIBA Conformance Certification

The screenshot shows the RSNA website with the following content:

- Header:** RSNA Radiological Society of North America. Navigation menu: Members, Trainees, International, Companies, Media, Patients. Search bar and user greeting: Welcome, Ricardo Avila, MS! Log out.
- Navigation:** Annual Meeting, Membership, Science, Education, Journals, Informatics, R&E Foundation, About RSNA.
- Section Header:** LEADING SCIENTIFIC ADVANCEMENTS IN MEDICAL IMAGING.
- Main Title:** Quantitative Imaging Biomarkers Alliance (QIBA) Conformance Certification Services.
- Text:** QIBA® is now offering a new conformance testing service to help clinical sites demonstrate they can achieve high-quality quantitative imaging results. A clinical site that achieves QIBA Profile specifications will receive a QIBA® Conformance Certification Mark that can be used to distinguish itself as performing quantitative imaging studies with high levels of precision. Scanner and analysis software vendors can also obtain the QIBA® Conformance Certification Mark to demonstrate their specific medical device(s) or software has been tested and has demonstrated conformance with a given QIBA Profile. QIBA Conformance Certification Services, including an image quality assessment phantom and online phantom analysis services, are currently only available for the QIBA CT Small Lung Nodule Volume Assessment and Monitoring in Low-Dose Screening Profile.
- Image:** Quantitative Imaging Biomarkers Alliance logo.
- Text:** Benefits of obtaining a QIBA® Conformance Certification Mark for a Clinical Site:
  - Confirm that your clinical site is delivering high quality CT lung nodule imaging measurements to patients.
  - Quantitatively identify, optimize and monitor any potential CT image quality performance issues.
  - Obtain high-quality measurements based on fundamental CT image quality characteristics and lung imaging protocols which can be useful when conducting clinical trials and algorithmic imaging research.
  - Promote your high-performance, quantitative imaging capability by posting the QIBA® Conformance Certification Mark to your website and imaging site materials.
  - Participation will help improve future CT lung cancer imaging guidelines.
- Image:** QIBA Clinical Site Conformance Mark logo.
- Text:** Benefits of obtaining a QIBA® Conformance Certification Mark for a Scanner or Software Vendor:
  - Demonstrate to your current and potential customers that your medical device or software meets the thorough specifications outlined in a QIBA® Profile.
  - Annually verify the performance of your medical device helping ensure that the high performance remains consistent under a variety of acquisition and measurement conditions.
  - Provide quantitative and independently confirmed device data to your customers on the best methods and protocols to use with your medical device.
  - Promote your high-performance, quantitative imaging capability by posting the QIBA® Conformance Certification Mark to your medical device or software web pages and promotional materials.
  - Participation will help improve future CT lung cancer imaging guidelines.
- Text:** MORE INFO / SIGN UP

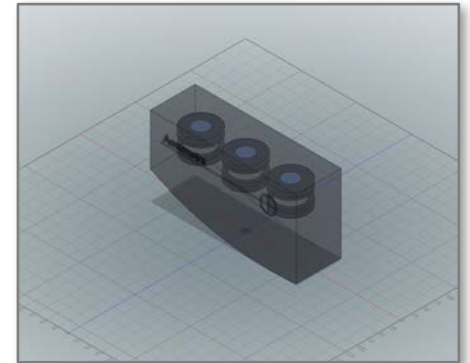
The screenshot shows the Accumetra website with the following content:

- Header:** Accumetra. Navigation menu: Solutions, News, About, Contact. LOG IN button.
- Image:** A patient lying on a table being attended to by medical professionals.
- Section Header:** Advancing the Science OF IMAGE-BASED DECISION MAKING.
- Text:** Accumetra is committed to advancing the science of image-based decision making. We provide new and advanced tools to better understand, optimize, and monitor image quality and expert consultation to help quantitatively improve clinical site performance. Accumetra is now working with the Radiological Society of North America's (RSNA) Quantitative Imaging Biomarkers Alliance (QIBA) to provide conformance certification services to clinical sites, CT scanner vendors, and analysis software vendors. These new services enable organizations to achieve conformance with QIBA's CT Small Lung Nodule Profile and receive a new QIBA Conformance Certification Mark. The new QIBA Conformance Certification service provides an easy-to-use phantom and cloud based quantitative analysis tools that allow institutions to thoroughly understand and optimize CT image quality for specific clinical measurement tasks. Learn more about this ground breaking new approach to achieving high levels of CT lung nodule measurement performance through the link below.
- Text:** SIGN UP FOR THE NEW QIBA CONFORMANCE CERTIFICATION SERVICE
- Text:** Once conformance certification has been achieved, your institution can use these Conformance Certification Marks to demonstrate the achievement to customers and collaborators.
- Image:** Three circular logos representing different types of conformance marks:
  - CLINICAL SITE CONFORMANCE MARK
  - CT SCANNER VENDOR CONFORMANCE MARK
  - CT SOFTWARE VENDOR CONFORMANCE MARK
- Text:** Consulting Services | Latest News

# CT Image Quality Control

## Using Low-Cost Phantoms and Cloud-based Services Will Help Clinical Sites and Studies To:

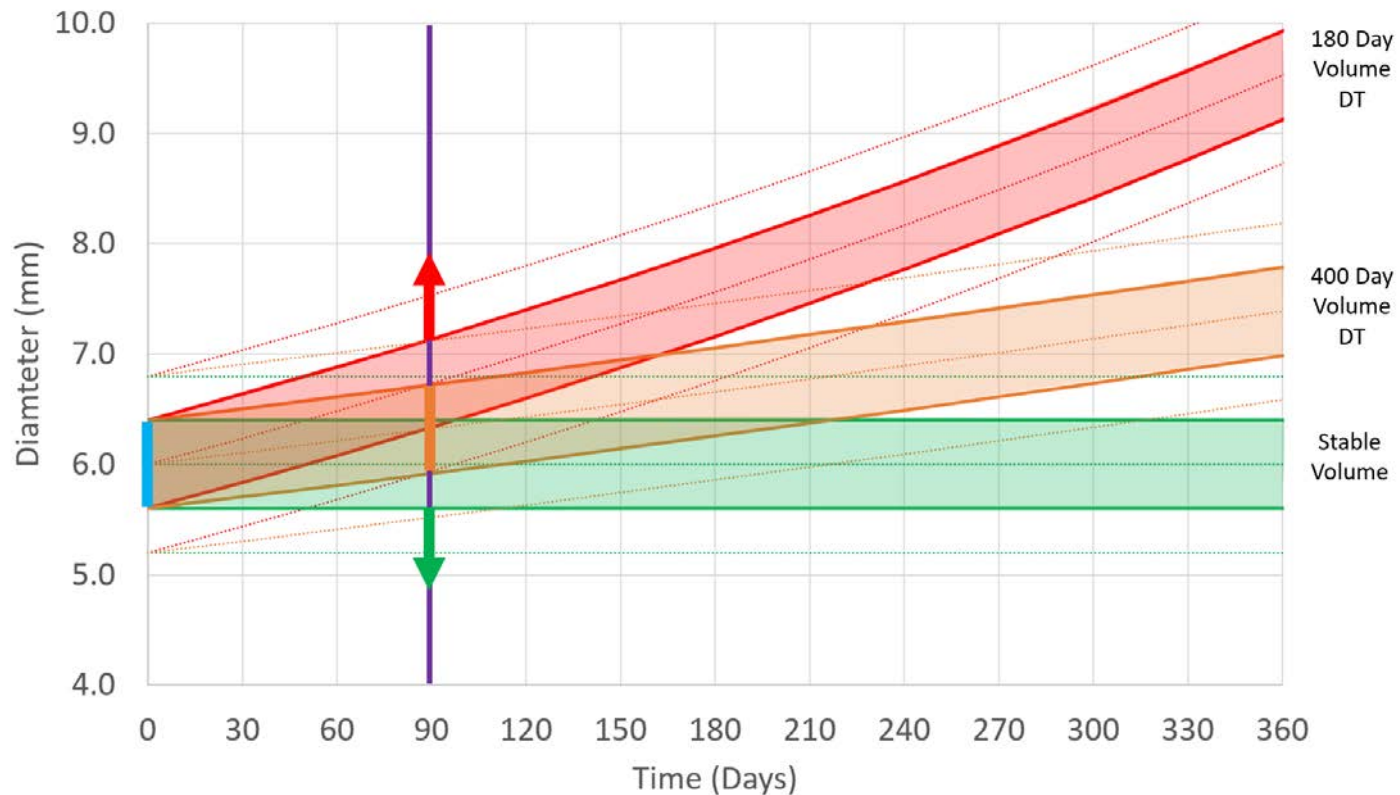
1. Eliminate Low Quality CT Scans
2. Help with Protocol & Scanner Changes
3. Help Optimize Your Acquisition Protocol
4. Set Better Follow-up Times
5. Perform Better Imaging Research



# Precision Follow-up Time

## Nodule Diameter Growth

What can we say if we use great CT imaging of a ~6mm nodule at baseline and again after 90 days?



# Potential Future Capabilities

- Nodule Follow-Up Times
  - Lower follow-up time from 3 months down to 1.5 months OR achieve higher sens/spec at 3 months
- Automated Detection & Volume Change
  - With Enough Image Quality We Could One Day Auto Detect  $\geq$  3mm Lung Nodules At Annual Screenings And Highlight Only Those That Are Confirmed To Be Growing at a Malignant Rate.

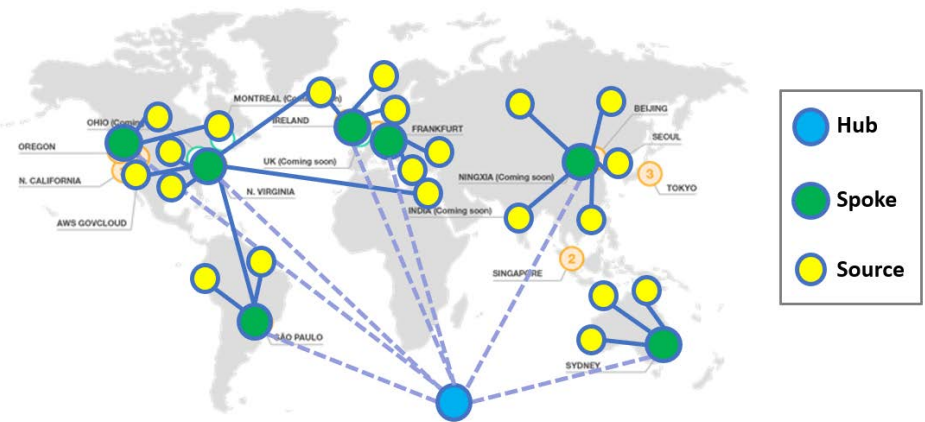
We Can Now Specify The Needed Resolution, Noise, Spatial Warping To Reach These Goals...

# Early Lung Imaging Confederation (ELIC) Project

## A New Global Lung Imaging Research Resource

**Problem:** Many Promising CT Lung Cancer Screening Research Opportunities Including Artificial Intelligence/Deep Learning Require 10x to 100x Larger Datasets (e.g.  $10^4 \rightarrow 10^6$ )

**Solution:** Create a New and Secure CT Lung Imaging Computing Environment That Removes Barriers to Site Participation and is Populated With De-Identified, High Quality Data



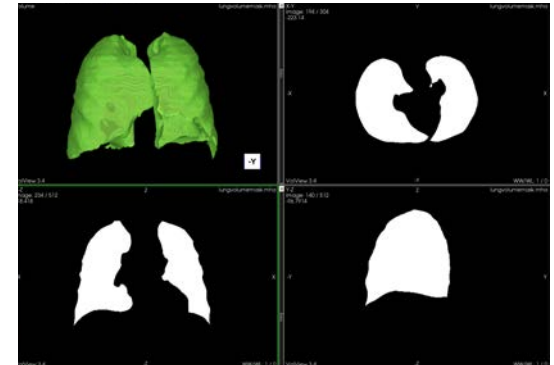
### **Critical Requirements:**

- Keep CT Image Data Locally and Send Algorithms To Spokes To Perform Analysis
- Make Setup and Secure Running of Spokes Automated, Easy, and Efficient
- Have Strong Governance and Pre-Established Data Use Agreements
- Leverage The Latest Computing Resources & Best Practices (Cloud, Open Source, ...)
- Provide CT Image Quality Monitoring and Optimization Tools To Ensure High Quality Data

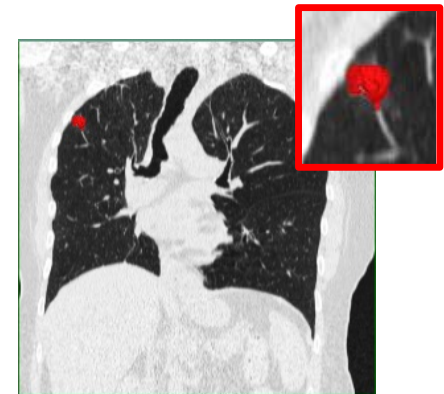
# ELIC Pilot Project

- Create a First Version of the ELIC Hub and Spoke Environment
- Run ELIC on the Amazon Cloud With 10 Global Spokes Each Providing 100 De-identified CT Lung Images (Total Cases = 1,000)
- Develop/Run Two Open Source Lung Measurement Algorithms
- Perform a Live ELIC Demo at the 19<sup>th</sup> WCLC (Toronto, 9/22) Showing Running of Global Experiments at 10 ELIC Spokes
- Demonstrate That Prospective CT Image Quality Can Be Monitored and Optimized With the RSNA/QIBA CT Small Lung Nodule Profile
- Distribute All Code Developed as Free and Open Source Software – Global Sites Can Contribute To Software Development

## Lung Volume



## Lung Nodule Volume



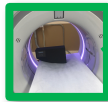


# ELIC Live Demonstration Using The Amazon Web Services (AWS) Cloud

## Hub

- Virginia, USA

Phantom  
Image Quality  
Testing



- Edge Locations
- Multiple Edge Locations
- Regional Edge Caches

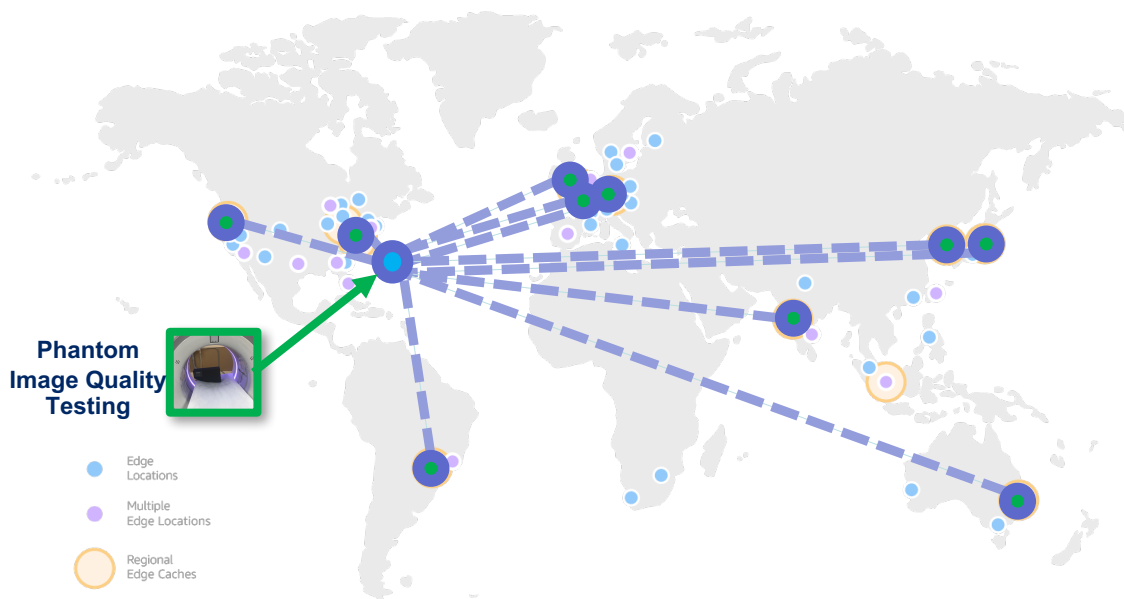
Can Be Local  
Computing  
Hardware

## Spokes

1. Virginia, USA
2. Mumbai, India
3. London, UK
4. Frankfurt, Germany
5. Montreal, Canada
6. Sydney, Australia
7. Tokyo, Japan
8. Paris, France
9. Seoul, South Korea
10. Sao Paulo, Brazil

ELIC Live Demonstration Spoke Locations Do Not Indicate ELIC Future Plans

# ELIC Pilot Project



## Opportunities

- Global Research Studies
- Regional Analyses
- Artificial Intelligence
- Technology Surveillance
- Global Quality Monitoring

**The ELIC Architecture Is Designed To Efficiently Support Storage and Analysis of Millions of Subjects**

**Thank You**

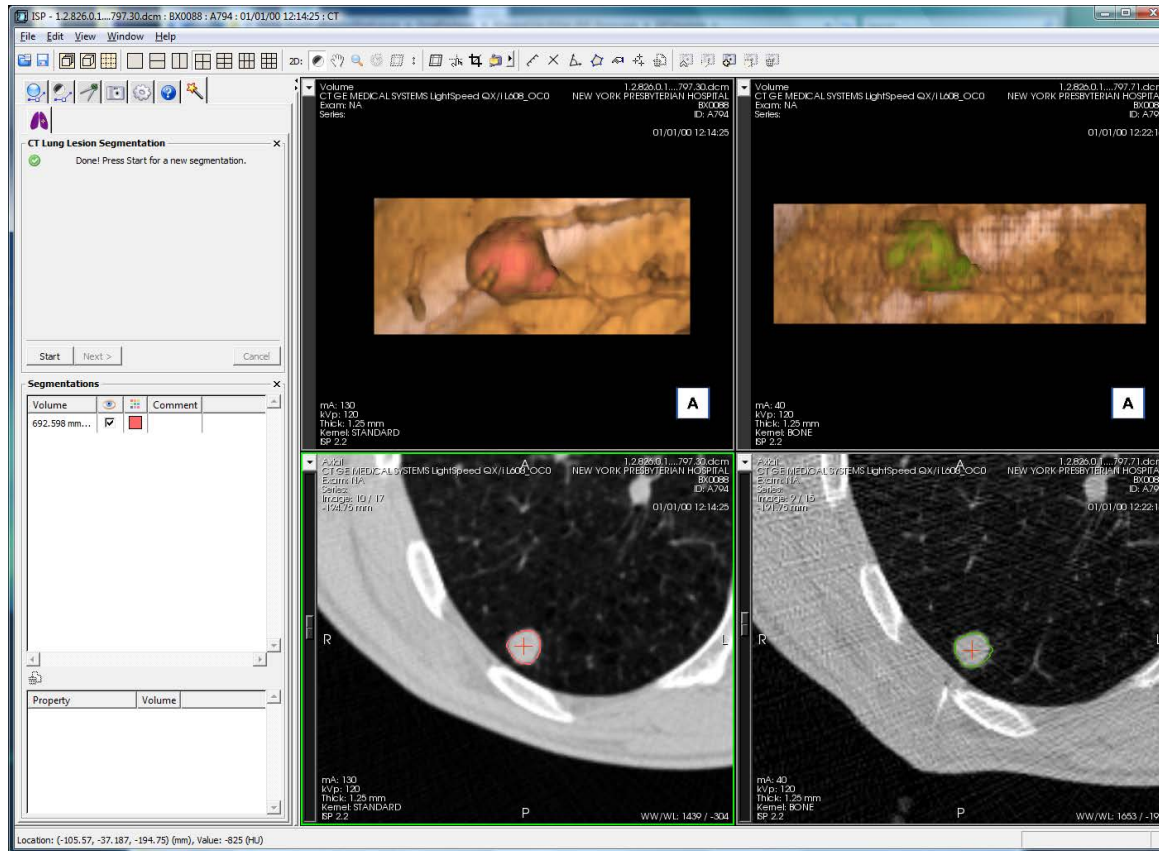
# Problem

- **Precise Quantitative CT Measurements Are Often Needed**
  - CT Lung Nodule Follow-Up, Cardiac Calcification Scoring
- **CT Scanners/Software Do NOT have The Tools To Support This**
  - Fundamental CT Scanner Performance Varies Widely – Even Within A Single Image
  - Multiple Scanners Are Often Used At A Clinical Site With Different Properties
  - Setting Up a High Quality Imaging Protocol Is Error Prone Due to Large Numbers of Scan Parameters and Continuously Changing Technology
- **Clinical Sites Are Now Able To Use a New Low-Cost Phantom and Online Phantom Analysis Tools To Consistently Achieve The Needed CT Image Quality For Specific Clinical Tasks**

# Pulmonary Nodules

Time 1

Time 2



$$= 668 \text{ mm}^3$$

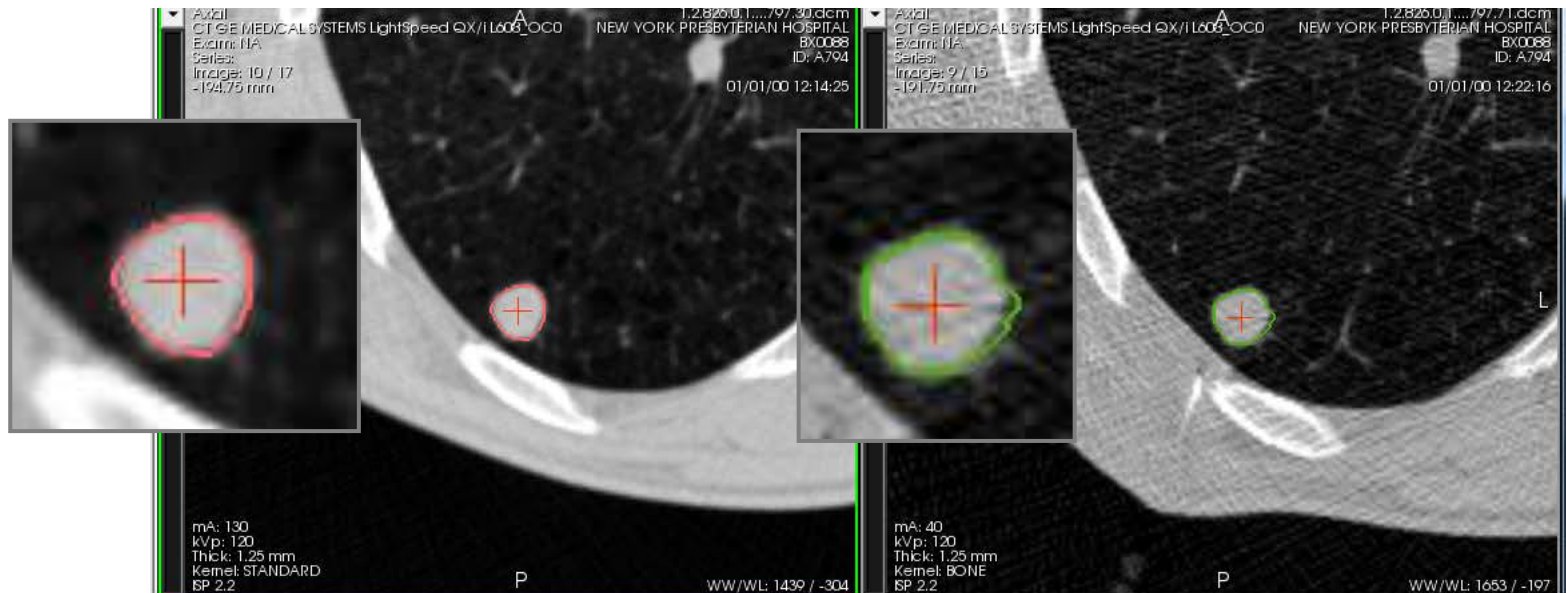
$$T2 = 661 \text{ mm}^3$$

$\Delta V = \text{No Change}$

# Image Measurement Precision

## Need to be able to:

- Measure the change in volume of a solid lung nodule with a specific level of error (95% CI).



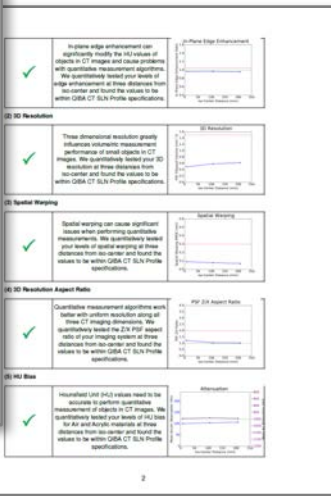
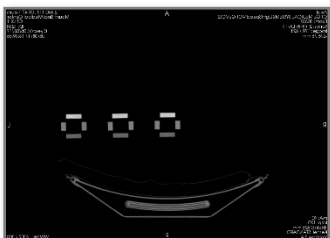
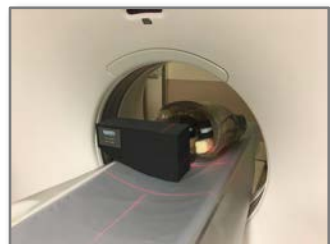
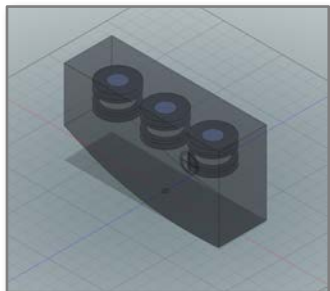
$$T1 = 668 \pm 183 \text{ mm}^3$$

$$T2 = 661 \pm 181 \text{ mm}^3$$

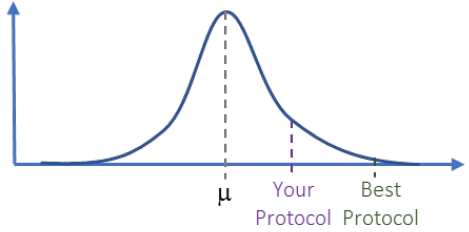
+ 37%  
+ 1.2 mm

Volume Change Error = -7 , Volume Change Error = -7  $\pm$  257 mm<sup>3</sup>

# RSNA/QIBA Conformance Certification Pilot Project Using Cloud-Based Computing Services



**Check Each  
Time Scanner  
or Protocol  
Changes and  
Once Per Year**



**Guidance  
Webpages &  
FAQs**

**Optimize**

# Automated CT Scanner/Protocol Image Quality Report

## Protocol Settings



QIBA CT Small Lung Nodule (SLN) Profile  
Automated CT Image Quality Conformance Report  
Assessment Performed Using The Accumetra CTLX1 Phantom  
And ACQA Prototype Image Quality Assessment Software Platform (v0.7)

December 10, 2017

### Scanner and Protocol Settings

Manufacturer:	GE MEDICAL SYSTEMS	Tube kVp:	120.00
Scanner Model:	Revolution CT	Tube mA:	19.00
Scanner Station:	REVCT	Slice Thickness:	0.62
Study Date:	20170920	Slice Spacing:	0.625
Recon Kernel:	STANDARD	Pitch:	0.99

Sampling Rate:	0.625 x 0.625 x 0.625 mm
Volume Size:	512 x 512 x 137 voxels
Study Description:	
Series Description:	ISOTROPIC50
Series Instance UID:	1.2.840.113619.2.416.113380311699552862934385553576134305349
Directory Name:	1.2.840.113619.2.416.113380311699552862934385553576134305349 19mA.0.625Std STD ISO50

### Conformance Assessment Status

The required number of CTLX1 phantom modules were found (3).

The DICOM slice thickness is within acceptable limits for this analysis ( $\leq 1.25\text{mm}$ ).

The DICOM slice spacing is within acceptable limits for this analysis ( $\leq 2.0$ ).

The DICOM CT scan pitch is within acceptable limits for this analysis ( $\leq 2.0$ ).

All QIBA CT SLN Profile automated conformance checks have passed for this CT scanner and image acquisition protocol.

### Measured Image Quality Characteristics

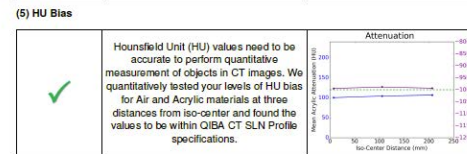
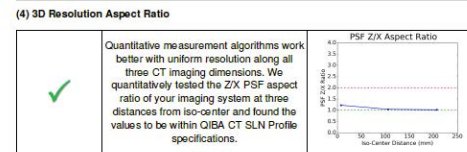
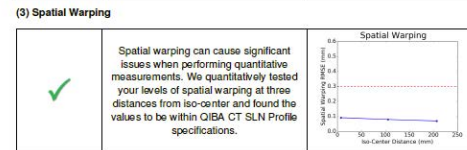
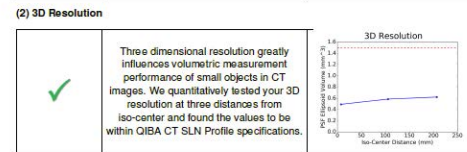
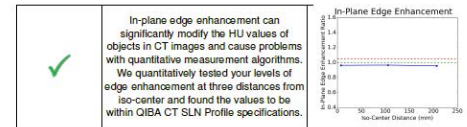
The QIBA CT Small Lung Nodule Profile requires that CT image quality performance is verified for six fundamental image quality characteristics throughout the acquired CT image field of view for a CT scanner and image acquisition protocol to be used for solid lung nodule volume measurement. The performance of each of these characteristics plotted from scanner iso-center to periphery is displayed below along with whether the measured performance achieves the QIBA Small Lung Nodule Profile image quality performance specifications. Additional information on these image quality characteristics including guidance on improving performance is available at Accumetra's QIBA Conformance Certification Pilot Project Page.

#### (1) Edge Enhancement

1

## Image Quality Measurements

## Analysis Status



2



# Report With Issues



**QIBA CT Small Lung Nodule (SLN) Profile  
Automated CT Image Quality Conformance Report**  
Assessment Performed Using The Accumetra CTLX1 Phantom  
And ACQA Prototype Image Quality Assessment Software Platform (v0.7)

December 10, 2017

**Scanner and Protocol Settings**

Manufacturer:	GE MEDICAL SYSTEMS	Tube kVp:	120.00
Scanner Model:	Revolution CT	Tube mA:	69.00
Scanner Station:	REVCT	Slice Thickness:	2.50
Study Date:	20170920	Slice Spacing:	2.500
Recon Kernel:	STANDARD	Pitch:	0.99
Sampling Rate:	0.625 x 0.625 x 2.500 mm		
Volume Size:	512 x 512 x 35 voxels		
Study Description:	STANDARD 2.5mm		
Series Description:	STANDARD 2.5mm		
Series Instance UID:	1.2.840.113619.2.416.2033369520407.89983364245632445114236403		
Directory Name:	1.2.840.113619.2.416.2033369520407.89983364245632445114236403		

**Conformance Assessment Status**

The required number of CTLX1 phantom modules were found (3).

Error: Slice thickness must be  $\leq 1.25$  mm to meet the QIBA Small Lung Nodule Profile requirements.

The DICOM slice spacing is within acceptable limits for this analysis ( $\leq$  slice thickness).

The DICOM CT scan pitch is within acceptable limits for this analysis ( $\leq 2.0$ ).

Error: CT scan 3D PSF sigma ellipsoid volume must be  $\leq 1.5mm^3$  to meet the QIBA Small Lung Nodule Profile requirements.

Error: CT scan 3D PSF sigma Z/X aspect ratio must be  $\leq 2.0$  to meet the QIBA Small Lung Nodule Profile requirements.

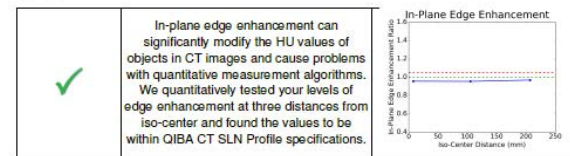
At least one problem was found with the CT images provided. Consider resubmitting a CTLX1 phantom scan with a revised image acquisition protocol.

**Measured Image Quality Characteristics**

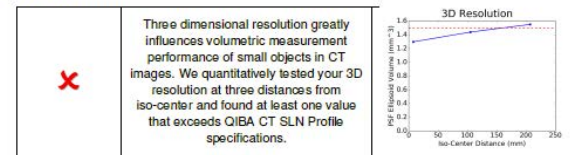
The QIBA CT Small Lung Nodule Profile requires that CT image quality performance is verified for six fundamental image quality characteristics throughout the acquired CT image field of view for a CT scanner and image acquisition protocol to be used for solid lung nodule volume measurement. The performance of each of these characteristics plotted from scanner iso-center to periphery is displayed below along with whether the measured performance achieves the QIBA Small Lung Nodule Profile image quality performance specifications. Additional information on these image quality characteristics

including guidance on improving performance is available at Accumetra's QIBA Conformance Certification Pilot Project Page.

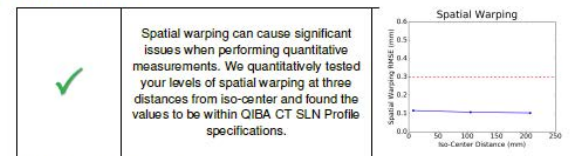
**(1) Edge Enhancement**



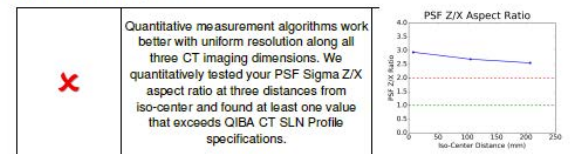
**(2) 3D Resolution**



**(3) Spatial Warping**

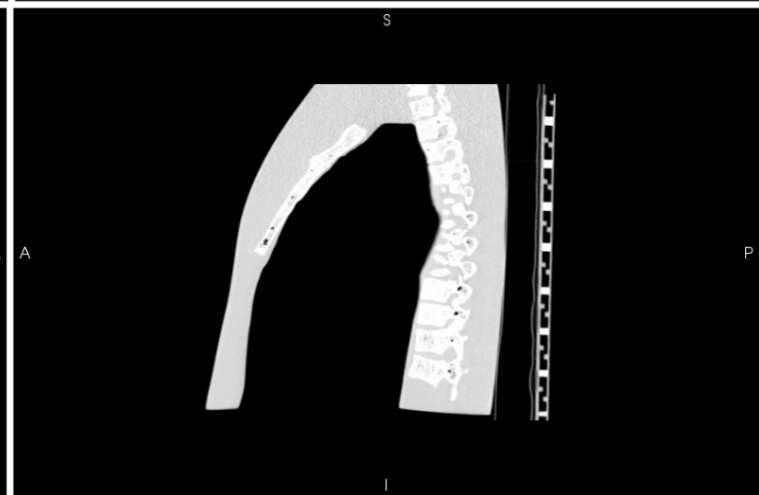
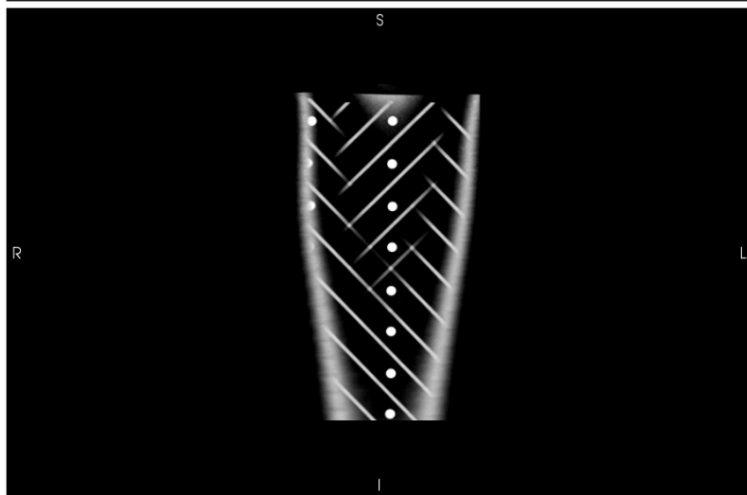
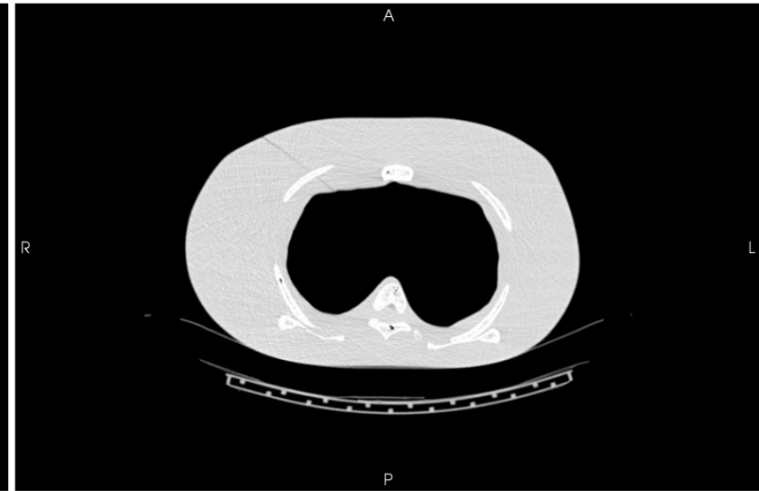
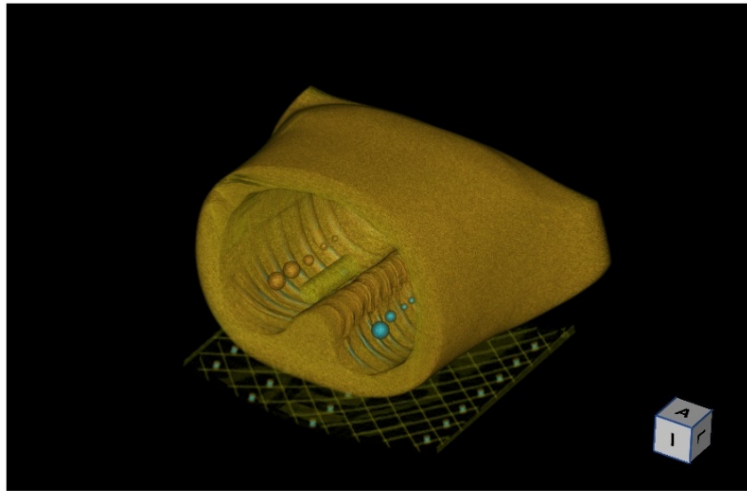


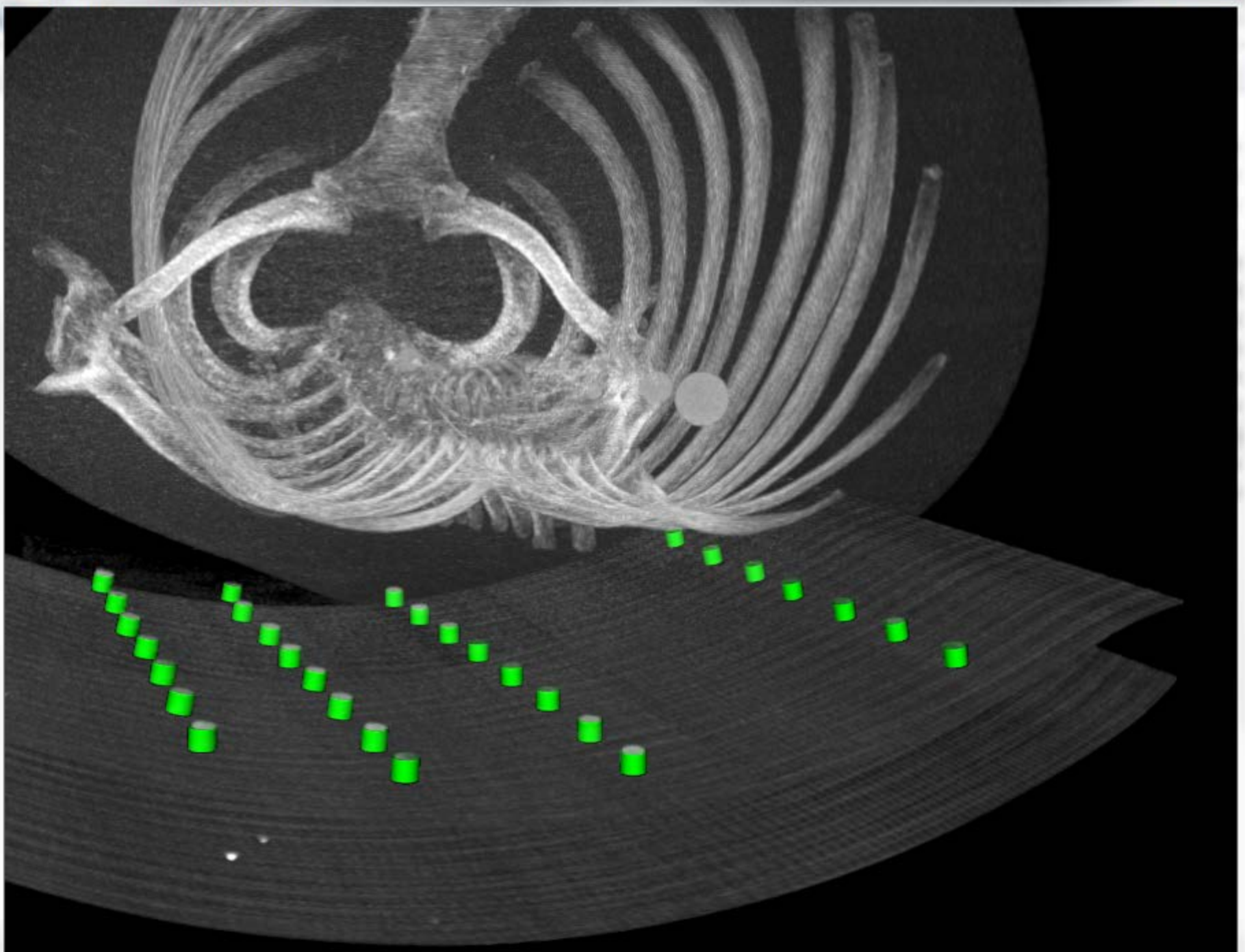
**(4) 3D Resolution Aspect Ratio**

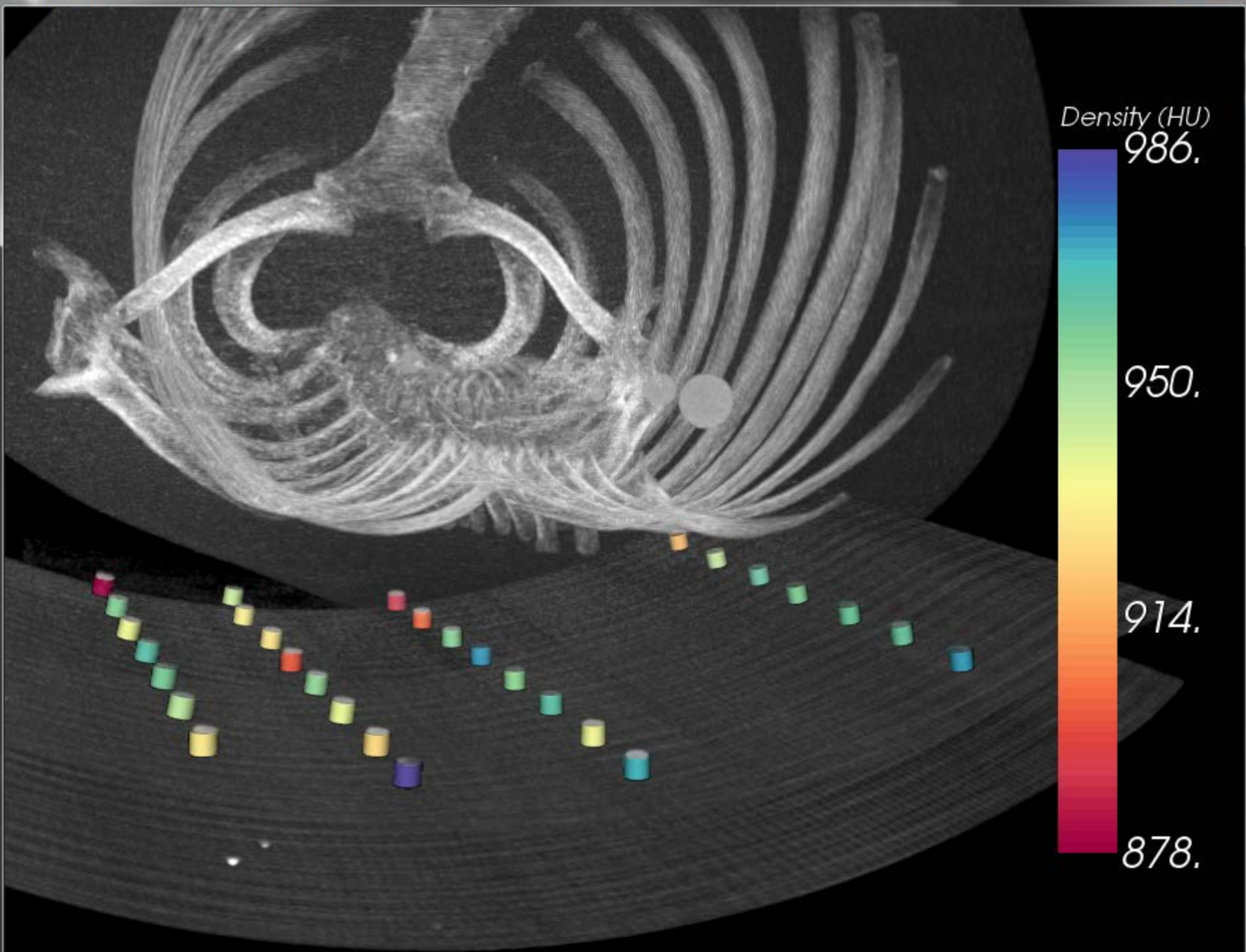


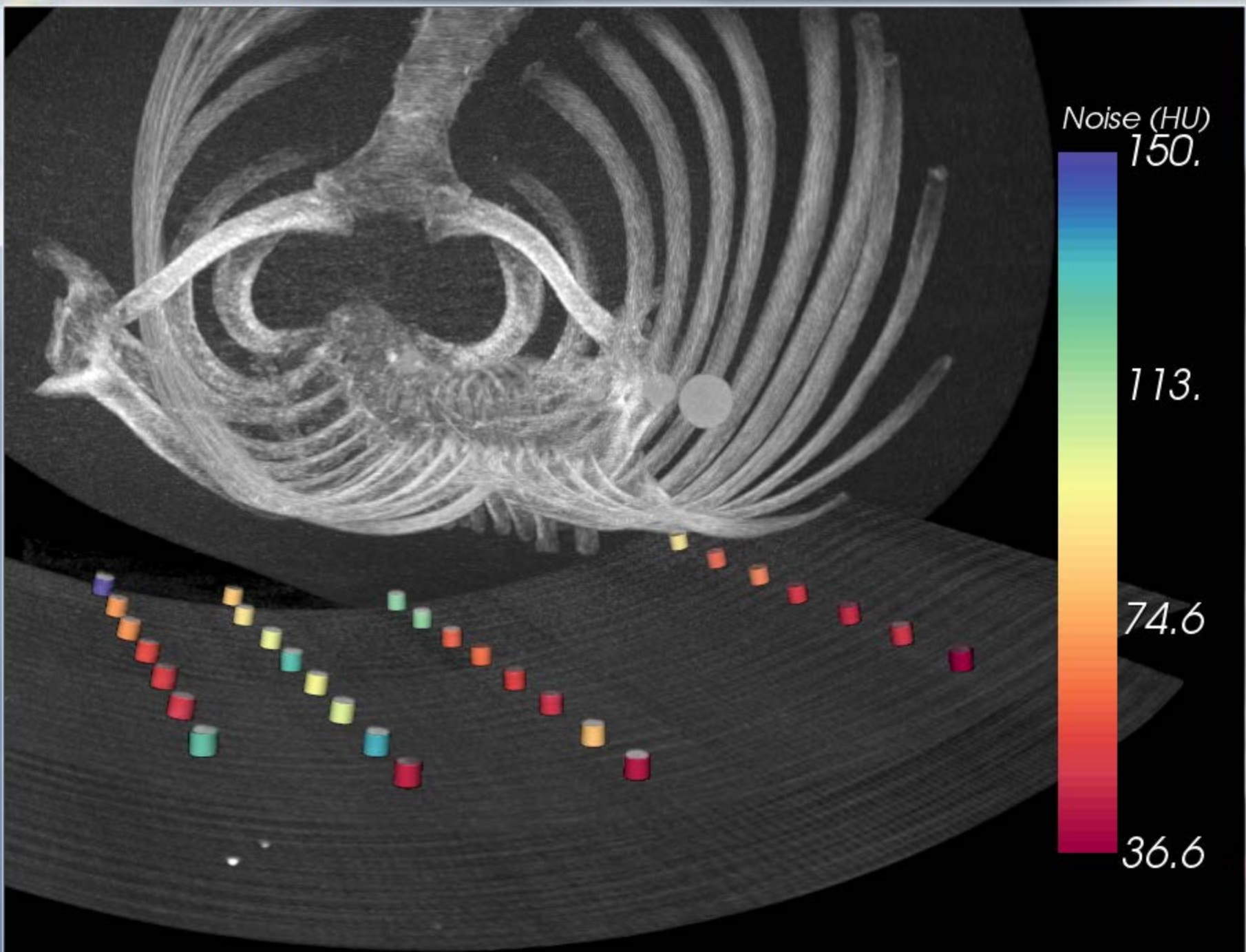
**(5) HU Bias**

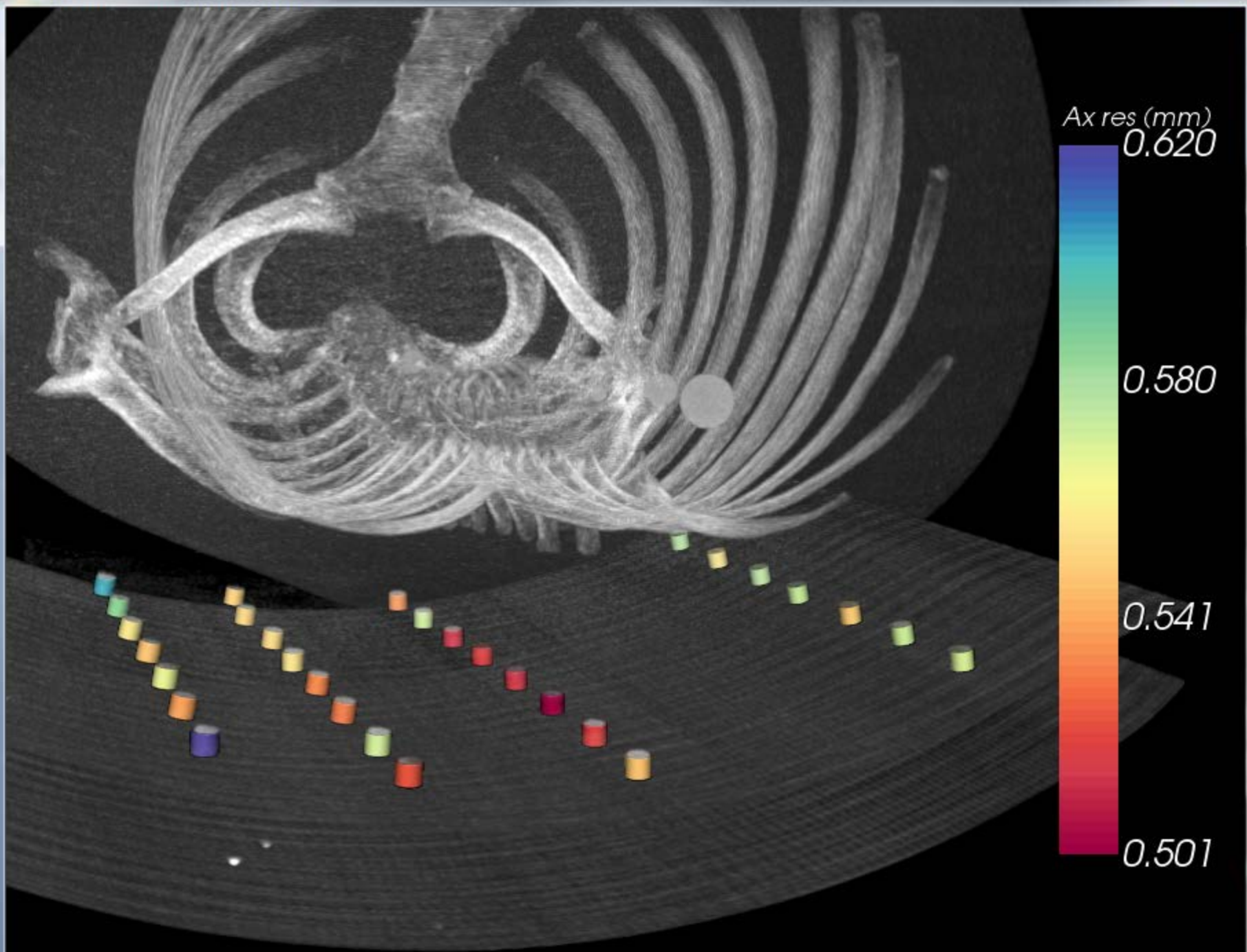
# Table Phantom Scanning

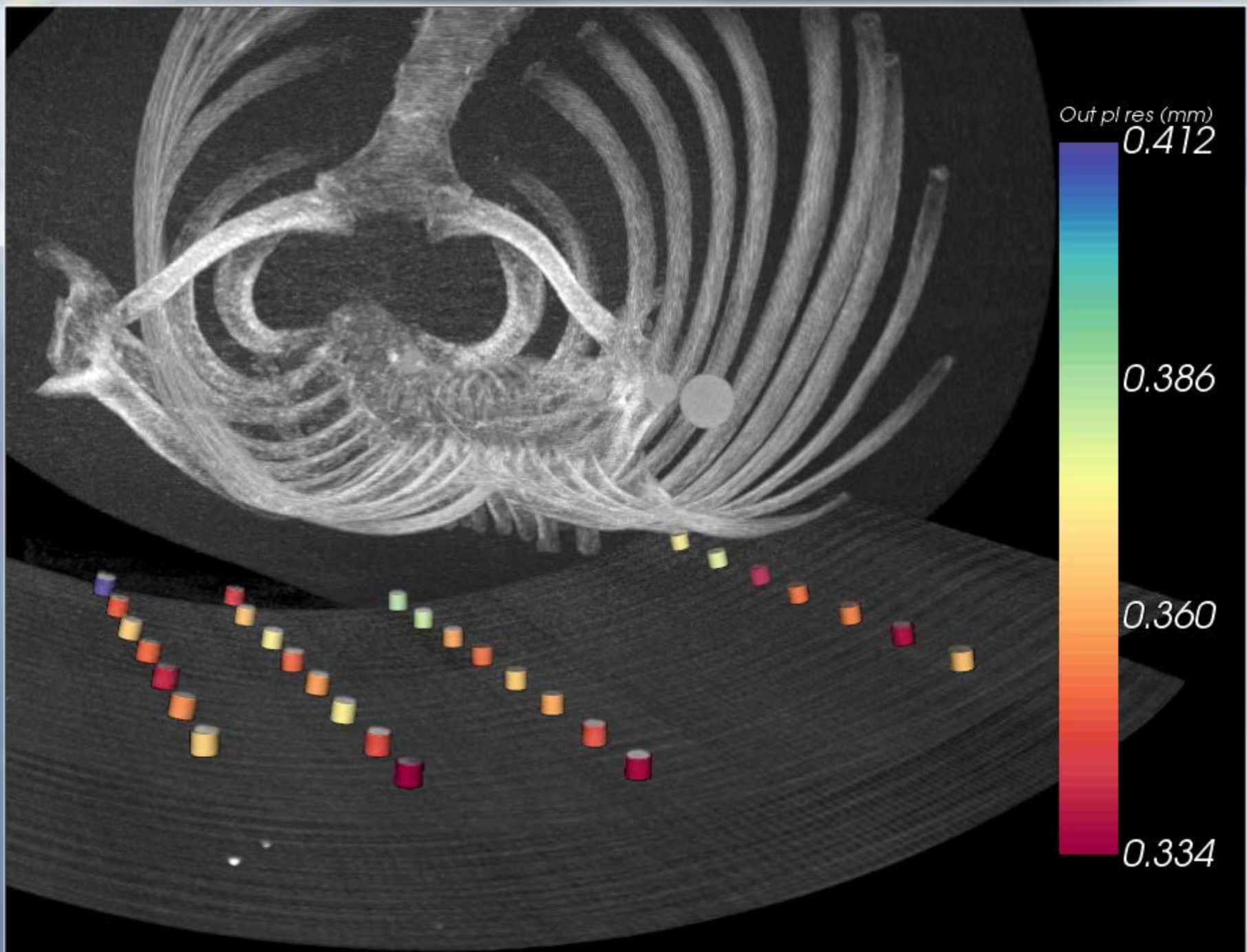












# Where Will Improved Image Quality Take Us?

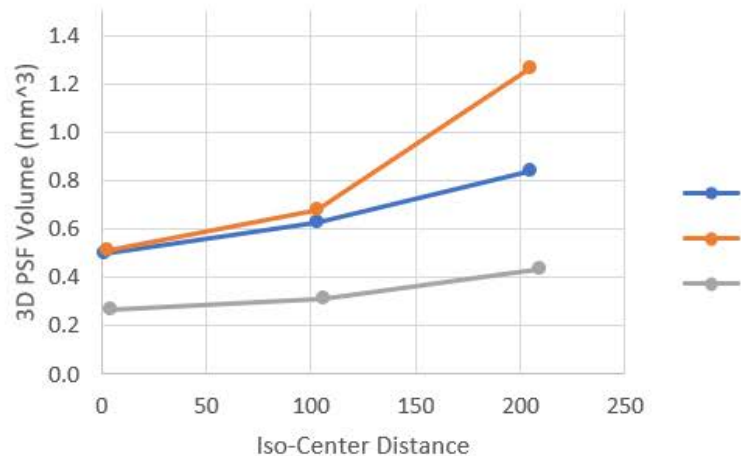
T1



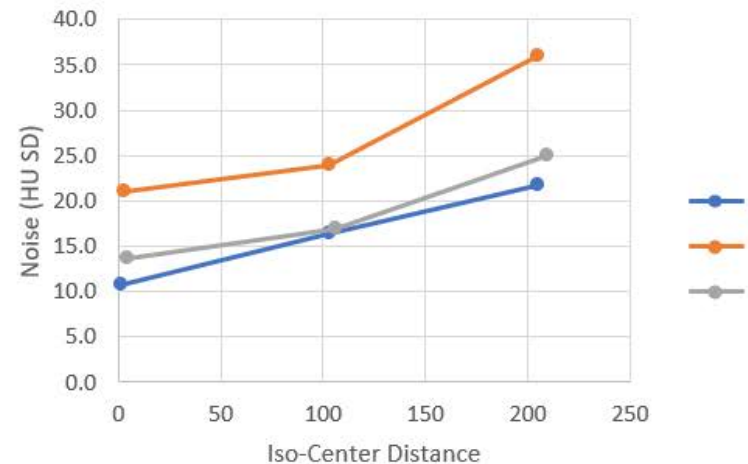
T1 + 90 days



Resolution vs Iso-Center Distance



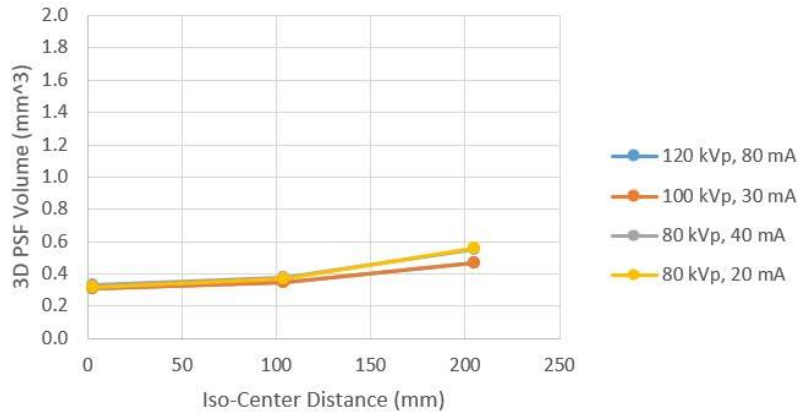
Noise vs Iso-Center Distance



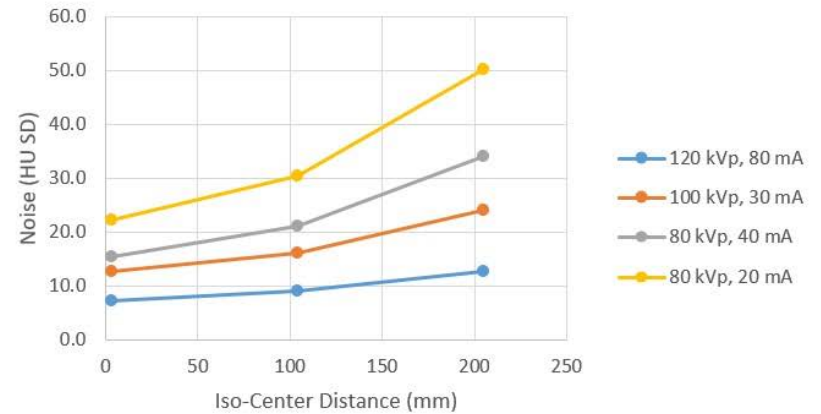


# Radiation Dose and Resolution

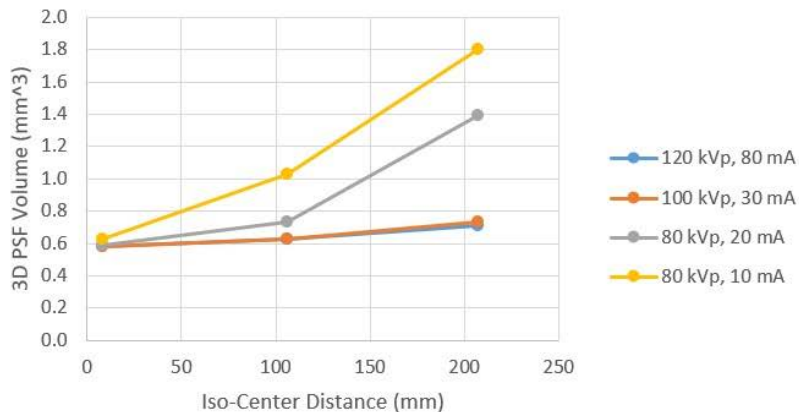
Scanner A: 3D Resolution vs Iso-Center Distance



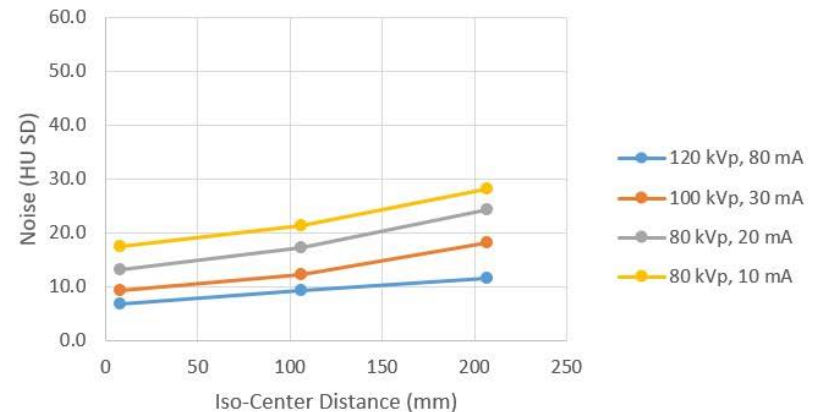
Scanner A: Noise vs Iso-Center Distance



Scanner B: 3D Resolution vs Iso-Center Distance



Scanner B: Noise vs Iso-Center Distance



# Requested vs Observed Slice Thickness

