

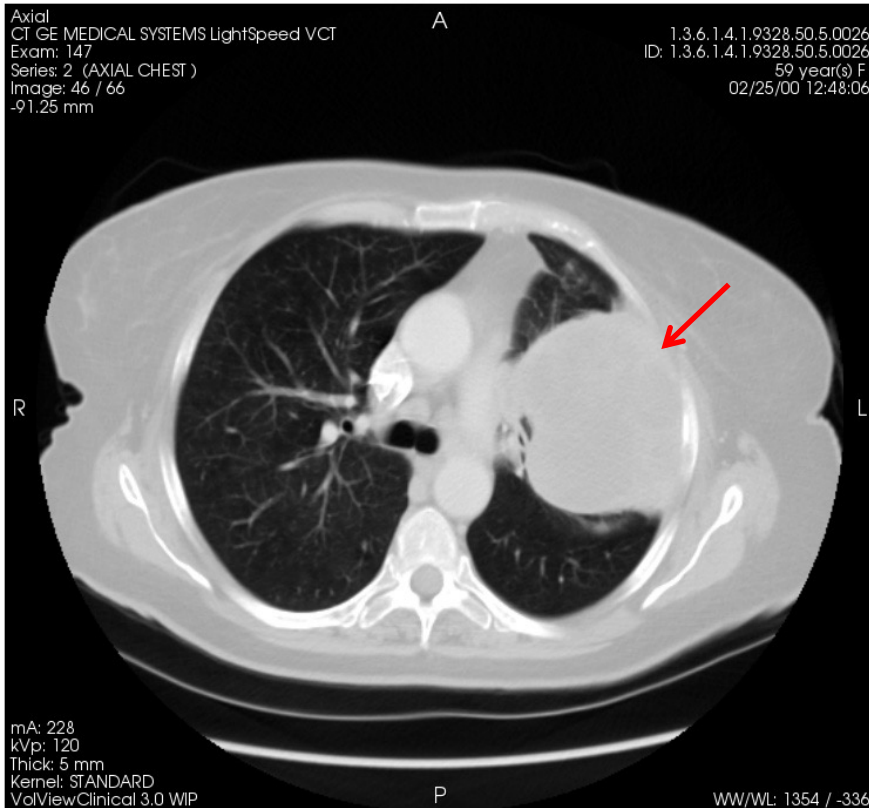
# **Improving CT Lung Cancer Screening Through Calibration Phantom and Software Innovations**

**Rick Avila**  
**Accumetra, LLC**

November 5, 2021

# Lung Cancer Screening

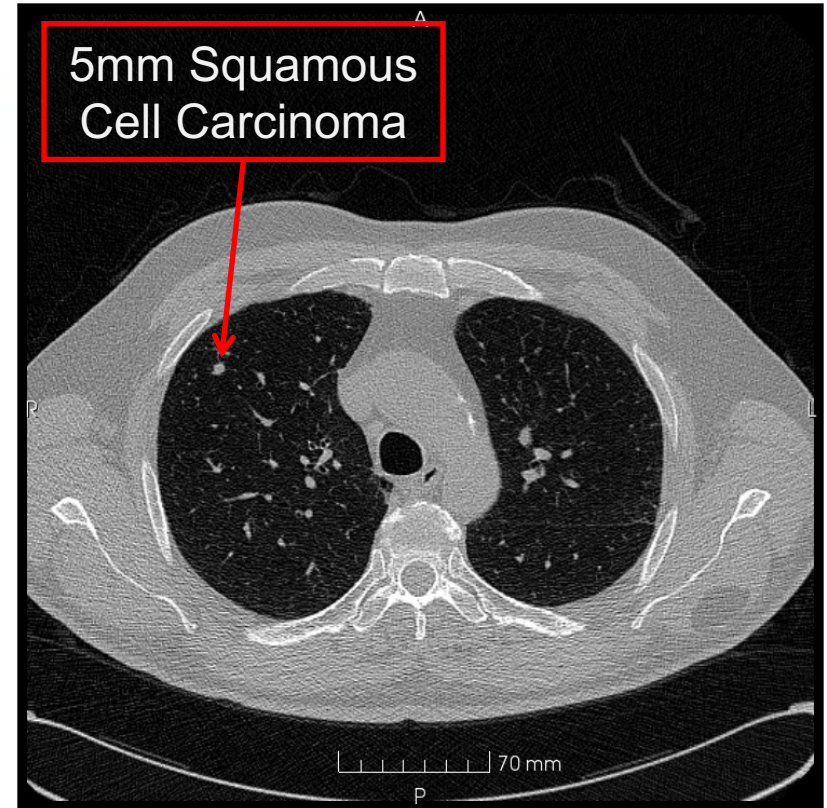
## Late-Stage Lung Cancer (1.76 Million Deaths/Year)



[R. Gottlieb, Roswell Park Cancer Institute]

**~5% five year survival**

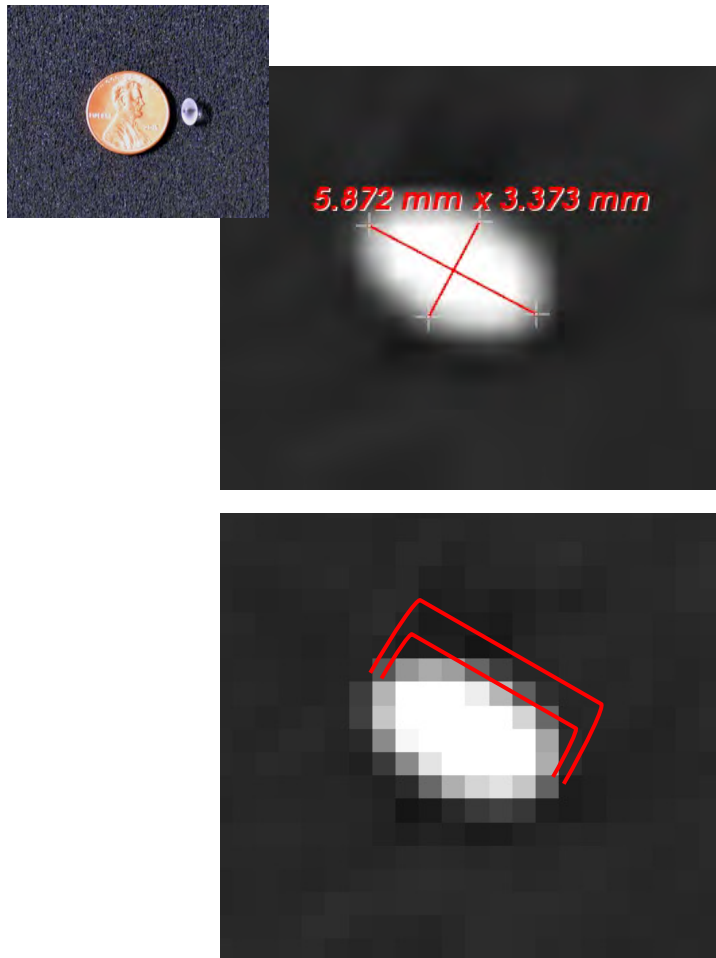
## Early Lung Cancer



[Dr. Javier Zulueta, University of Navarra]

**~85% five year survival**

# 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**

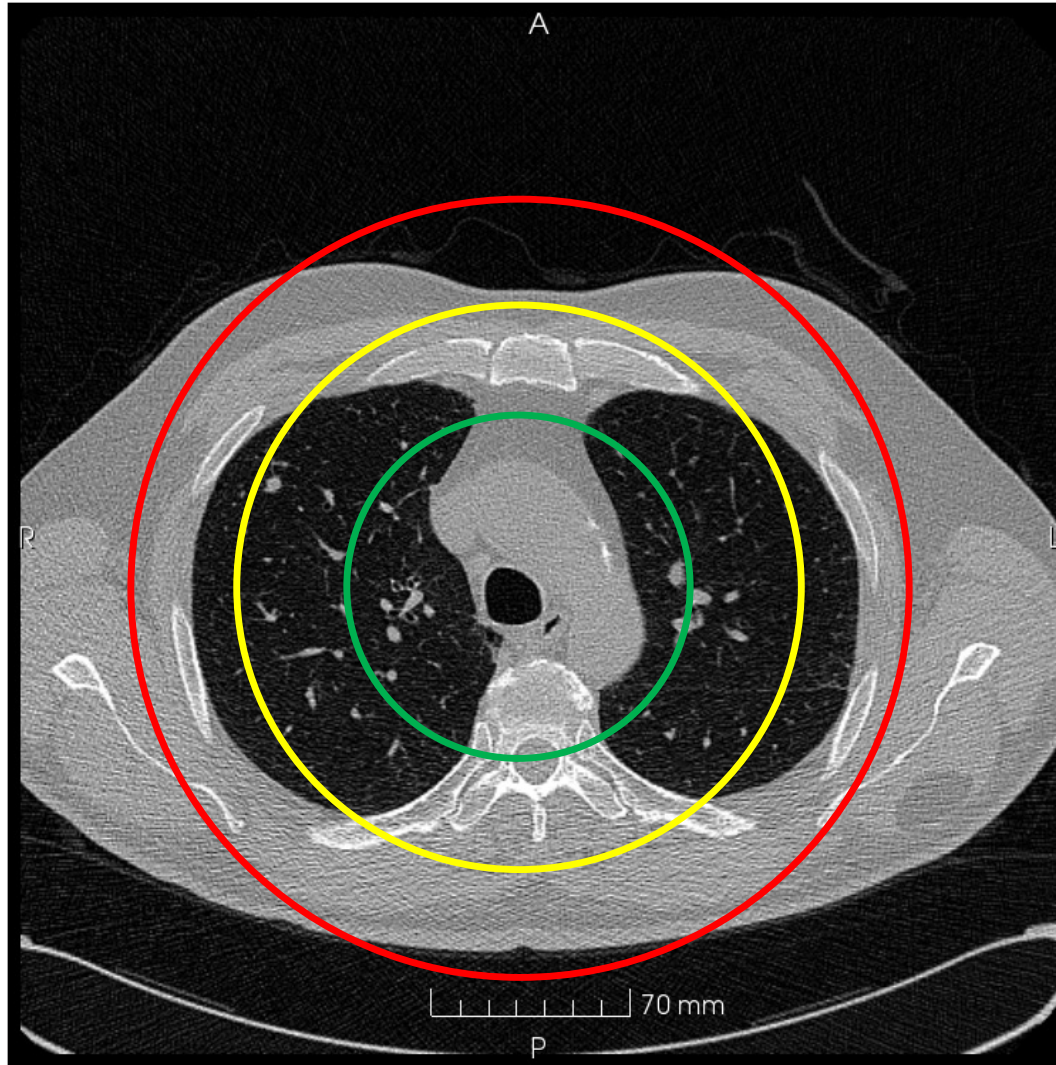
Nodule Diameter	Diameter Change %	Volume Change %
6.0	17%	59%
7.0	14%	49%
8.0	13%	42%
9.0	11%	37%
10.0	10%	33%

**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)**

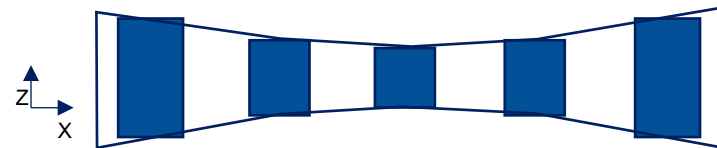
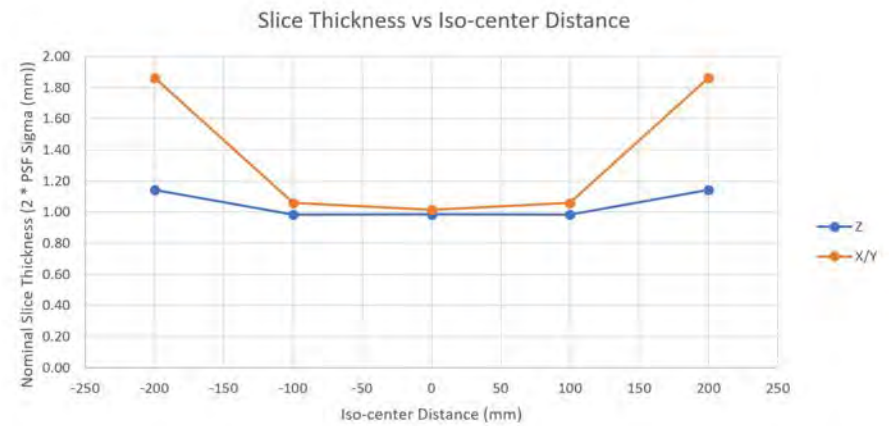
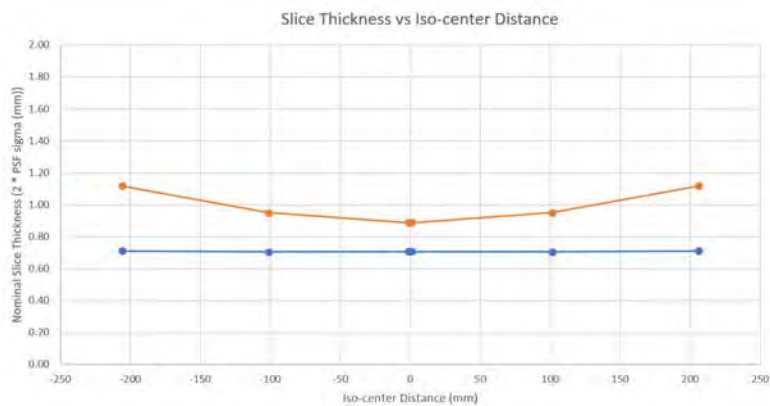
**Numerous CT Image Quality Issues Can Bias This Measurement**  
**Use of Precise and Quality Controlled Quantitative Image Measurement Tools Is Critical**

# In Plane CT Image Quality



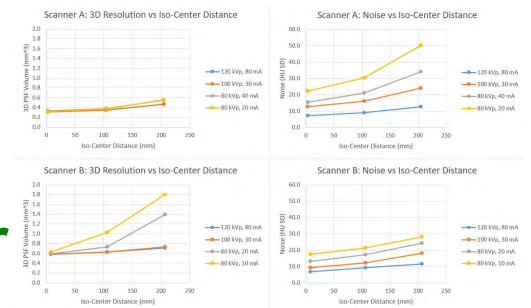
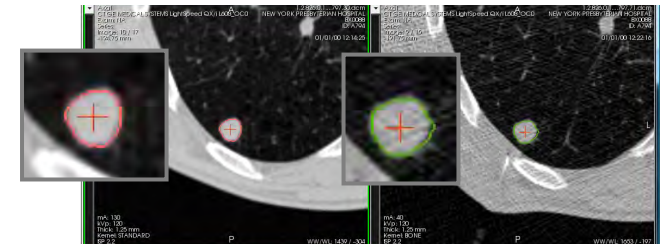
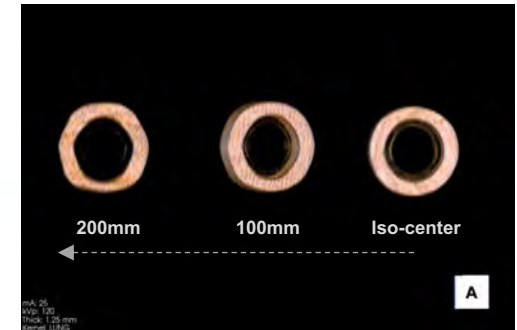
- Best
- Medium
- Worst

# Slice Thickness In X, Y, and Z



# 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
  - ...

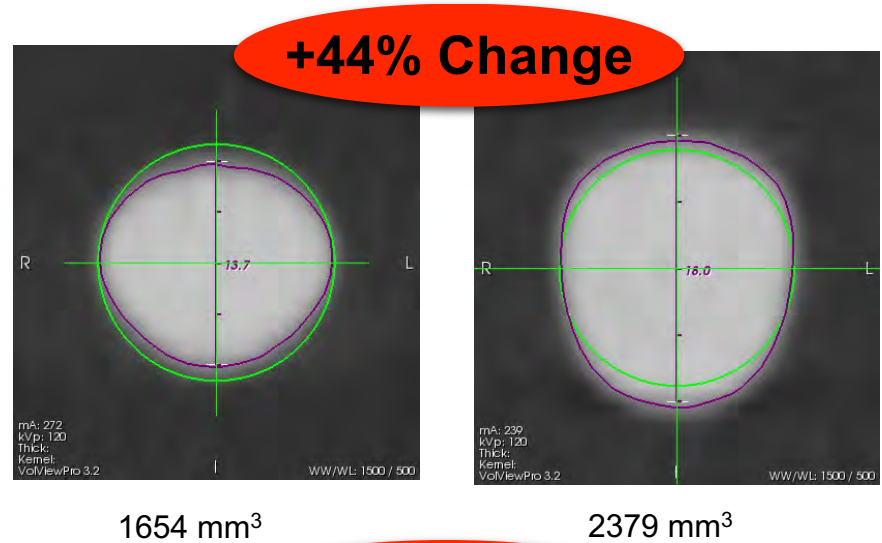


**We need to constantly measure and monitor  
CT detection and measurement equipment**

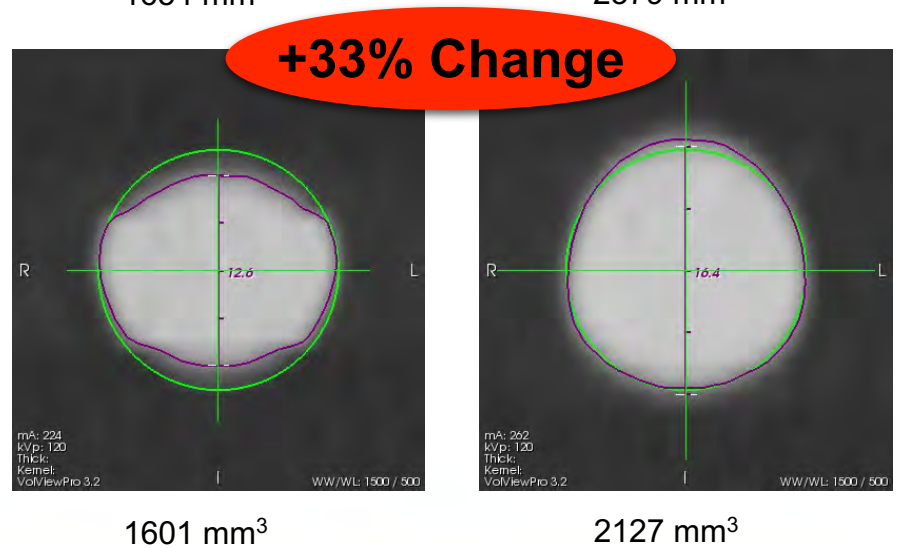
# 2010: Roche ABIGAIL Study



**Model A  
Site 1**

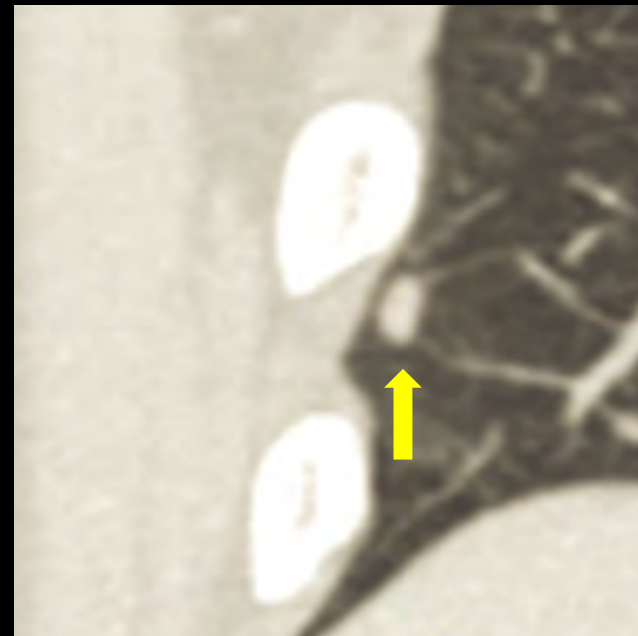
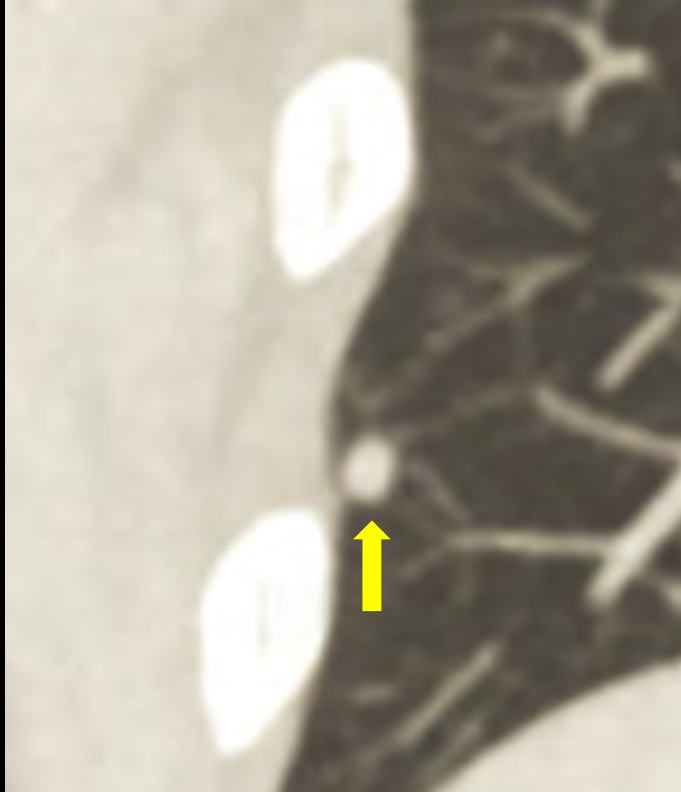


**Model A  
Site 2**



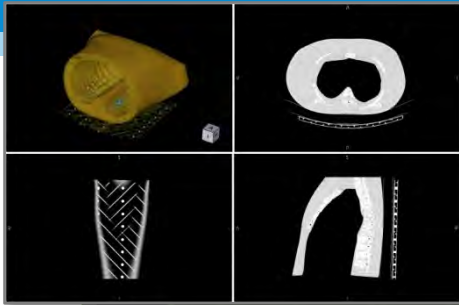
[Henschke, ... Avila, J Med Imaging 2016]

# Clinical Biopsy Case

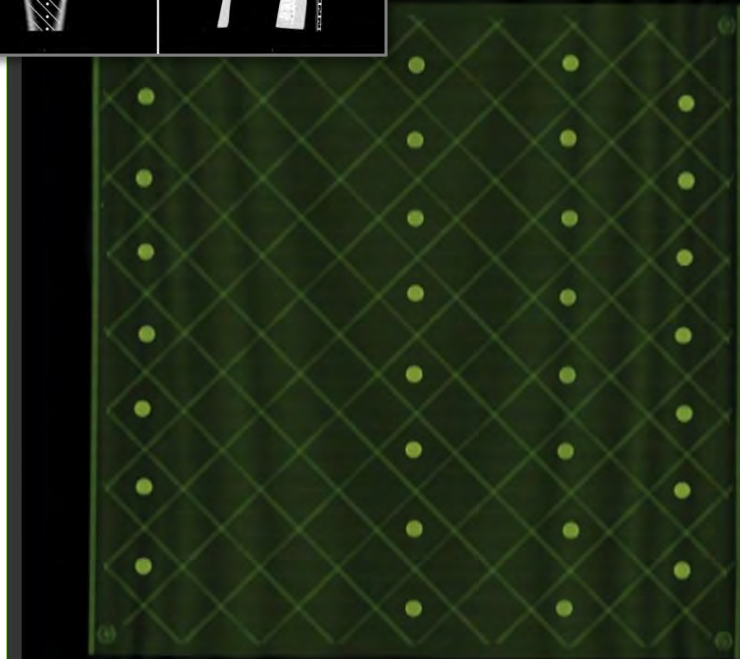




# Table Phantom Scanning On a 16 Slice

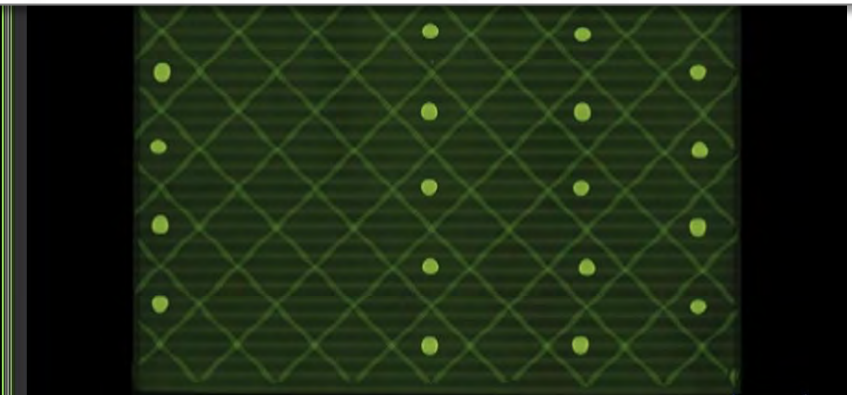
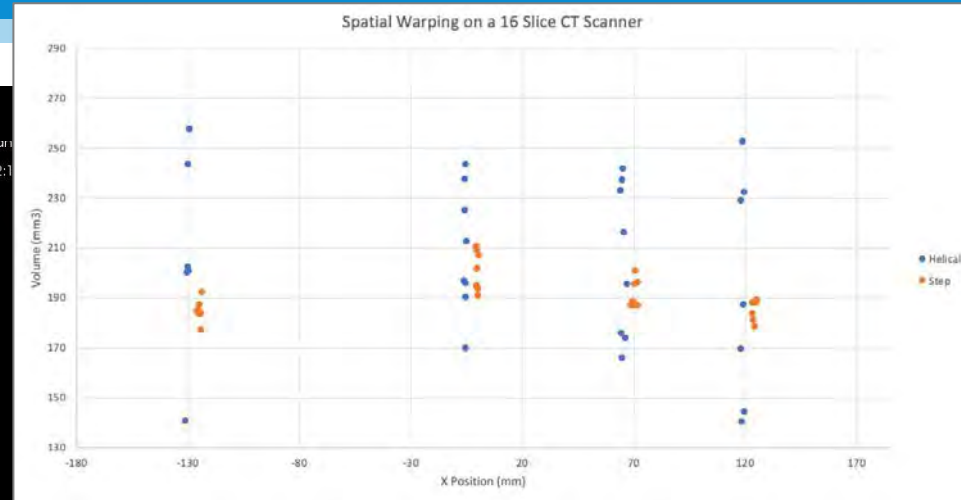


id: tablephant  
07/31/15 12:1



A

Step & Shoot Acquisition



A

Helical Acquisition

# CT Scanner Spatial Warping

- CT spatial warping was 1st reported at meetings in 2011.
- It took > 3 years to publish spatial warping results observed on multiple scanners from a phase II clinical trial (JMI 2016).
- Numerous presentations by me and others every year from 2011 – 2021 have described this problem.
- Yet, even today in 2021:
  - FDA approves these CT scanners for lung screening.
  - AAPM provides screening protocols for these scanners.
  - No mention of these model scanners in numerous lung screening guidelines.
  - Numerous medical physicists continue to deny this is real.
- So after > 10 years of studying and reporting on this it is long past time for the community to accept that this major CT image quality problem happened and that global CT image quality monitoring needs to be updated and running continuously so image quality lapses of this magnitude never happen again.

## AAPM 2019 LCS Protocols

Lung Cancer Screening CT Protocols Version 5.1, 13 September 2019

**LUNG CANCER SCREENING CT (Selected GE scanners with AEC (anrma))** [\(Back to Index\)](#)

SCOUT AP 300-1400, from top of shoulder through mid-thorax. If automatic exposure control is used, PA scout if manual mA is used.

	LightSpeed Nt	LightSpeed Nt	LightSpeed VCT	LightSpeed VCT
Scan Type	Volume	Volume	Volume	Volume
Rotation Time (s)	0.1	0.5	0.5	0.5
Beam Collimation (mm)	43750	30	40	40
Detector Configuration	Full FOV 16x128	16x128	8x64 625	8x64 625
Pitch	1.375	1.076	0.984	0.984
Speed (mm/s)	13.75/27.50	27.5	30.30	30.30
AP	100	100	100	100
max mA	40	40	30	30
max mA	100	100	110	110
Noise Index (mAs/mA)	32	32	32	32
SI-CM	Large Body	Large Body	Large Body	Large Body
CTDIvol	2.8/1.2 mGy	2.4 mGy	2.3 mGy	2.2 mGy

Plane	Axial	Axial	Axial	Axial
Algorithm	Long or Bone	Long or Bone	Long or Bone	Long or Bone
Recon Mode	Full or Plus	Full or Plus	Full or Plus	Full or Plus
Thickness (mm)	2.5	2.5	2.5	2.5
Interval (mm)	1.25	1.25	1.25	1.25
ALGORITHM V (if used)				

Plane	Axial	Axial	Axial	Axial
Algorithm	Long or Bone	Long or Bone	Long or Bone	Long or Bone
Thickness (mm)	3.0/1.5	3.0	3.0	3.0
Interval (mm)	3.4/1.7/0.8	1.0/0.5	1.4	0.7
ALGORITHM V (if used)			10	10

Plane	MP	MP	MP	MP
Algorithm	MP	MP	MP	MP
Thickness (mm)	8	4	4	4
Interval (mm)	3	3	3	3
ALGORITHM V (if used)				

Recon Option

	MP	MP	MP	MP
Search Interval	100-200	100-200	100-200	100-200
Ang. Position	100-200	100-200	100-200	100-200
Large Patient	100-200	100-200	100-200	100-200

\*Noise Index values (SI-CM) require a FOV of 2.5 times reconstructed image thickness, as defined, for full reconstruction. If other scan thicknesses are used, SI-CM or 1.25 cm, are selected for the first reconstruction, then a different Noise Index value must be chosen in order to achieve the CTDIvol values described here. This is because the Noise Index value is related to the image thickness of the first reconstruction.

Agree: Weight (mm) Agree: Weight (mm) mA Agree: CT (DIPN) (mm)

Small Patient 100-200 100-200 100-200 100-200

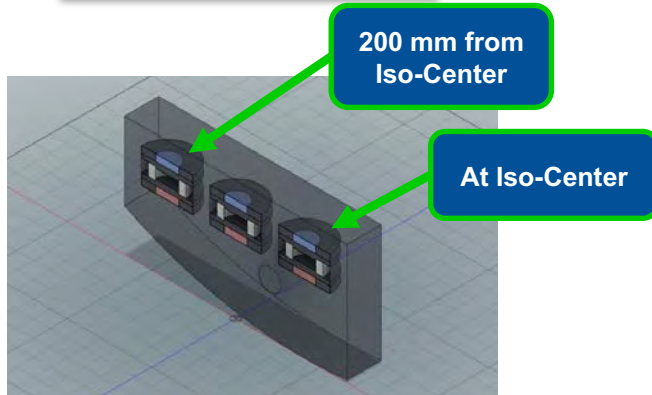
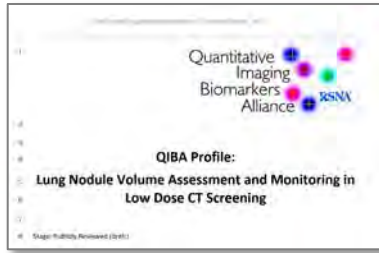
Ang. Position 100-200 100-200 100-200 100-200

Large Patient 100-200 100-200 100-200 100-200

The disclaimer found on page 1 is an integral part of this document.  
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# CTLX1 Phantom

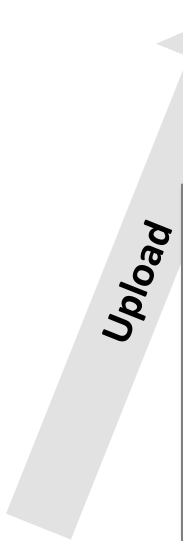
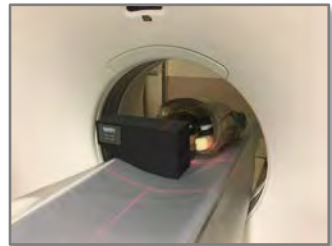
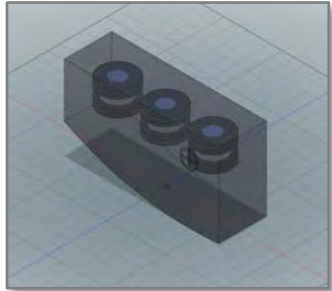
The 1<sup>st</sup> Phantom To Build A 3D Math Model Across The Full Scanner FOV



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

# CT Image Quality Verification Using Cloud-Based Computing Services



**Accumetra**  
www.accumetra.com

**QIBA CT Small Lung Nodule (SLN) Profile**  
Automated CT Image Quality Conformance Report  
Assessment Performed Using The Accumetra CT SLN Phantom  
And ACCA Prototype Image Quality Assessment Software Platform (v6.1)  
December 10, 2017

**Scanner and Protocol Settings**

Manufacturer:	GE MEDICAL SYSTEMS	Tube Angle:	0.000
Scanner Model:	Revolution CT	Tube vol:	18.50
Scanner Station:	REVCT	Slab Thickness:	0.82
Stack Size:	250SLAC	Slab Number:	0.000
Recon Method:	STANDARD	Phi:	0.00

**Reporting Data:**  
Volume Size: 512x 512 x 120 voxels  
Stack Orientation: Axial  
Series Description: ACCURACIOS  
Series Instance UID: 1.2.840.113619.2.416.1.1599011899506204365500761400348  
Study Instance UID: 1.2.840.113619.2.416.1.1599011899506204365500761400348  
Study Name: 1599011899506204365500761400348

**Conformance Assessment Status**

- The required number of CT SLN phantom nodules were found (2).
- The DICOM slice thickness is within acceptable limits for this protocol (w/ 1.25mm).
- The DICOM slice collimation is within acceptable limits for this analysis (w/ slice thickness).
- The DICOM CT scan pitch is within acceptable limits for this analysis (w/ 1.0).

**Measured Image Quality Characteristics**

The QIBA CT Small Lung Nodule Profile requires that CT image quality performance is verified for six anatomical image quality characteristics throughout the AccuMeta CT image field of view. In a CT scanner and acquisition optimized for use for small lung nodule volume measurement, the performance of each of these characteristics is quantified and reported as either a pass or fail. The pass or fail is determined by comparing the measured image quality characteristics to the QIBA Small Lung Nodule Profile image quality performance specifications. Additional information on these image quality characteristics including protocols for improving performance is available at Accumetra's QIBA Conformance Guidelines PDF Project Page.

(1) Edge Enhancement

Quantitative edge enhancement can significantly quantify the full extent of detected CT SLN edge and noise problems with quantitative measurement algorithms. We quantitatively tested your levels of edge enhancement. All three distances from the center and found the values to be within QIBA CT SLN Profile specifications.

(2) 2D Resolution

These dimensional resolution greatly influence volumetric measurements performance at small objects in CT images. We quantitatively tested your 2D resolution at three distances from the center and found the values to be within QIBA CT SLN Profile specifications.

(3) Scatter Imaging

Scatter weighting can cause significant volume edge enhancement problems. We quantitatively tested your scatter weighting at three distances from the center and found the values to be within QIBA CT SLN Profile specifications.

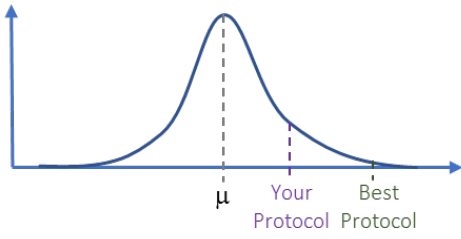
(4) 3D Resolution (Agatston Rate)

Quantitative measurement algorithms work better with uniform resolution along all three CT imaging dimensions. We quantitatively tested the ENR based rates of your imaging system at three distances from the center and found the values to be within QIBA CT SLN Profile specifications.

(5) HU Bias

Measured line HU values need to be accurate to perform quantitative measurement of objects in CT images. We quantitatively tested your levels of HU bias for all axial slices regardless of their distances from the center and found the values to be within QIBA CT SLN Profile specifications.

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

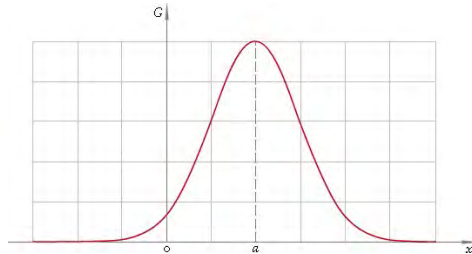


**Guidance**  
Webpages & FAQs

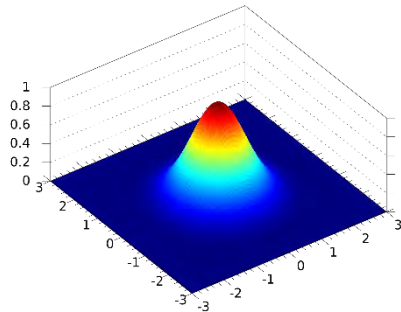
**Optimize**

# We Build 3D Mathematical Models of CT Scanners With An Emphasis On 3D Resolution

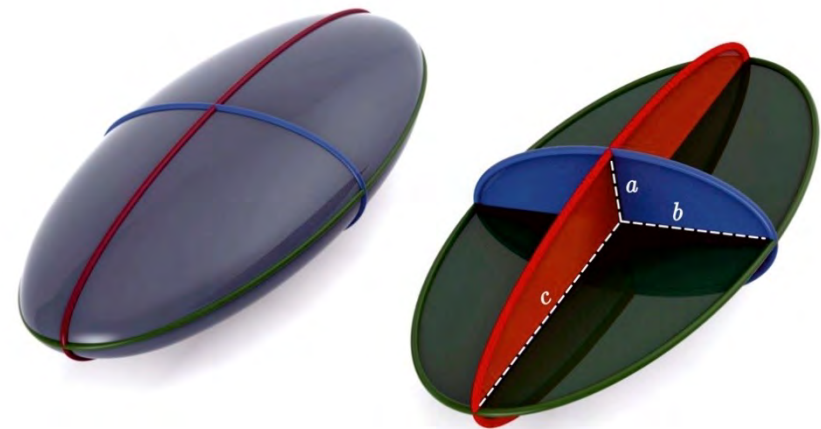
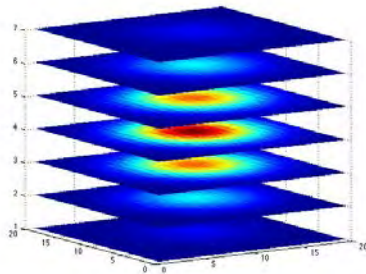
1D  
Gaussian



2D  
Gaussian








3D  
Gaussian



3D Gaussian PSF along with  
3D sampling rate represents the  
resolution of the system

# Ellipsoid Scanning Simulation

Simulated Object	<u>Object Contrast</u>	<u>Object Position</u>	<u>Object Orientation</u>		
	215 HU	Any	Any		
	<u>Object Size</u>				
	4.0 mm x 3.0 mm x 2.25 mm	6.0 mm x 4.5 mm x 3.375 mm	8.0 mm x 6.0 mm x 4.50 mm	10.0 mm x 7.50 mm x 5.625 mm	12.0 mm x 9.00 mm x 6.75 mm
Simulated Scanner	<u>CT Linearity</u>	<u>Resolution (PSF <math>\sigma</math>)</u>	<u>Sampling Rate</u>	<u>Noise</u>	
	Perfect	0.798 x 0.798 x 0.697	0.89 x 0.89 x 1.25	40 HU SD	
Simulated Images					

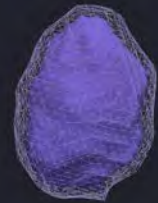
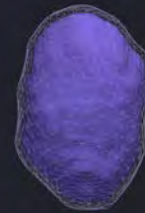
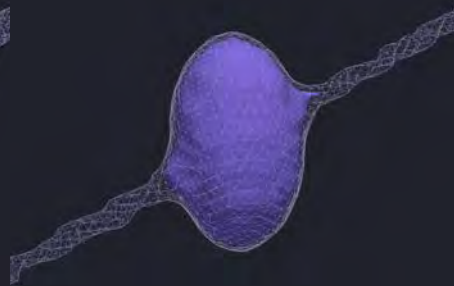
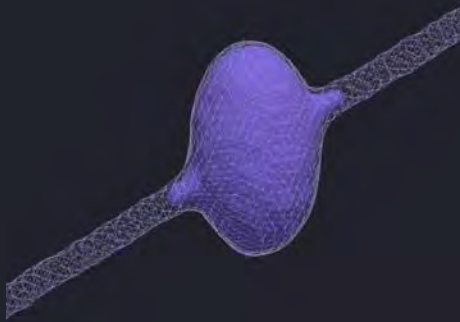
# CT Image Quality: Where Do You Want To Operate When Tracking a Nodule?

Next Gen Scanner

Best Global

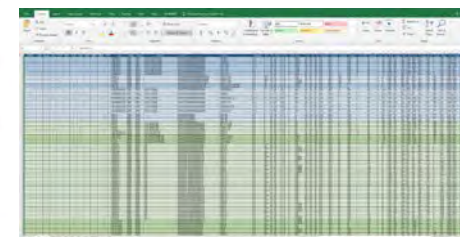
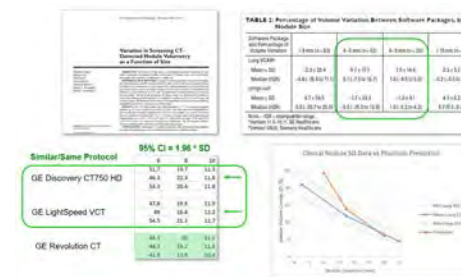
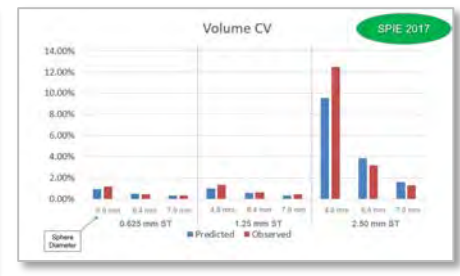
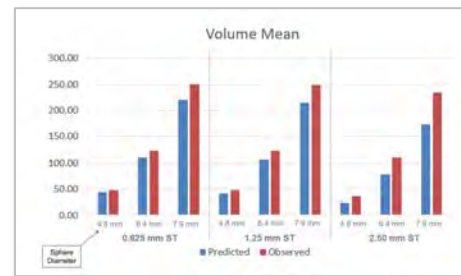
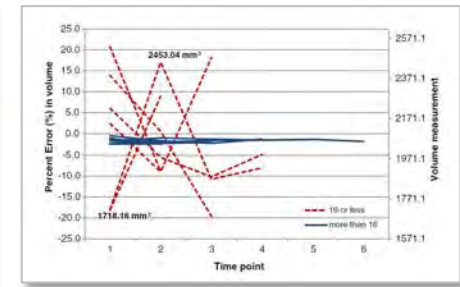
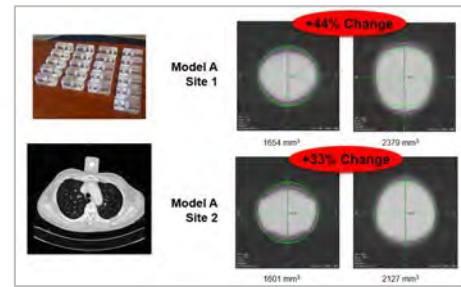
Avg SLN Passing

Max SLN Limit



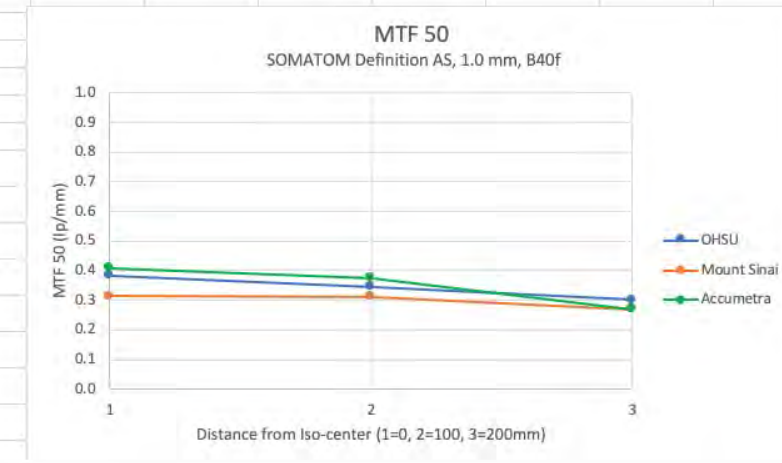
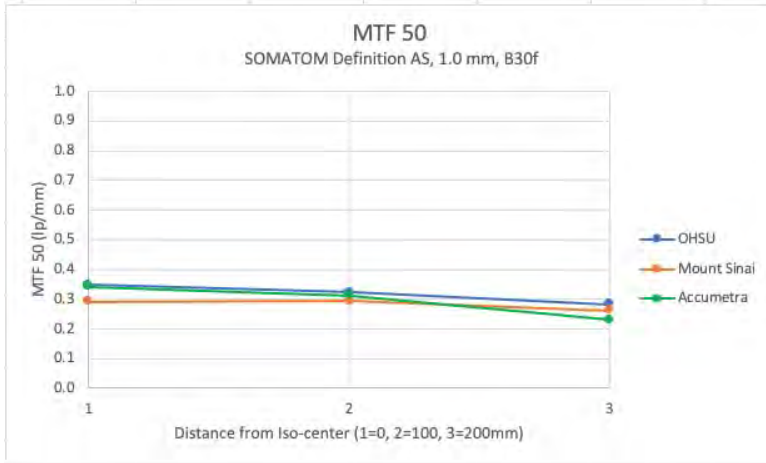
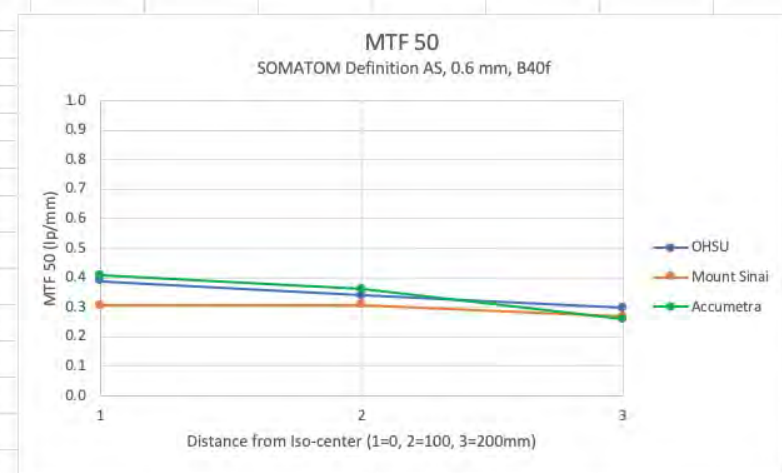
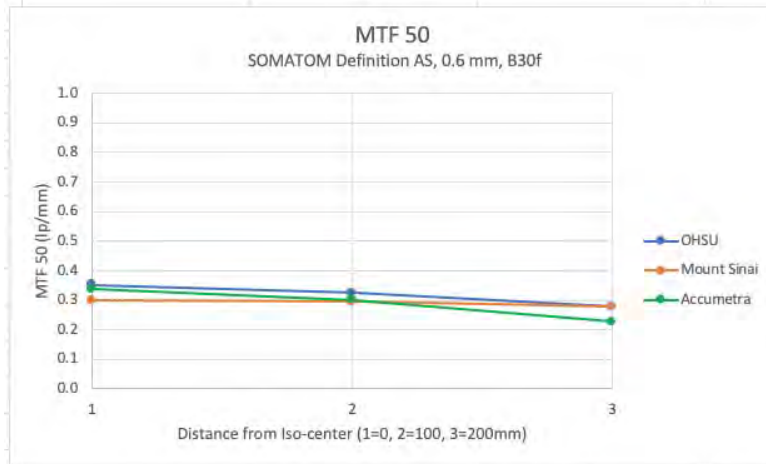
# Supporting Studies

- **Volumetric Performance in a Phase II Lung Cancer Clinical Trial (N=20 sites)**
- **Anthropomorphic Phantom Prediction Study, SPIE 2017**
- **Clinical Small Lung Nodule Prediction Results**
- **2016-2017 International Performance Study (N=27+ CT scanners)**
- **2018-2019 International Performance Study (N=85+ CT scanners)**





# OHSU, Mount Sinai, and Accumetra : MTF 50



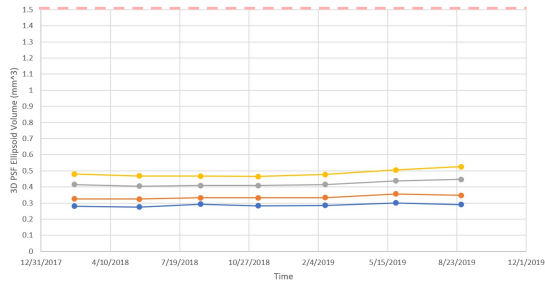
Problem: There is NO Accepted Standard For Measuring CT Resolution

# CT Image Quality Properties Over Time (1.5 Years)

## Fully Automated Analysis of Phantom Data : Scanner 1

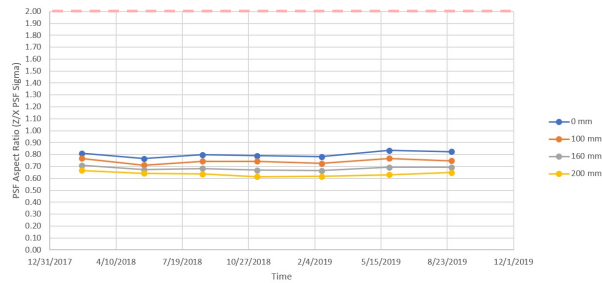
### 3D Resolution

3D Resolution Over Time (CT #2)



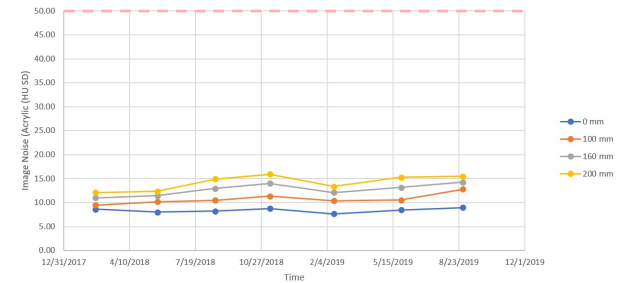
### 3D Resolution Aspect Ratio

3D Resolution Aspect Ratio Over Time



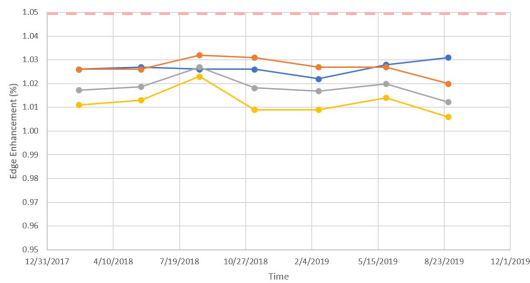
### Image Noise (Acrylic)

Image Noise Over Time



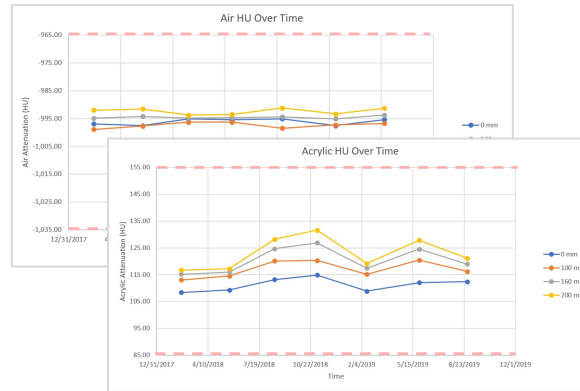
### Edge Enhancement %

Air To Delrin Edge Enhancement % Over Time

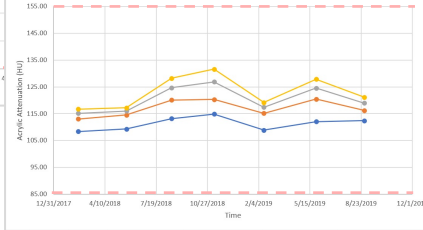


### HU Bias (Air & Acrylic)

Air HU Over Time

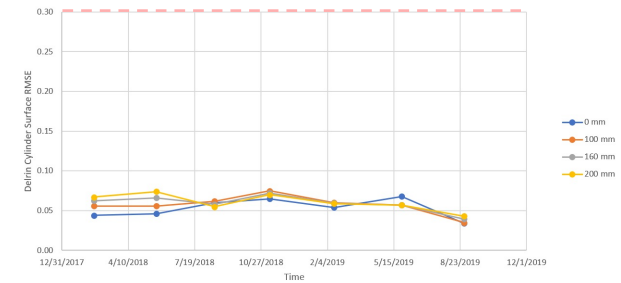


Acrylic HU Over Time



### 3D Spatial Warping

Spatial Warping Over Time



# CTLX1 Phantom Distribution

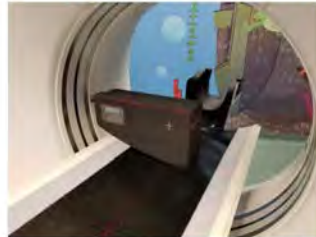
115 New CTLX1/2 Phantoms Distributed As Of 10/26/2021  
Many Thanks to The Prevent Cancer Foundation



Countries And  
Major Organizations  
Are Adopting The  
CTLX1/CTLX2  
Phantom

# CTLX1 In Use Throughout The World

## ACCUMETRA IQ PHANTOM



Children's hospital



NIH

CTLX1 phantom scan

- Potential context of use
  - Image quality assessment of CT system for lung cancer screening

Courtesy Rick Avila, Accumetra

27

### Accumetra CTLX1 phantom

- Three modules placed at 0mm, 102mm, and 204mm from isocentre
- Each module is hollow cylinder of Delrin
- Air region inside and outside cylinder
- Teflon cylinder and Acrylic cylinder above and below Delrin respectively

Unique phantom looks at performance across imaged field



Leeds is first site in the world to use this phantom on a mobile CT scanner



### Canadian Journal of Respiratory, Critical Care, and Sleep Medicine

Revue canadienne des soins respiratoires et critiques et de la médecine du sommeil

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### Management of screen-detected lung nodules: A Canadian partnership against cancer guidance document

Stephen Lam , Heather Bryant , Laura Donahoe , Ashleigh Domingo , Craig Earle , Christian Finley , Anne V. Gonzalez , Christopher Hergott , Rayjean J. Hung , Anne Marie Ireland , Michael Lovas , Daria Manos , John Mayo , Donna E. Maziak , Micheal McInnis , Renelle Myers , Erika Nicholson , Christopher Politis , Heidi Schmidt , Harman S. Sekhon , Marie Soprovich , Archie Stewart , Martin Tammemagi , Jana L. Taylor , Ming-Sound Tsao , Matthew T. Warkentin & Kazuhiro Yasufuku

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# The New CTLX2 Phantom

## Better Supports Radiation Dose vs Image Quality Studies

The CTLX2 will have an access port to insert “manufactured” nodules.



This nodule module has 6 6.0 x 3.6 x 3.6 nodules and 6 10.0 x 6.0 x 6.0 nodules



Phantom weighs around 9 Kg or 20 lbs when filled with water, Providing guidance on image quality when scanning a large patient.

This helps sites better determine small lung nodule CT image quality when Auto mA is enabled and also when lowering dose.

With the CTLX2 we are now seeing a lot more CT image quality problems (e.g. HU biases)



# COVID-19 CT Imaging Guidance

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**QIBA guidance: Computed tomography imaging for COVID-19 quantitative imaging applications**

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**ARTICLE INFO**

**KEYWORDS:**  
 COVID-19  
 Quantitative imaging  
 Artificial intelligence  
 Computed tomography

**ABSTRACT**

As the COVID-19 pandemic impacts global populations, computed tomography (CT) lung imaging is being used in many countries to help manage patient care as well as to rapidly identify potentially useful quantitative COVID-19 CT imaging biomarkers. Quantitative COVID-19 CT imaging applications, typically based on computer vision modeling and artificial intelligence algorithms, include the potential for better methods to assess COVID-19 extent and severity, assist with differential diagnosis of COVID-19 versus other respiratory conditions, and predict disease trajectory. To help accelerate the development of robust quantitative imaging algorithms and tools, it is critical that CT imaging is obtained following best practices of the quantitative lung CT imaging community. Toward this end, the Radiological Society of North America's (RSNA) Quantitative Imaging Biomarkers Alliance (QIBA) CT Lung Density Profile Committee and CT Small Lung Nodule Profile Committee developed a set of best practices to guide clinical sites using quantitative imaging solutions and to accelerate the international development of quantitative CT algorithms for COVID-19. This guidance document provides quantitative CT lung imaging recommendations for COVID-19 CT imaging, including recommended CT image acquisition settings for contemporary CT scanners. Additional best practice guidance is provided on scientific publication reporting of quantitative CT imaging methods and the importance of contributing COVID-19 CT imaging datasets to open science research databases.

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 0099-7071/© 2021 Published by Elsevier Inc.

**Table 1:** Recommended reconstruction kernels for quantitative CT COVID-19 applications.

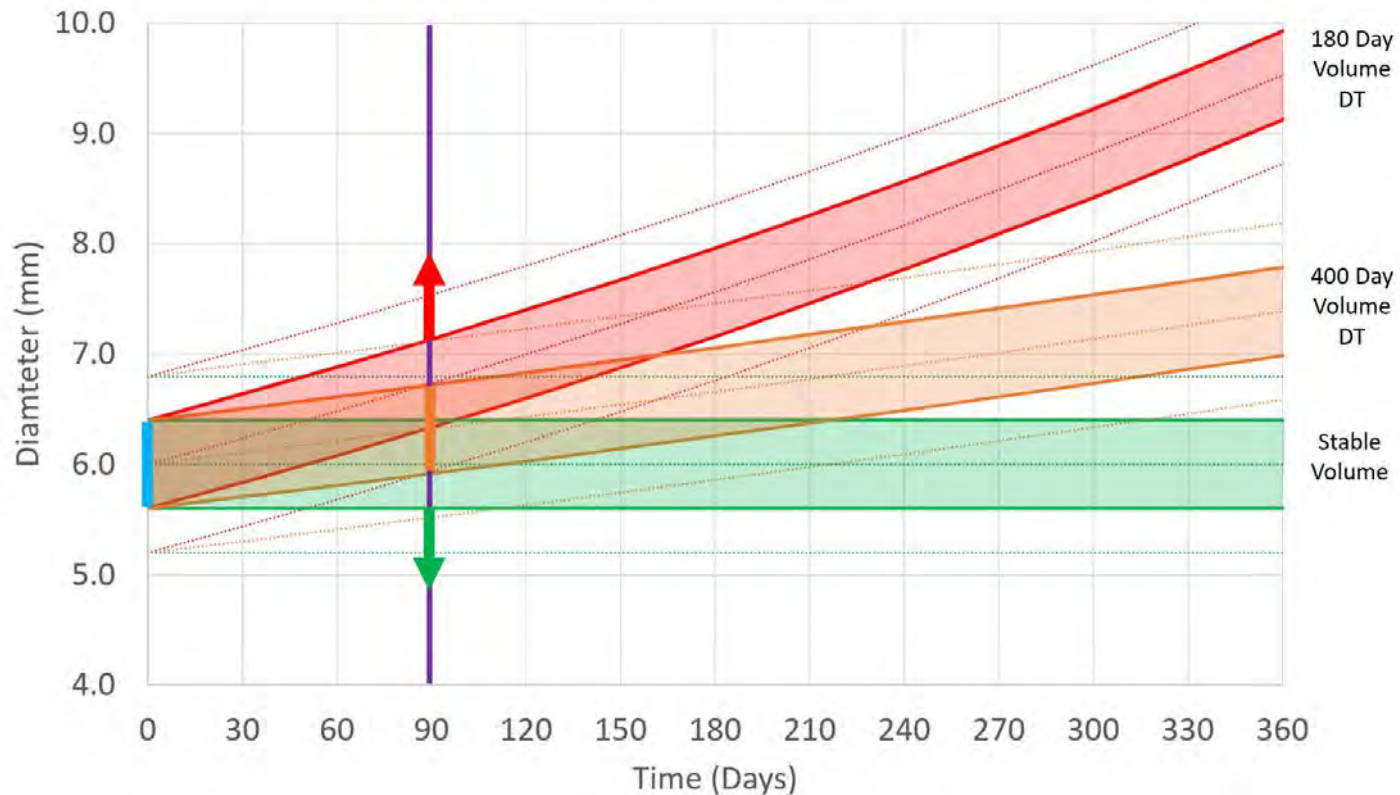
CT Scanner Manufacturer	Models	Recommended Reconstruction Kernels
Canon/Toshiba	All	FC05
General Electric	All	STANDARD
Philips	All	F, L
Siemens	Force	Br40
	All Others	B40, I40

We Are Preparing Similar Guidance  
 For Combined CT Lung Screening and COPD Imaging

# Precision Follow-up Time

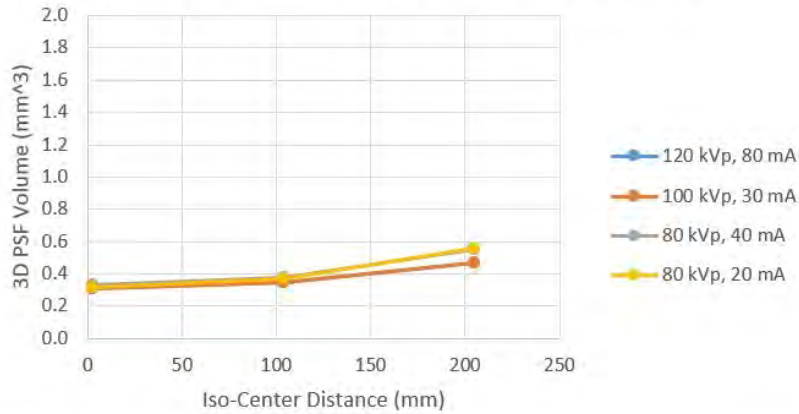
## Nodule Diameter Growth

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

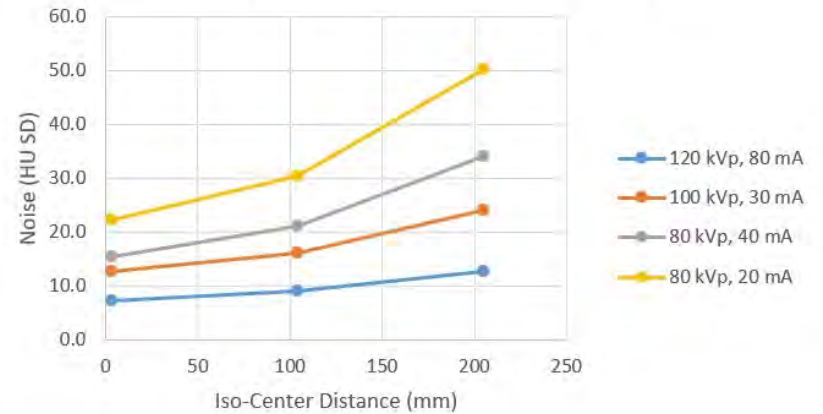


# Optimizing Radiation Dose and Resolution

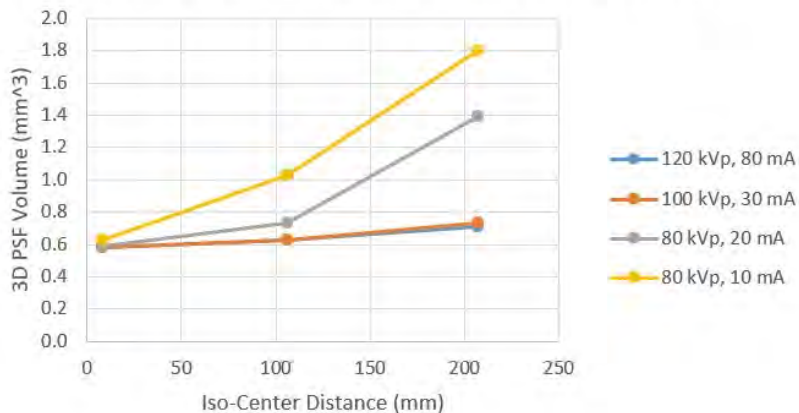
### Scanner A: 3D Resolution vs Iso-Center Distance



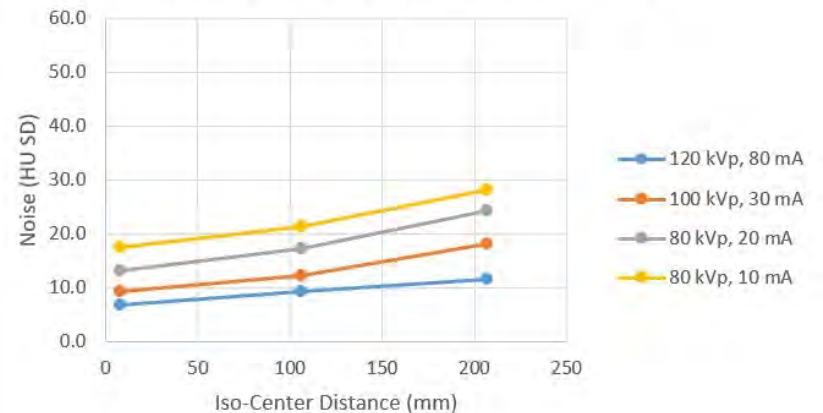
### Scanner A: Noise vs Iso-Center Distance



### Scanner B: 3D Resolution vs Iso-Center Distance



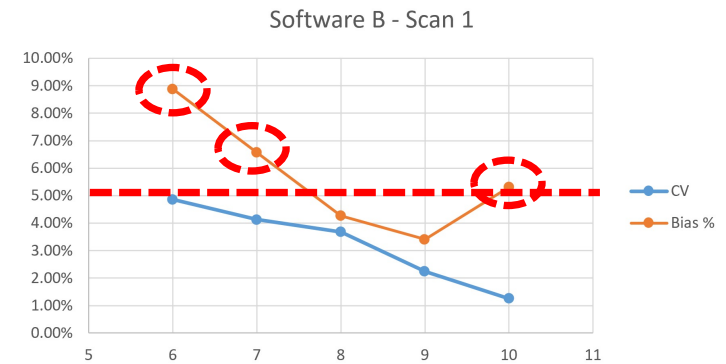
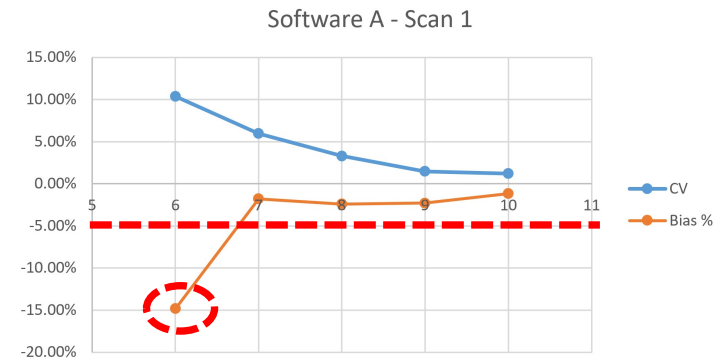
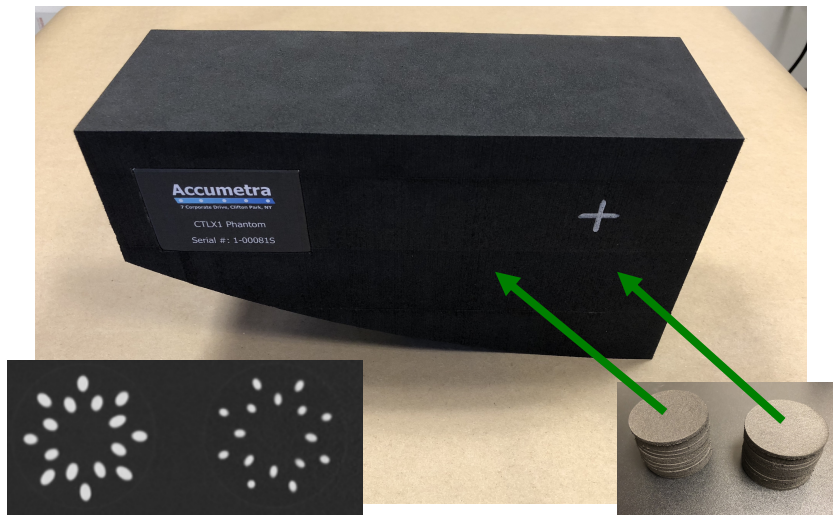
### Scanner B: Noise vs Iso-Center Distance





# Lung Nodule Software Bias

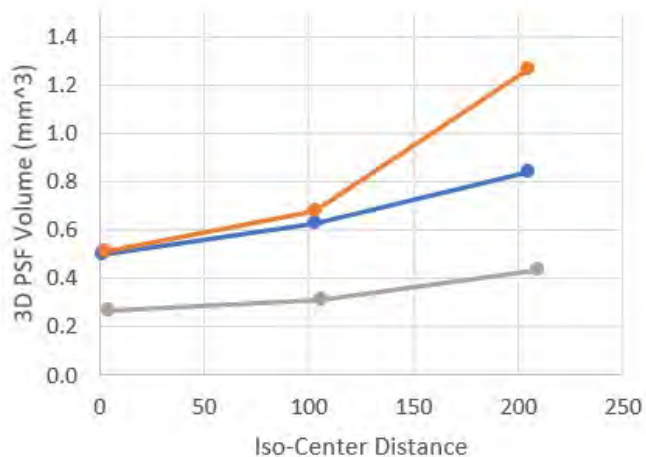
- The CTLX1S Contains 80 Acrylic Ellipsoids Ranging In Size From 6mm To 10mm
- Scanning And Measurement Using Two Software Systems Revealed High Bias



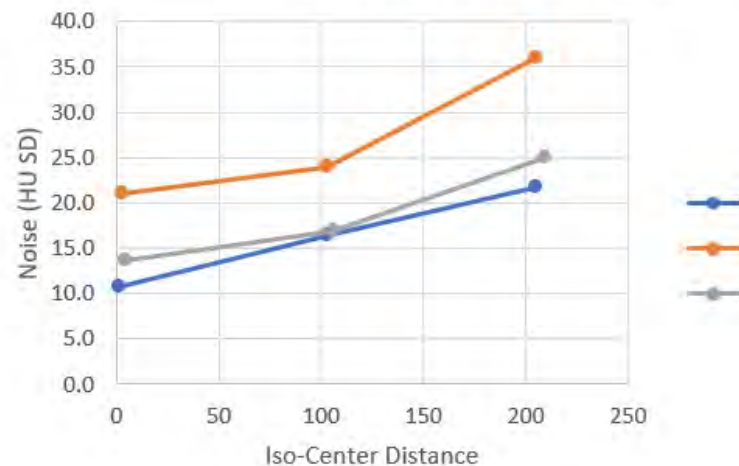
# Using Different CT Scanners To Follow-up



Resolution vs Iso-Center Distance



Noise vs Iso-Center Distance



# More AI Image Reconstruction Is Coming

- Machine learning / deep learning will increasingly be used throughout the CT image acquisition pipeline
- View Data Acquisition -> Reconstruction -> Post processing Filters
- Not every innovation change will be for the better
- The potential for major problems occurring is high. Particularly with challenging detection and measurement applications (e.g. assessing small lung nodule growth rates)

A Global Image Quality Safety Net Is As Important As Ever

# Summary

- **Global Network:** A new low cost CT calibration phantom (CTLX1, CTLX2) is being used by a globally network (N=115) to quickly verify CT image quality. It monitors, optimizes, and shares crowd-sourced protocols for lung cancer screening (+COPD is next).
- **3D Mathematical Models:** We create 3D math models of the scanner/protocol image formation process across the full 3D scanner field of view. Global sites can now easily & accurately assess the 3D performance of a CT scanner (highly useful and disruptive).
- **Clinical Application Performance Prediction:** The 3D math models are used with simulation software to directly predict performance for a wide range of applications.
- **CT Image Quality Clinical Uses:** Potential clinical uses include:
  - Setting more precise lung cancer screening follow-up times
  - Nodule volume growth/doubling time estimation tools that consider volumetric error
  - Optimizing both radiation dose and CT image quality for nodule detection and measurement
  - Enabling sites to use different, but calibrated, CT scanners and protocols for follow-up scans
  - Establishing and updating image acquisition recommendations in real-time
  - Maintaining a global safety net for catching issues when deploying new CT innovations (AI)
- **CT Image Resolution:** Preliminary data analysis indicates that CTLX1 results are both accurate and reproducible. But NO accepted 3D CT resolution standards exist to compare against!!

**Thank You**