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

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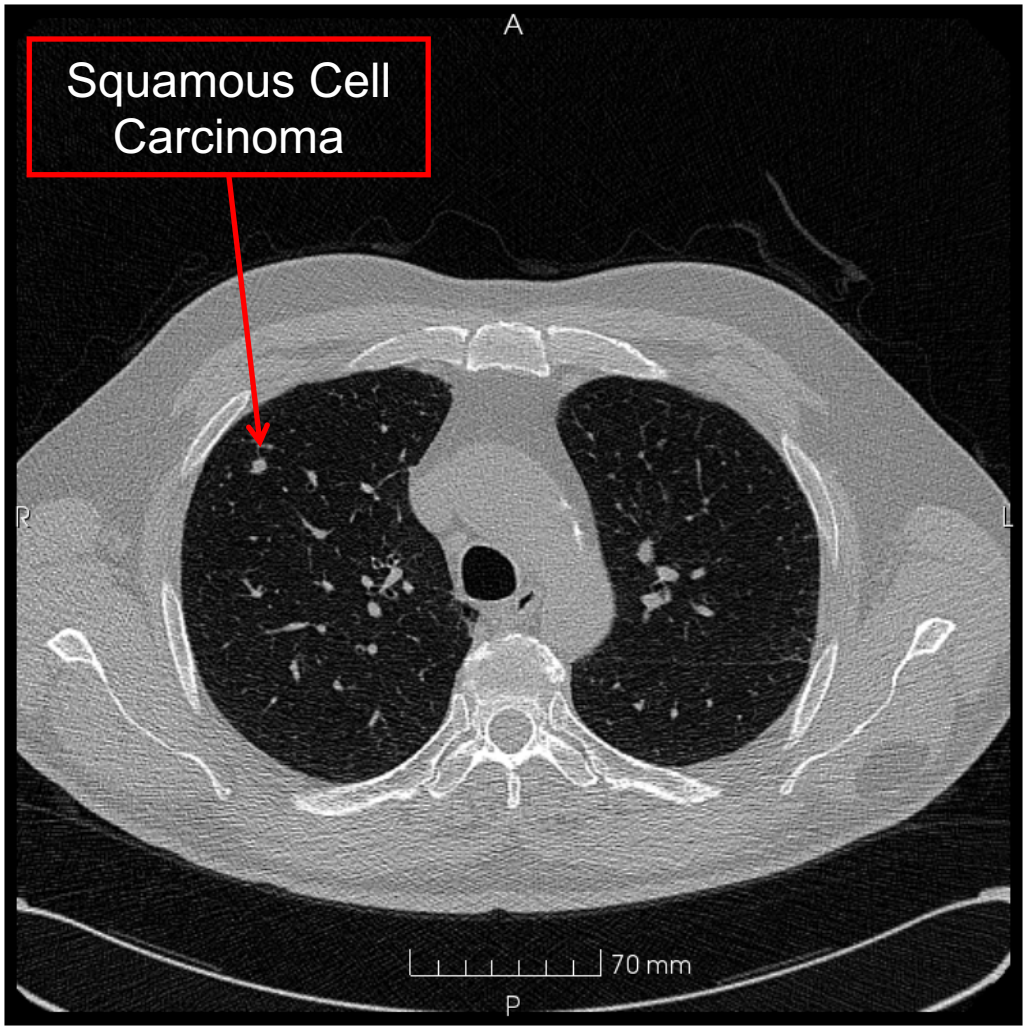
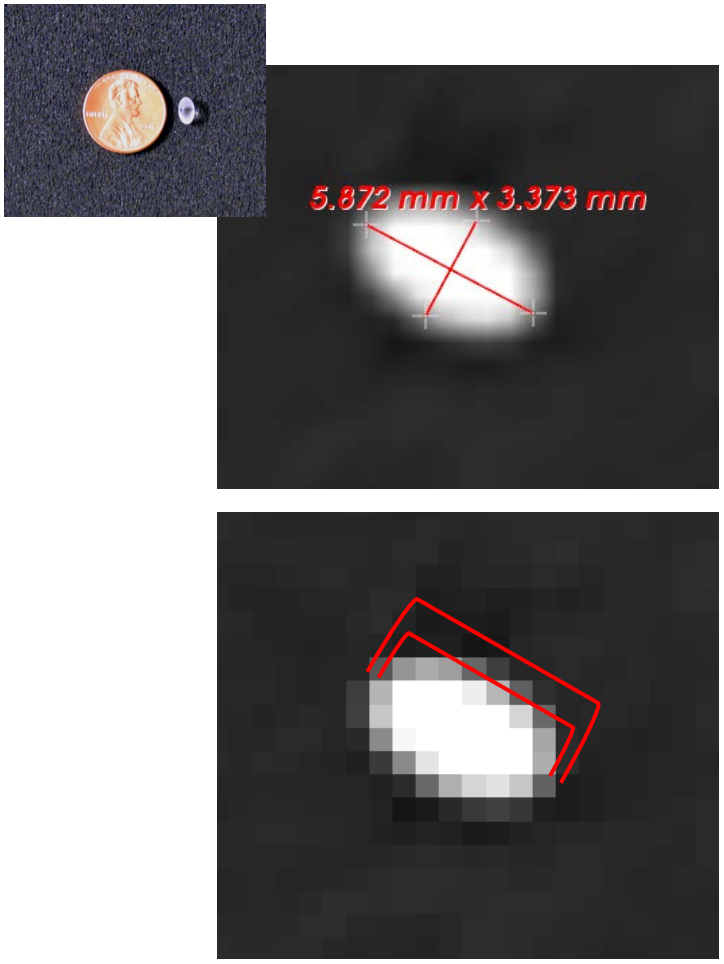
November 5, 2018

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%

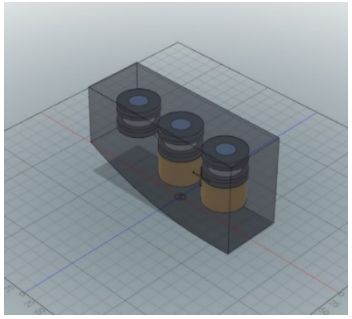
If This Is TRULY a +1.0 mm Max Diameter Increase Over 6 Months, This Is a > 250% Volume Increase Over A Year

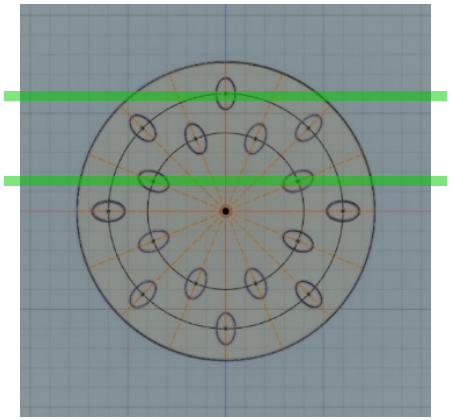
(640% for 3m)

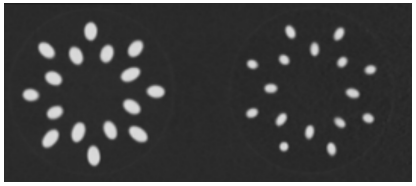
Numerous CT Image Quality Issues Can Bias This Measurement

Use of Precise and Quality Controlled Quantitative Image Measurement Tools Is Critical

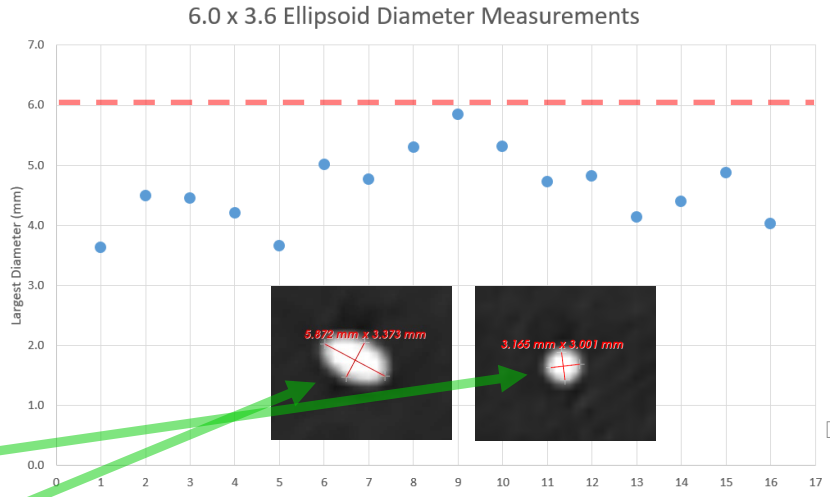
Small Lung Nodules

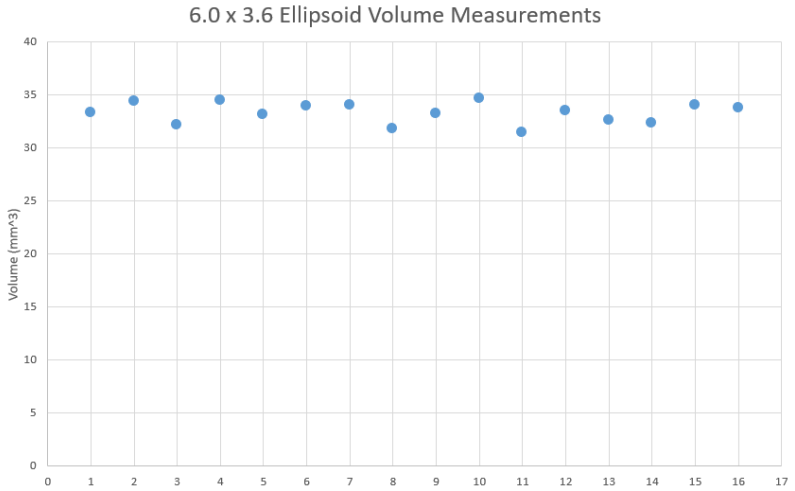






Coronal Image



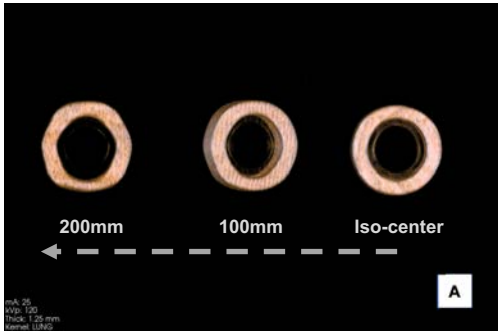


Axial Diameter
Mean: 4.60 mm
SD: 0.61 mm
CV: 13%

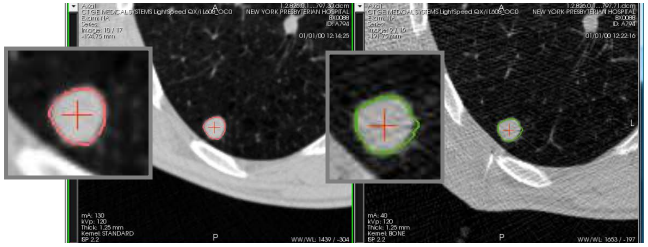
Volume
Mean: 33.33 mm
SD: 0.98 mm
CV: 3%

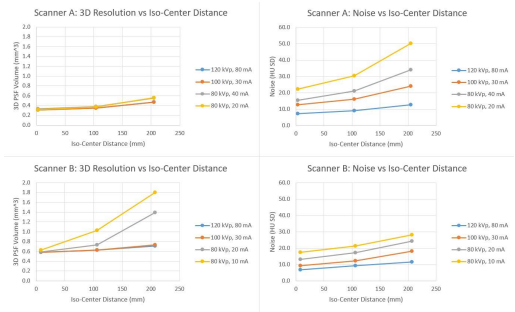
Quality of Lung Nodule Measurements: What Have We Learned Over The Last 15 years?

- 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 +- 40% Δ
  - 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/repaired 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

Quantitative Imaging Biomarkers Alliance

RSNA

2

3

4 **QIBA Profile:**

5 **Lung Nodule Volume Assessment and Monitoring in**

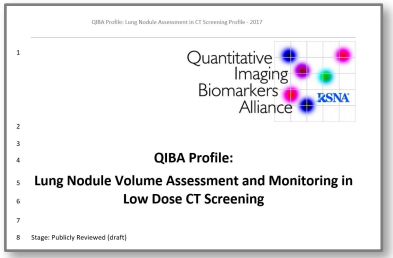
6 **Low Dose CT Screening**

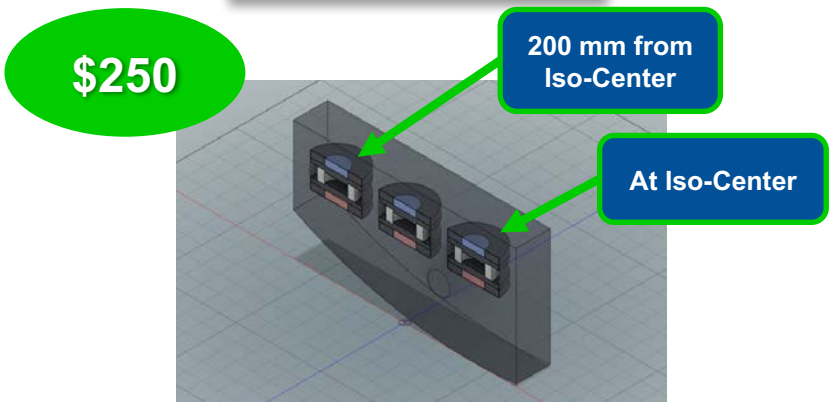
7

8 Stage: Publicly Reviewed (draft)

CTLX1 Phantom

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

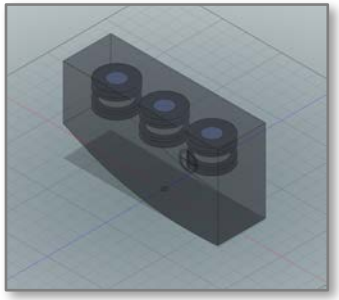


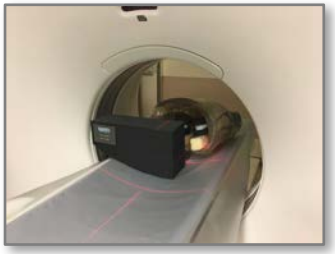


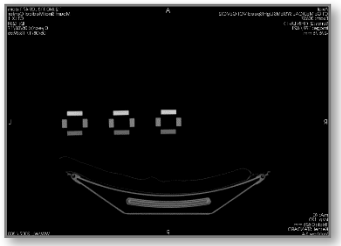
This Ellipsoid Represents The Smallest Size Lung Nodule That a CT Lung Cancer Screening Site Needs To Be Able To Reliably Measure

- **Fundamental CT Image Properties**
  - 3D Resolution:
    - 3D PSF Ellipsoid Volume <= 1.5mm^3
  - 3D Resolution Aspect:
    - PSF Z/X <= 2.0
  - Linearity Bias:
    - Air and Acrylic Bias < 35 HU
  - Image Noise:
    - Acrylic Noise <= 50 HU SD
  - Kernel Edge Enhancement:
    - Air to Delrin Enhancement <= 5%
  - 3D Spatial Warping:
    - Delrin Cylinder RMSE <= 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







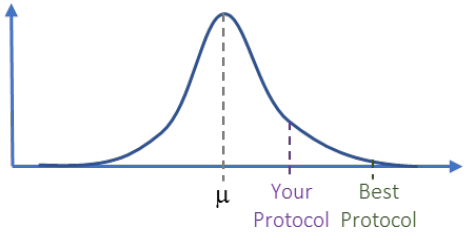
http://quality.rsna.org

Email

Upload

Optimize

Check Each Time Scanner or Protocol Changes and Once Per Year



Guidance

Webpages & FAQs

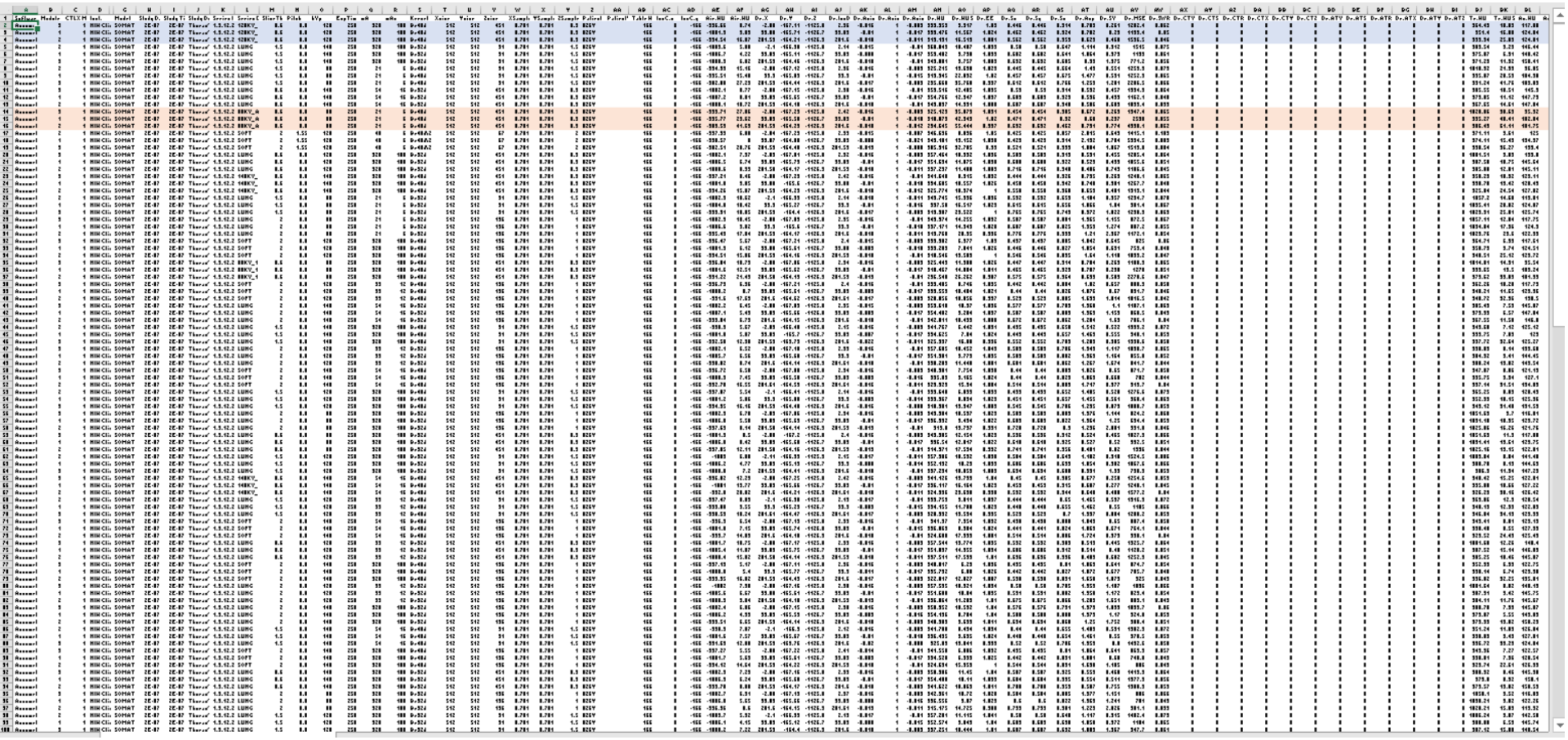
International CT Image Quality Monitoring

Thanks to the Prevent Cancer Foundation

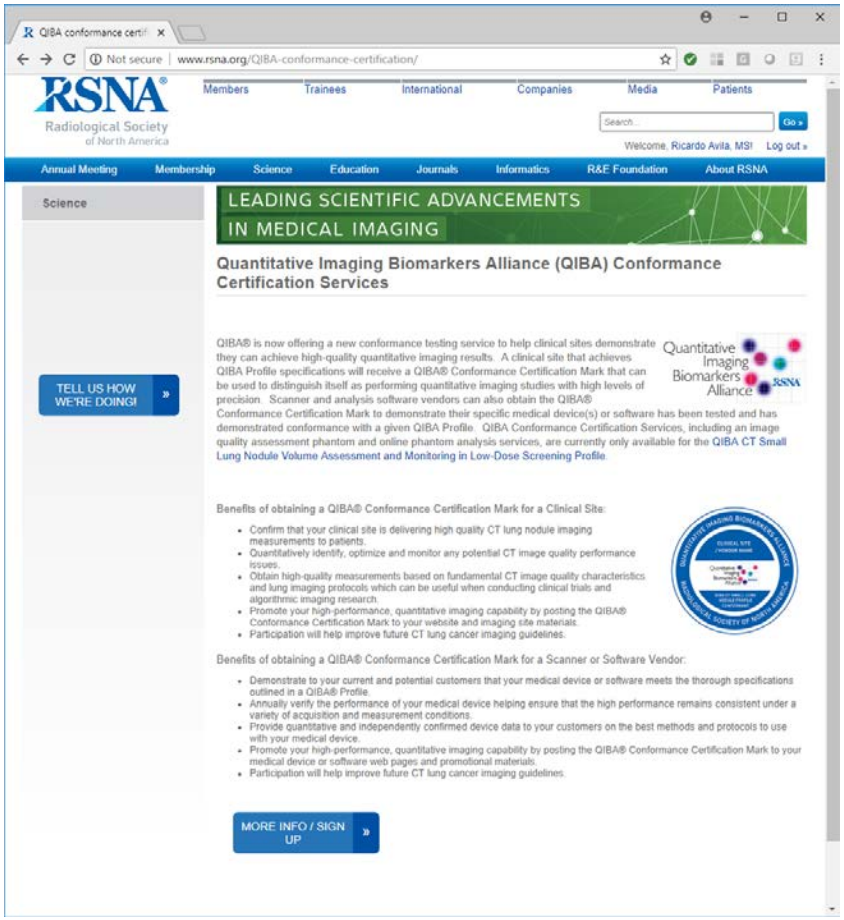
65 CTLX1 Phantoms Shipped As Of 11/3/2018

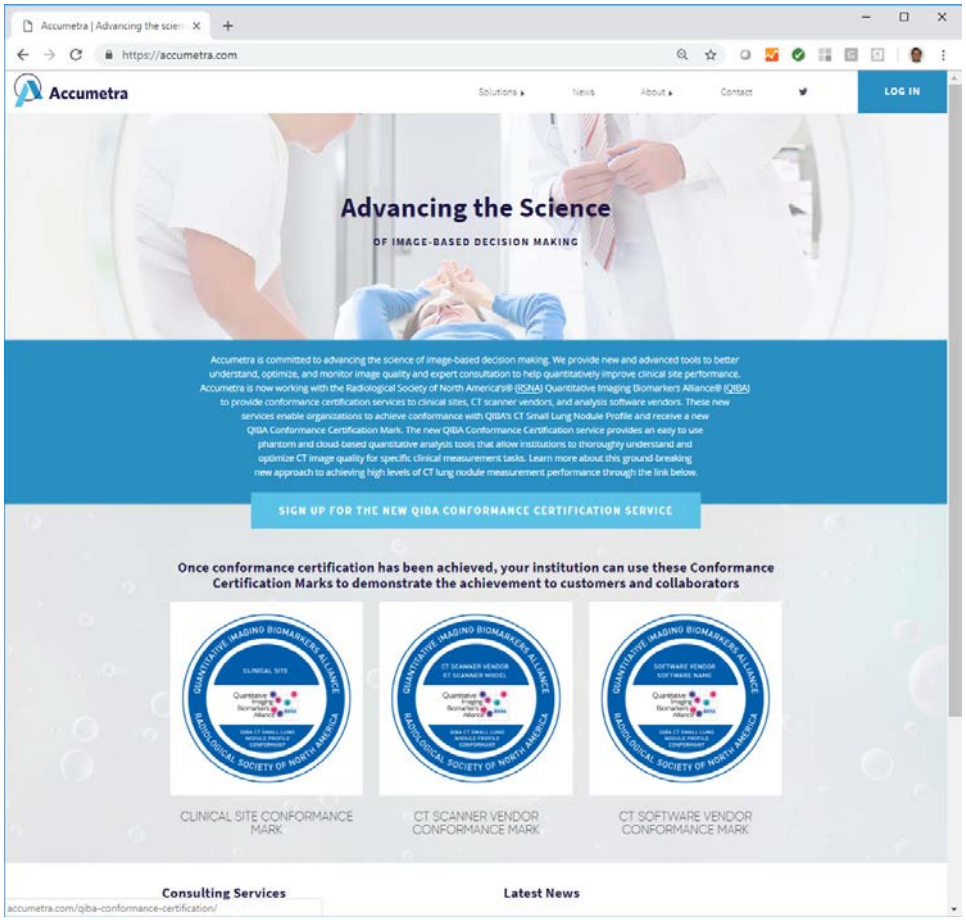
> 240 CTLX1 Scans Received

Quantitative Conformance Data



RSNA/QIBA Conformance Certification

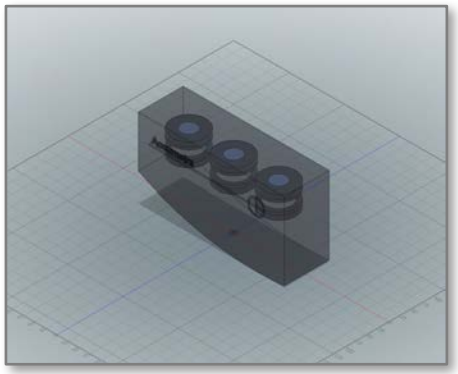




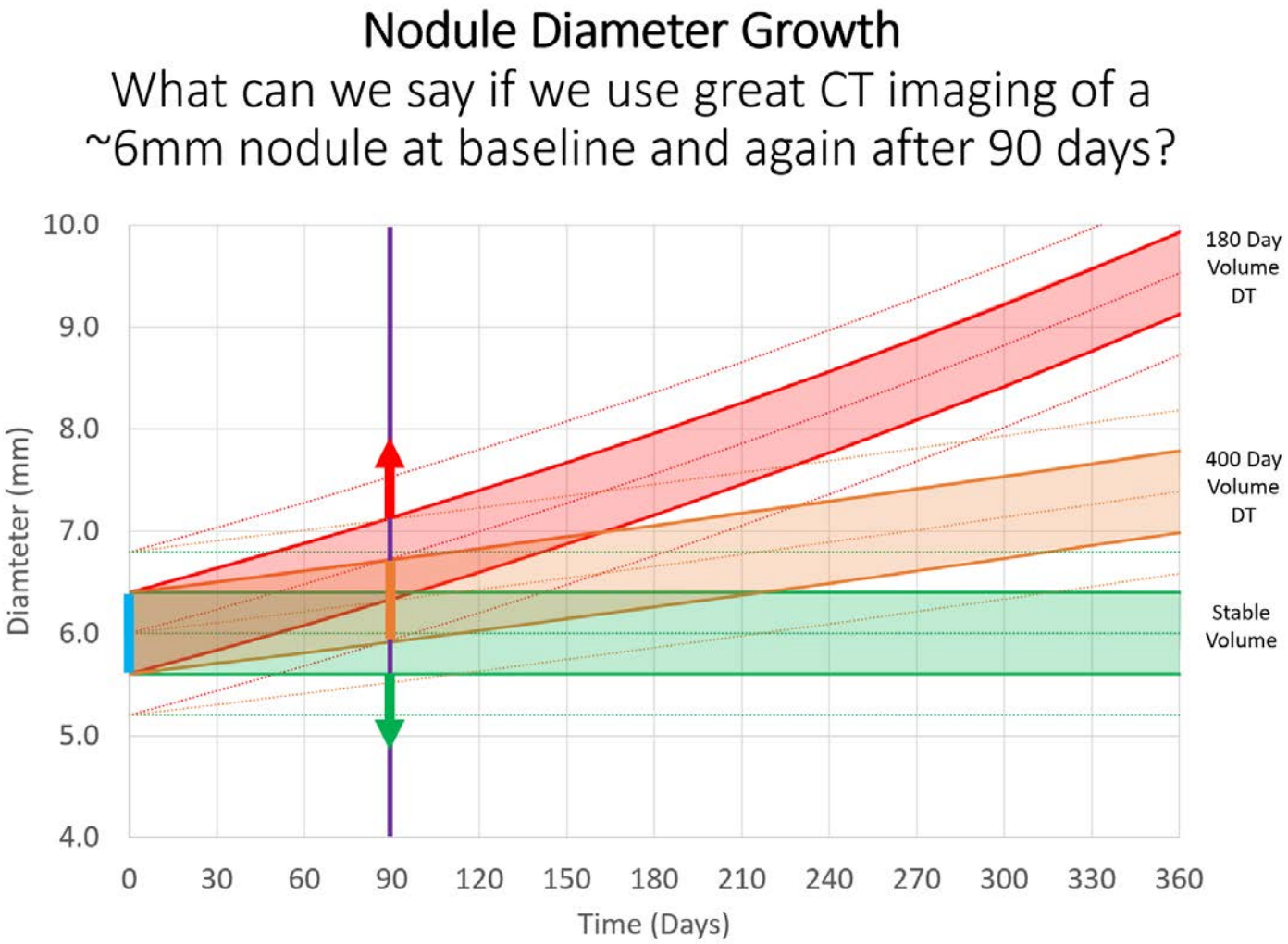
CT Image Quality Control

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



Potential Future Capabilities

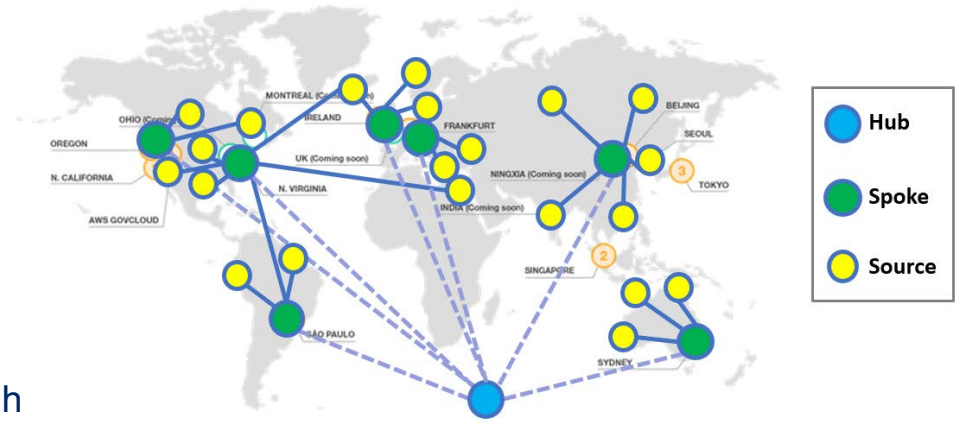
- Nodule Follow-Up Times
  - Lower follow-up time from 3 months down to 1.5 months OR achieve higher sens/spec at 3 months
- Automated Detection & Volume Change
  - With Enough Image Quality We Could One Day Auto Detect >= 3mm Lung Nodules At Annual Screenings And Highlight Only Those That Are Confirmed 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 → 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



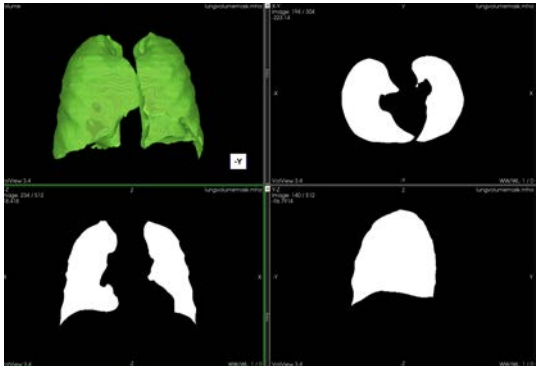
Critical Requirements:

- 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

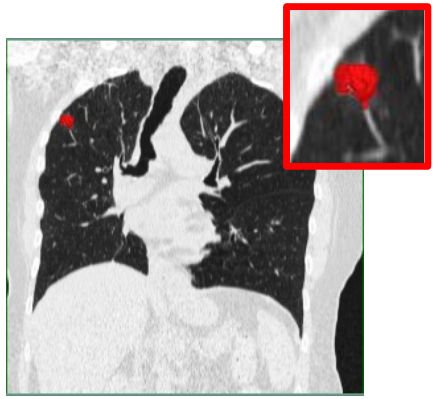
ELIC Pilot Project

- 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 19th 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



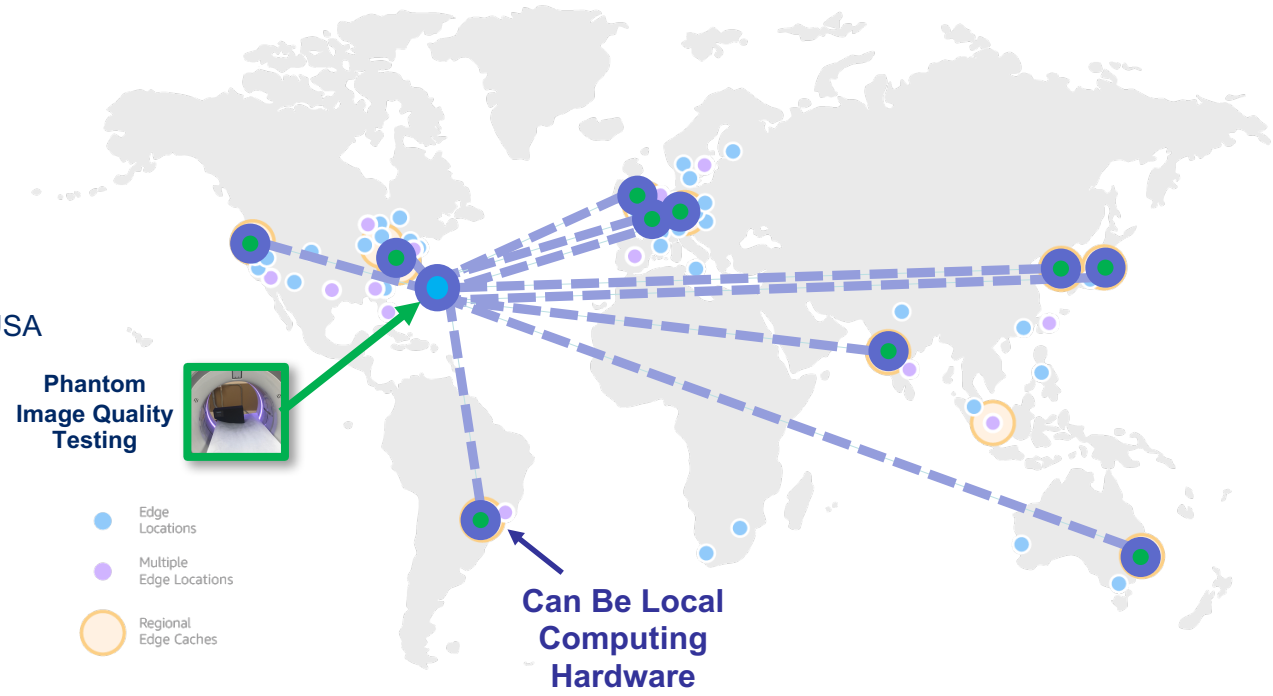
Lung Nodule Volume



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

Hub

- Virginia, USA

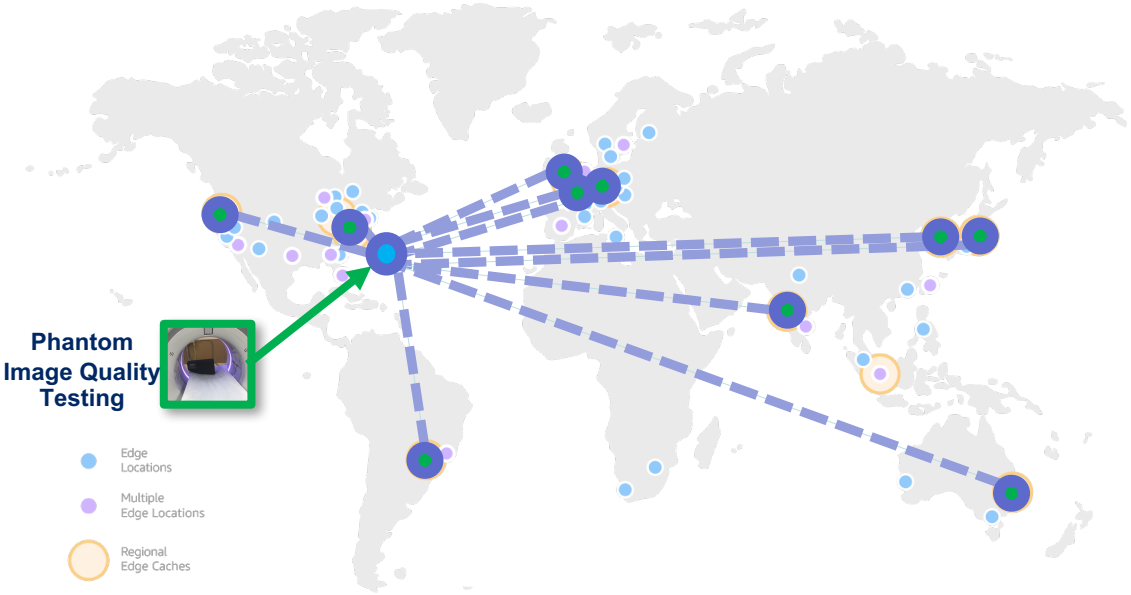


Spokes

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

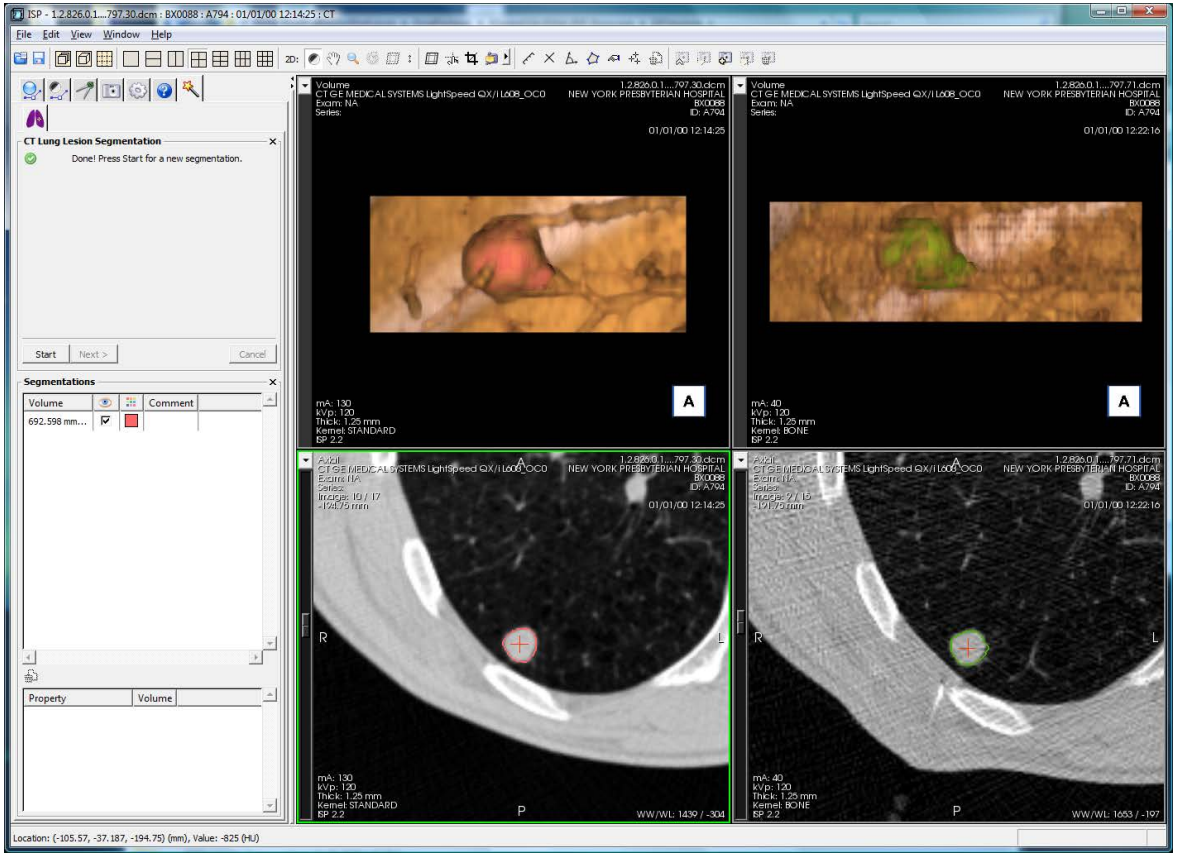
Thank You

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



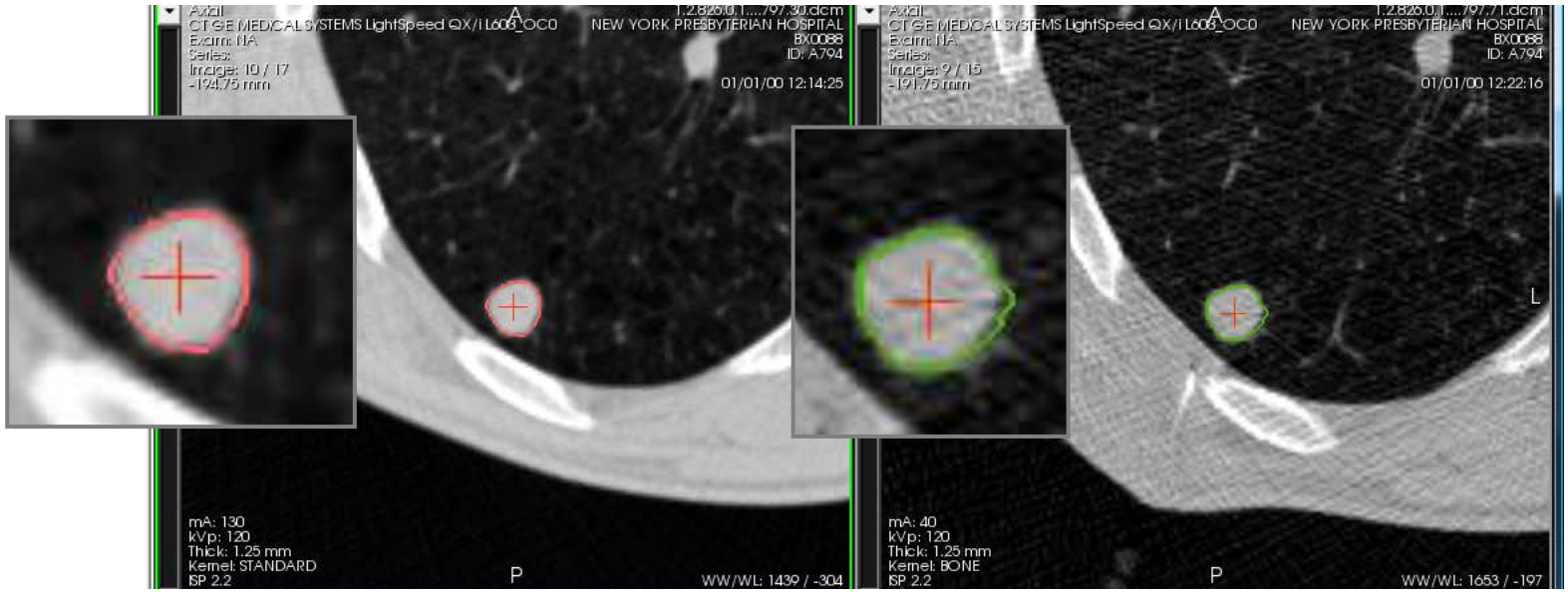
= 668 mm^3 T2 = 661 mm^3

ΔV = 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).

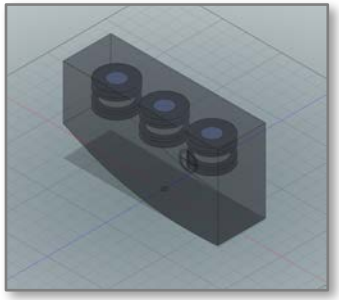


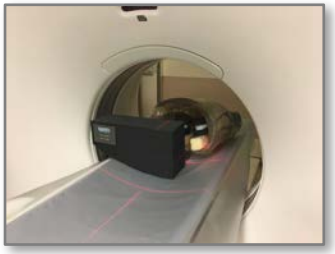
T1 = 668 +- 183 mm^3 **T2 = 661 +- 181 mm^3**

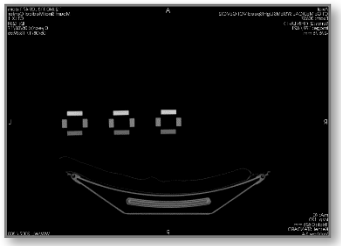
+ 37%
+ 1.2 mm

Volume Change Error = -7 , Volume Change Error = -7 +- 257 mm^3

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







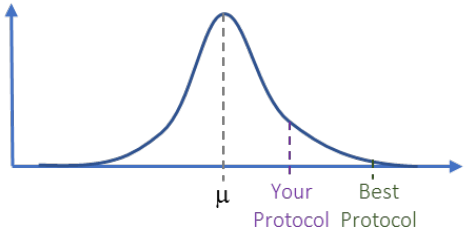
http://quality.rsna.org

Email

Upload

Optimize

Check Each Time Scanner or Protocol Changes and Once Per Year



Guidance

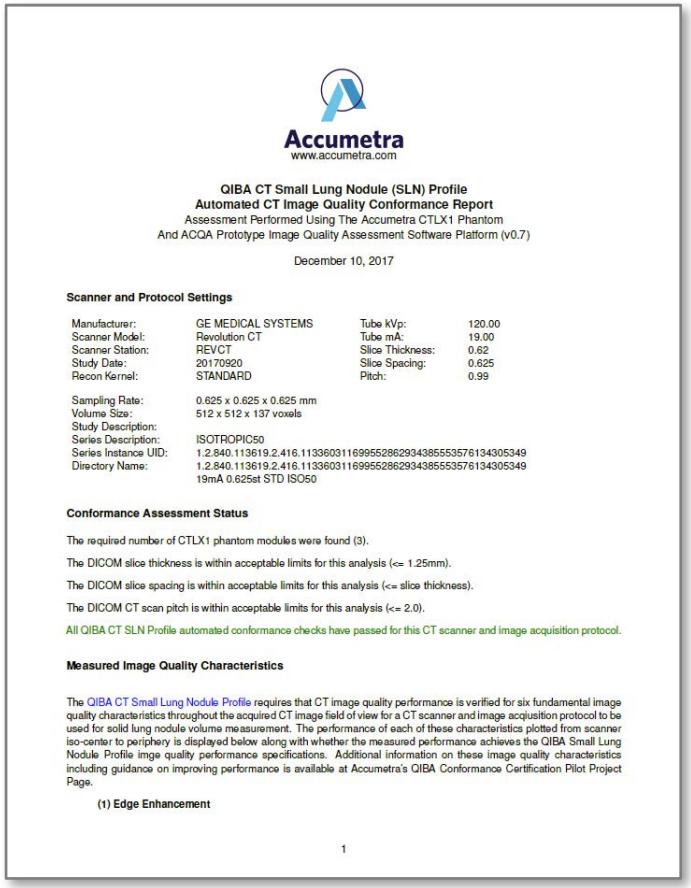
Webpages & FAQs

Automated CT Scanner/Protocol Image Quality Report

Protocol Settings

Analysis Status

Image Quality Measurements



Accumetra
www.accumetra.com

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:	1.2.840.113619.2.416.113360311699552862934385553576134305349
Directory Name:	1.2.840.113619.2.416.113360311699552862934385553576134305349 19mA 0.625st 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 (<= 1.25mm).

The DICOM slice spacing is within acceptable limits for this analysis (<= slice thickness).

The DICOM CT scan pitch is within acceptable limits for this analysis (<= 2.0).

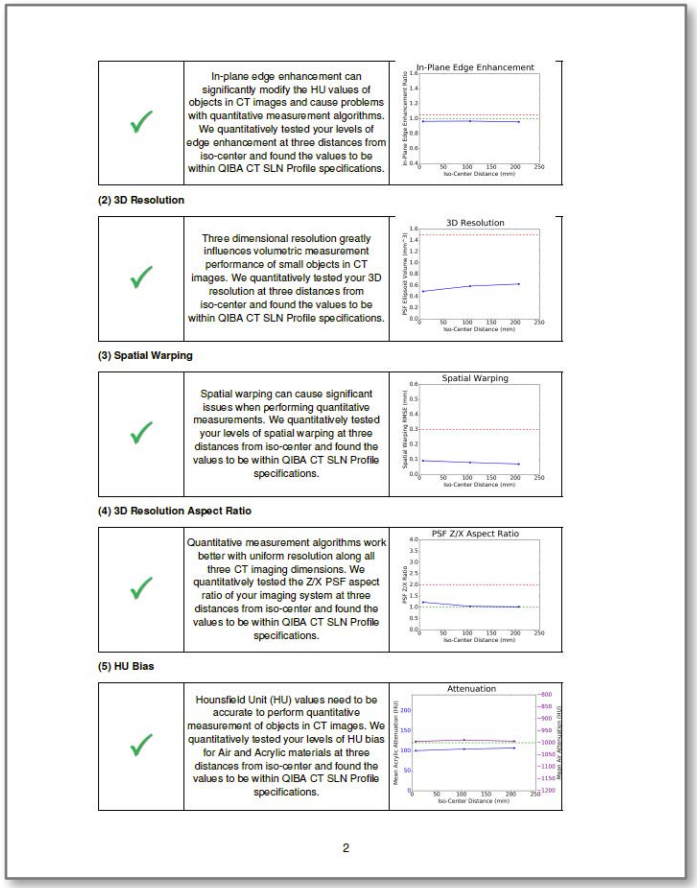
All QIBA CT SLN Profile automated conformance checks have passed for this CT scanner and image acquisition protocol.

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 imge 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



✓	In-plane edge enhancement can significantly modify the HU values of objects in CT images and cause problems with quantitative measurement algorithms. We quantitatively tested your levels of edge enhancement at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	In-Plane Edge Enhancement

(2) 3D Resolution

✓	Three dimensional resolution greatly influences volumetric measurement performance of small objects in CT images. We quantitatively tested your 3D resolution at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	3D Resolution

(3) Spatial Warping

✓	Spatial warping can cause significant issues when performing quantitative measurements. We quantitatively tested your levels of spatial warping at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	Spatial Warping

(4) 3D Resolution Aspect Ratio

✓	Quantitative measurement algorithms work better with uniform resolution along all three CT imaging dimensions. We quantitatively tested the Z/X PSF aspect ratio of your imaging system at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	PSF Z/X Aspect Ratio

(5) HU Bias

✓	Hounsfield Unit (HU) values need to be accurate to perform quantitative measurement of objects in CT images. We quantitatively tested your levels of HU bias for Air and Acrylic materials at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	Attenuation

2

Report With Issues

Accumetra
www.accumetra.com

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:			
Series Description:	STANDARD 2.5mm		
Series Instance UID:	1.2.840.113619.2.416.203336952040789833642456324451142364 03		
Directory Name:	1.2.840.113619.2.416.203336952040789833642456324451142364 03		

Conformance Assessment Status

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

Error: Slice thickness must be <= 1.25 mm to meet the QIBA Small Lung Nodule Profile requirements.

The DICOM slice spacing is within acceptable limits for this analysis (<= slice thickness).

The DICOM CT scan pitch is within acceptable limits for this analysis (<= 2.0).

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

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

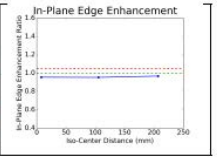
At least one problem was found with the CT images provided. Consider resubmitting a CTLX1 phantom scan with a revised image acquisition protocol.

Measured Image Quality Characteristics

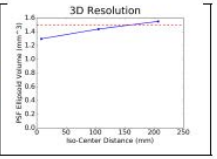
The QIBA CT Small Lung Nodule Profile requires that CT image quality performance is verified for six fundamental image quality characteristics throughout the acquired CT image field of view for a CT scanner and image acquisition protocol to be used for solid lung nodule volume measurement. The performance 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 imge 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.

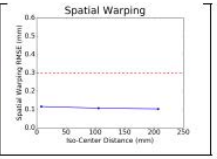
(1) Edge Enhancement

✓	In-plane edge enhancement can significantly modify the HU values of objects in CT images and cause problems with quantitative measurement algorithms. We quantitatively tested your levels of edge enhancement at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	

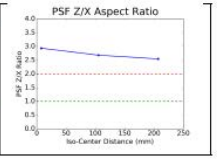
(2) 3D Resolution

✗	Three dimensional resolution greatly influences volumetric measurement performance of small objects in CT images. We quantitatively tested your 3D resolution at three distances from iso-center and found at least one value that exceeds QIBA CT SLN Profile specifications.	

(3) Spatial Warping

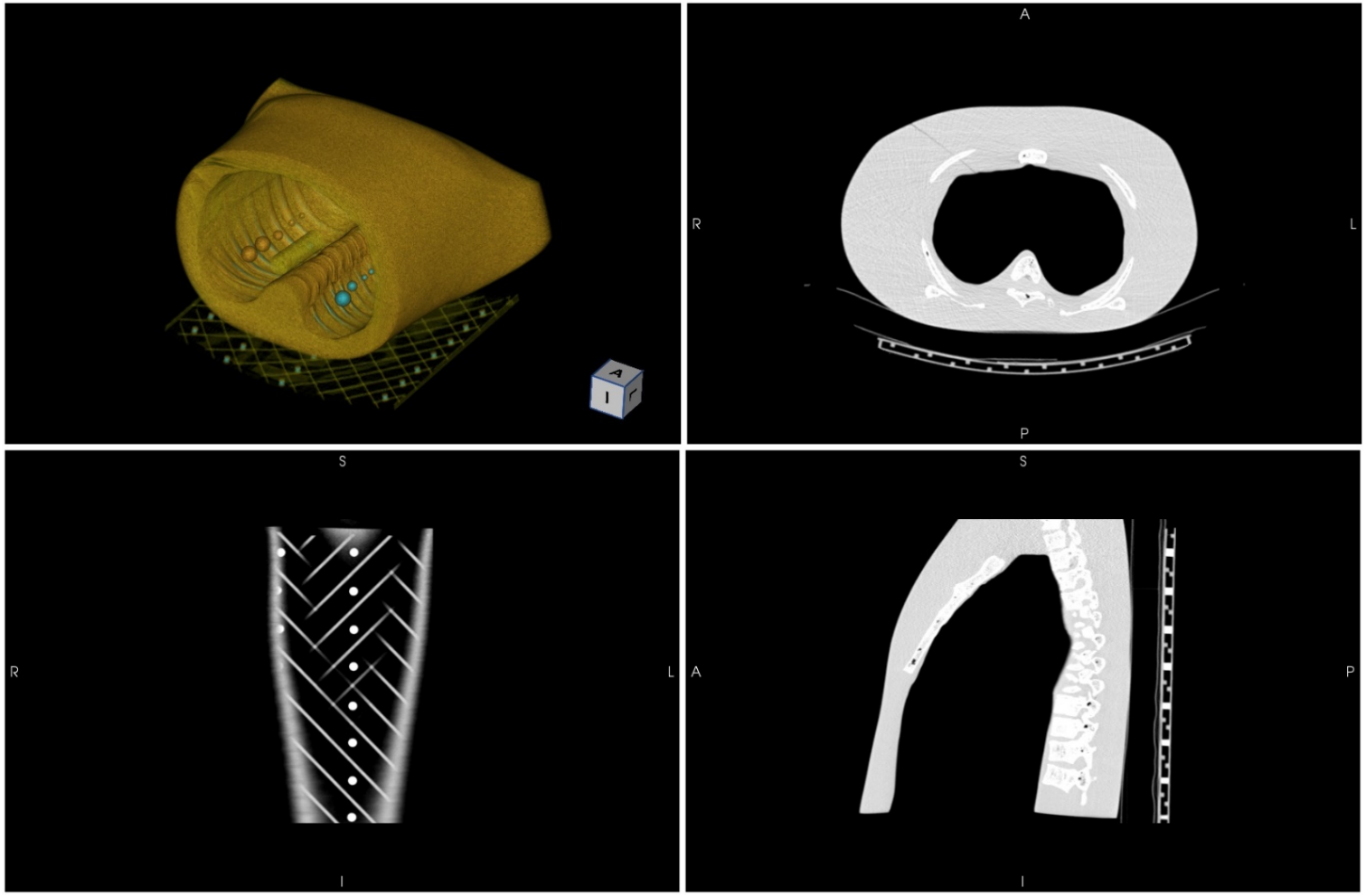
✓	Spatial warping can cause significant issues when performing quantitative measurements. We quantitatively tested your levels of spatial warping at three distances from iso-center and found the values to be within QIBA CT SLN Profile specifications.	

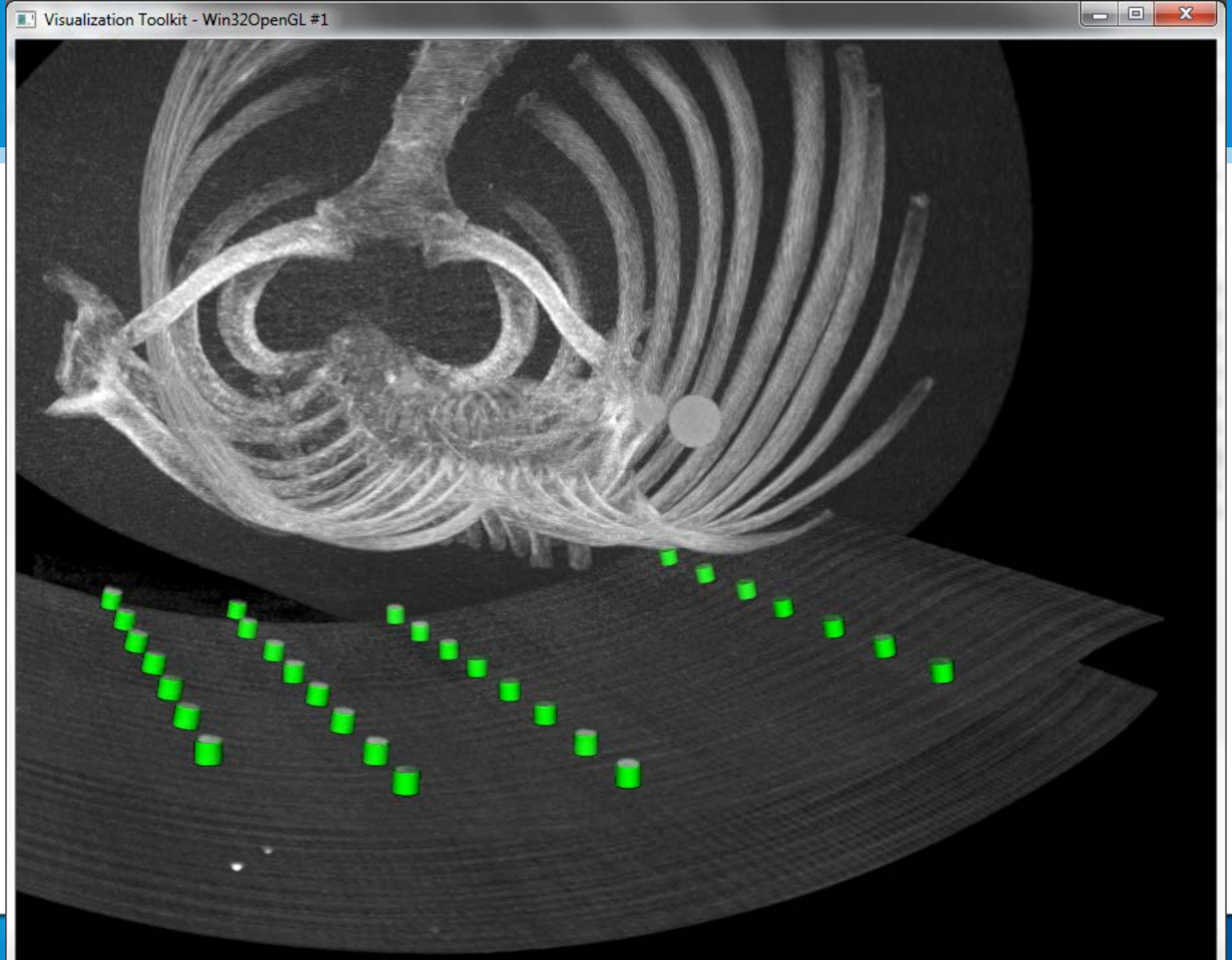
(4) 3D Resolution Aspect Ratio

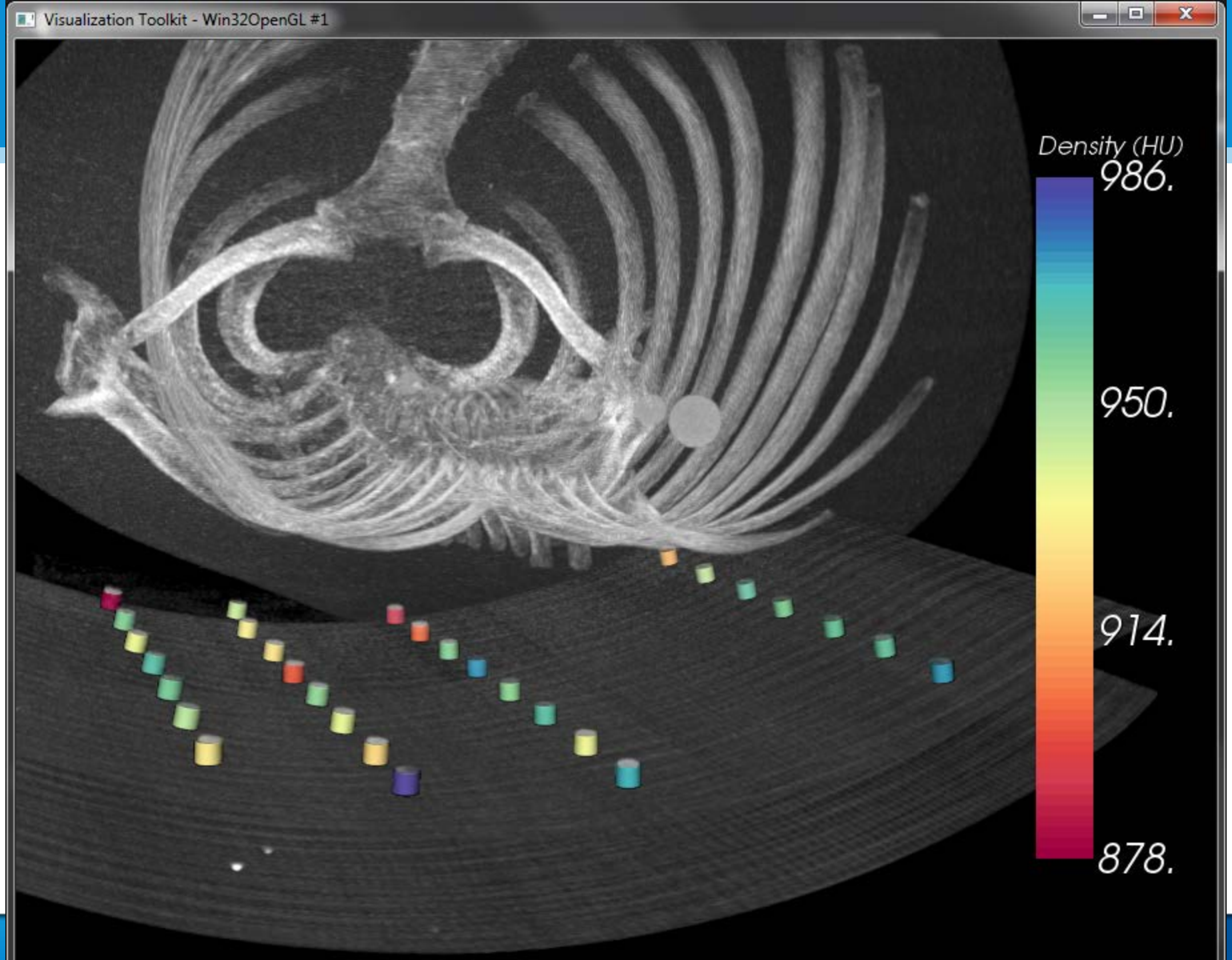
✗	Quantitative measurement algorithms work better with uniform resolution along all three CT imaging dimensions. We quantitatively tested your PSF Sigma Z/X aspect ratio at three distances from iso-center and found at least one value that exceeds QIBA CT SLN Profile specifications.	

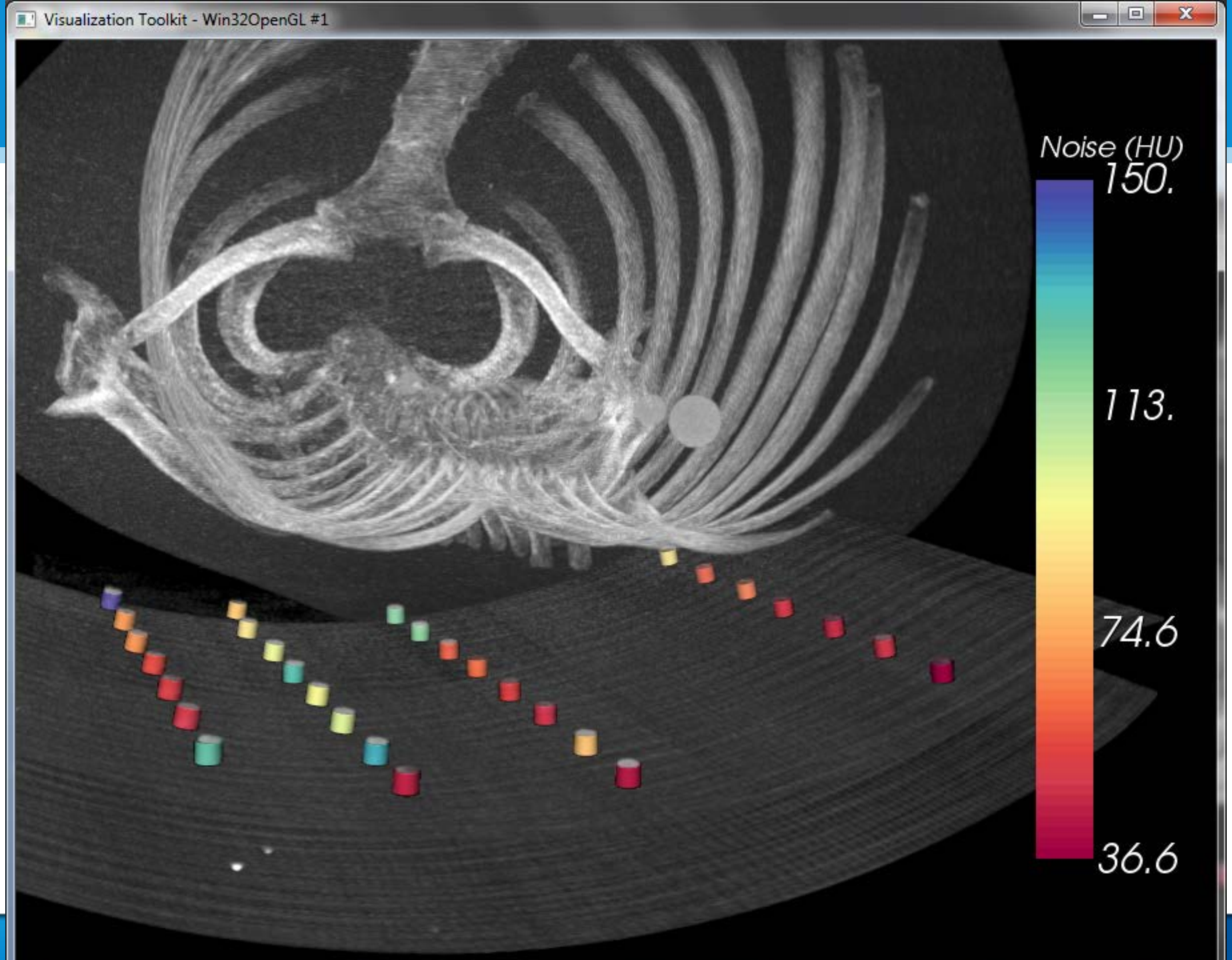
(5) HU Bias

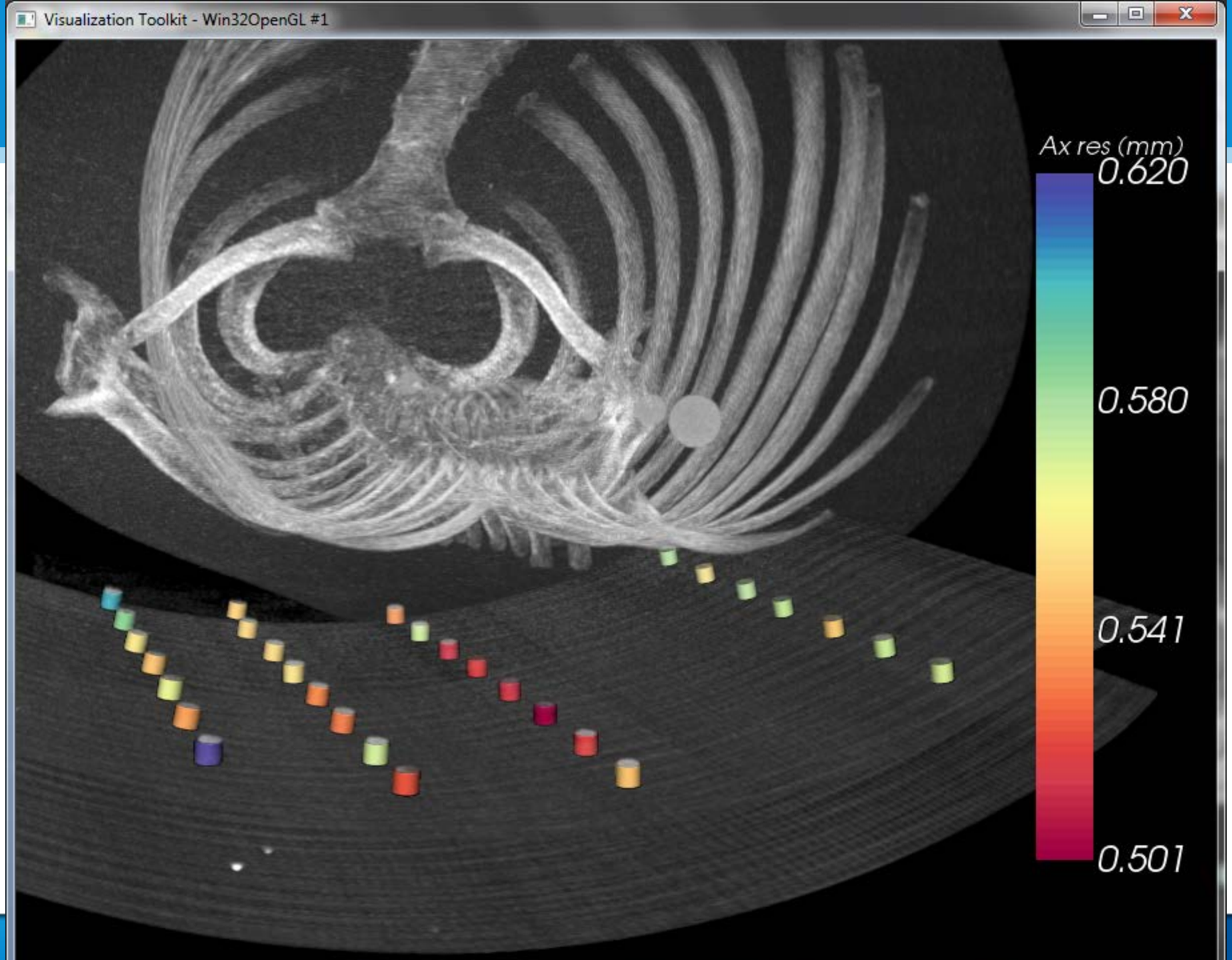
Table Phantom Scanning

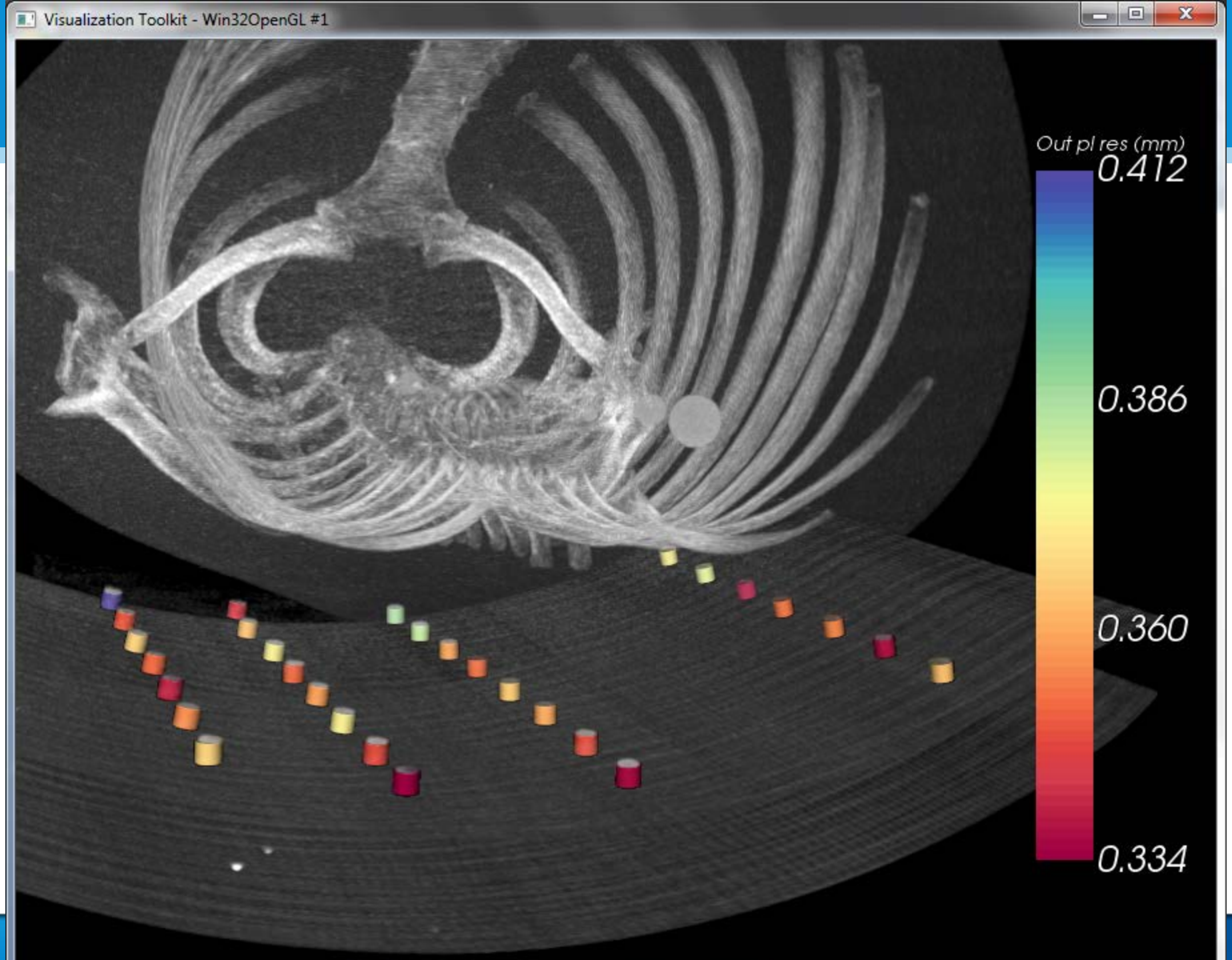



Visualization Toolkit - Win32OpenGL #1

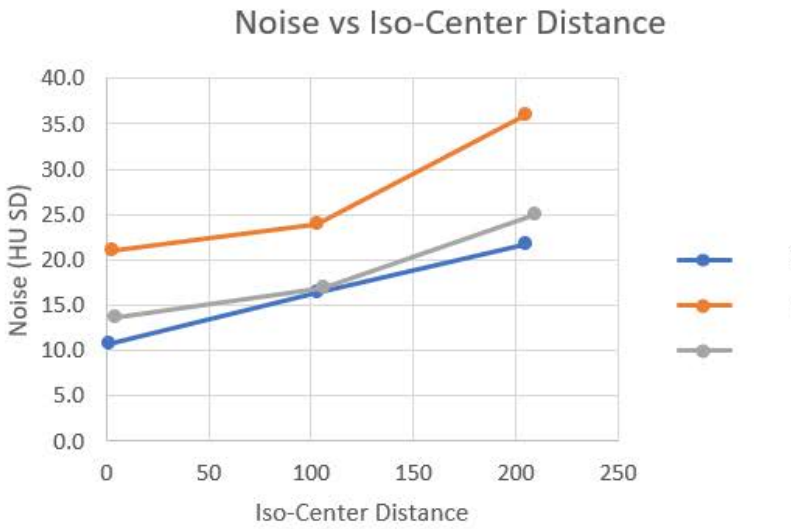

Visualization Toolkit - Win32OpenGL #1
Density (HU)
986.
950.
914.
878.


Visualization Toolkit - Win32OpenGL #1
Noise (HU)
150.
113.
74.6
36.6

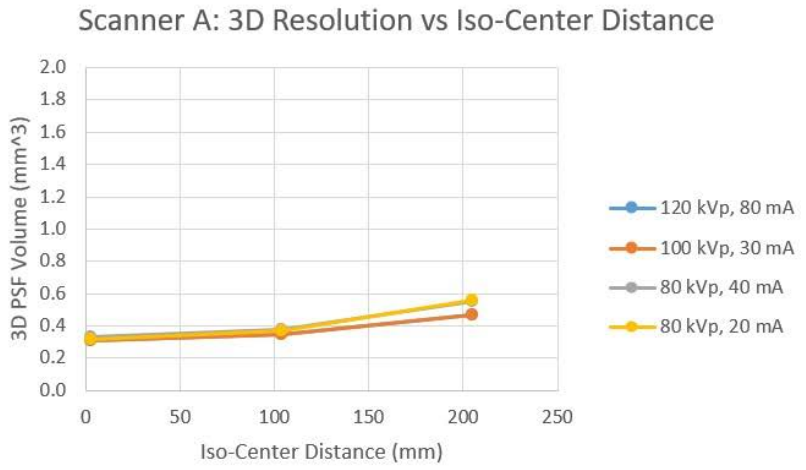

Visualization Toolkit - Win32OpenGL #1
Ax res (mm)
0.620
0.580
0.541
0.501

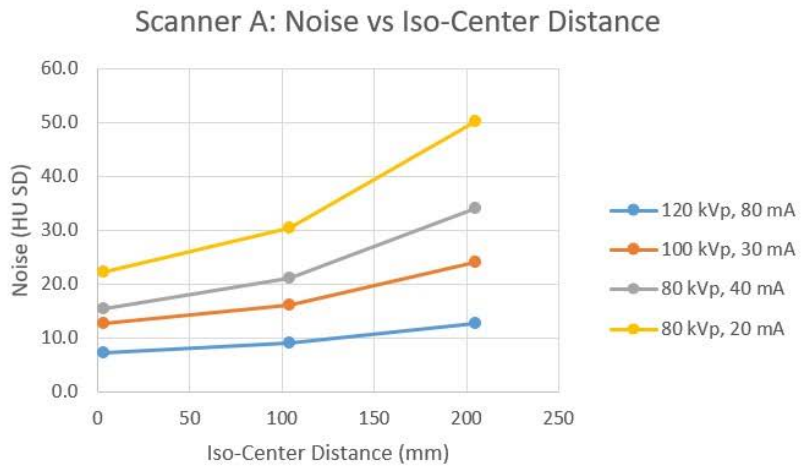

Visualization Toolkit - Win32OpenGL #1
Out pl res (mm)
0.412
0.386
0.360
0.334

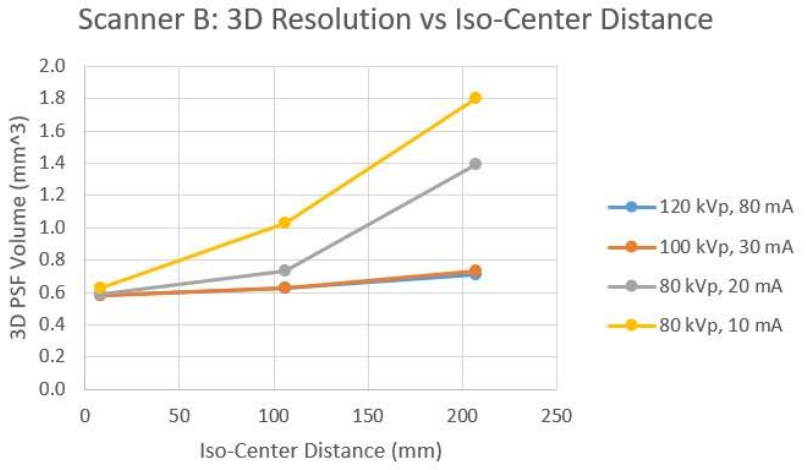
Where Will Improved Image Quality Take Us?

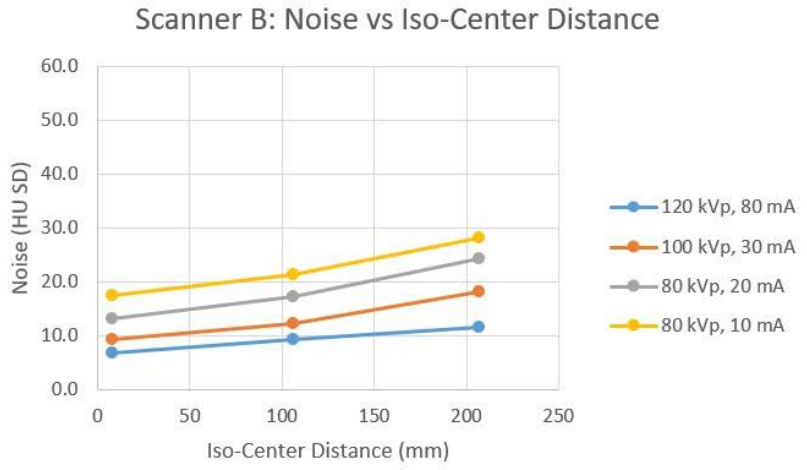


Radiation Dose and Resolution









Requested vs Observed Slice Thickness