Improving CT Lung Cancer Screening Through Calibration Phantom and Software Innovations

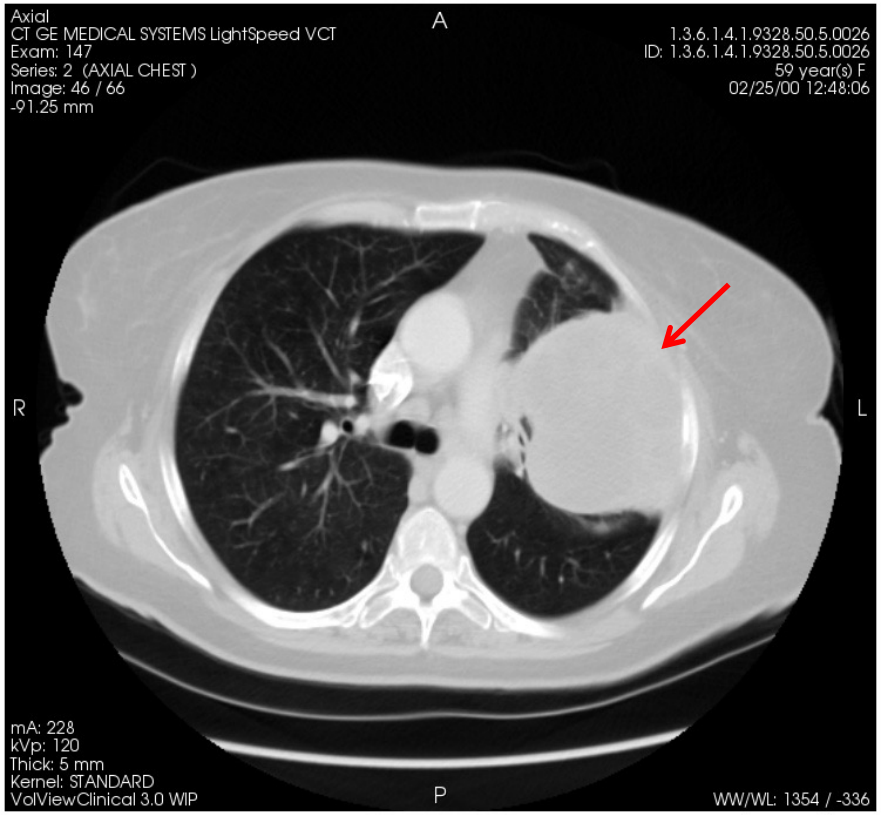
Rick Avila

Accumetra, LLC

November 5, 2021

Lung Cancer Screening

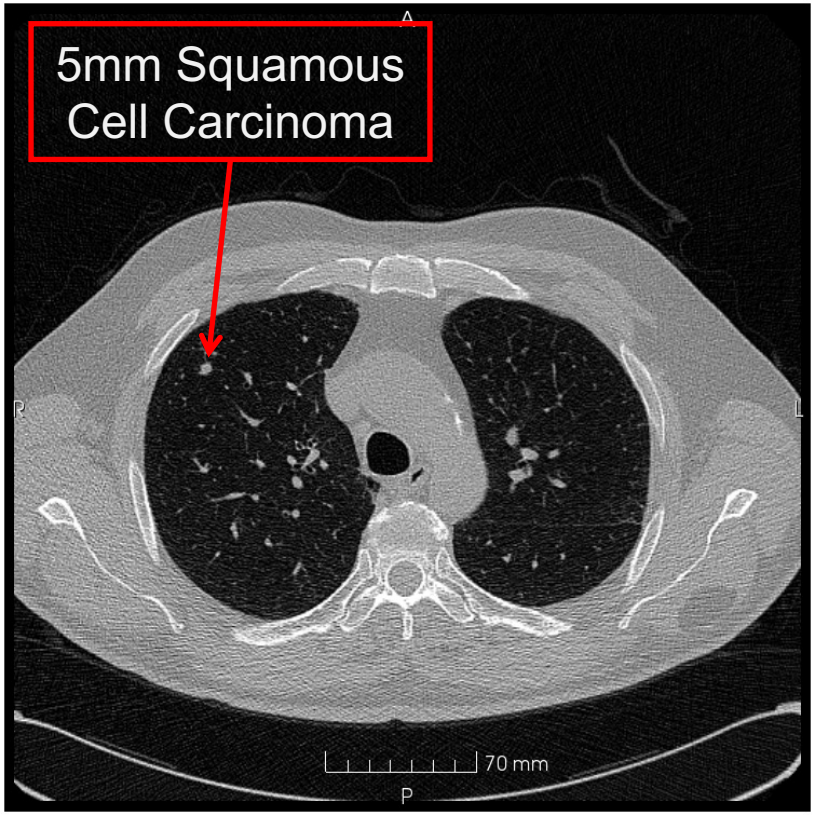
Late-Stage Lung Cancer
(1.76 Million Deaths/Year)



[R. Gottlieb, Roswell Park Cancer Institute]

~5% five year survival

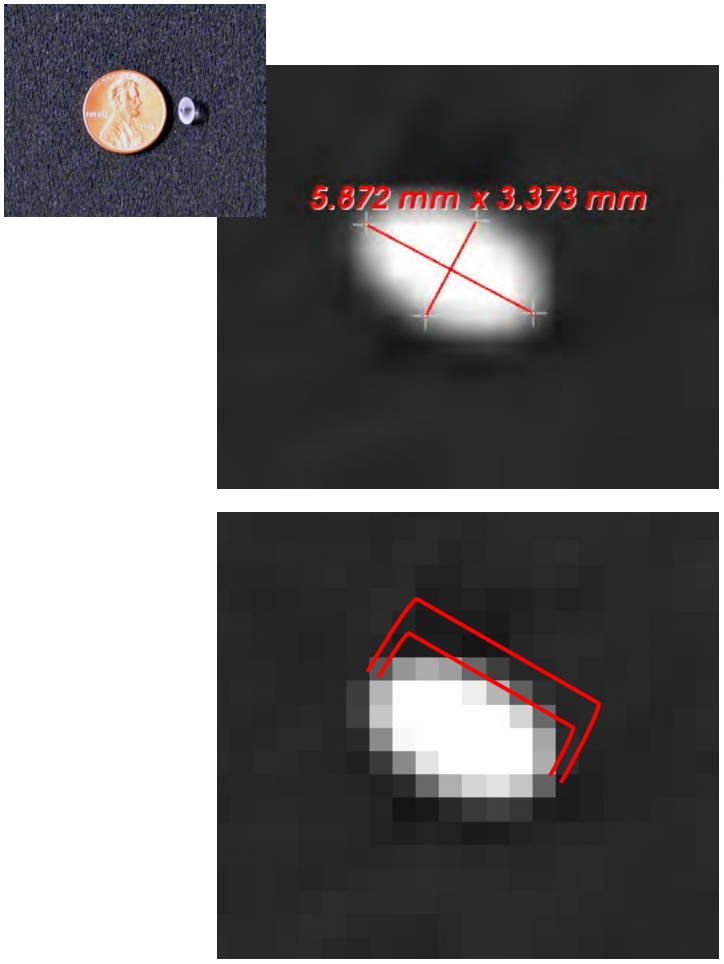
Early Lung Cancer



[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%

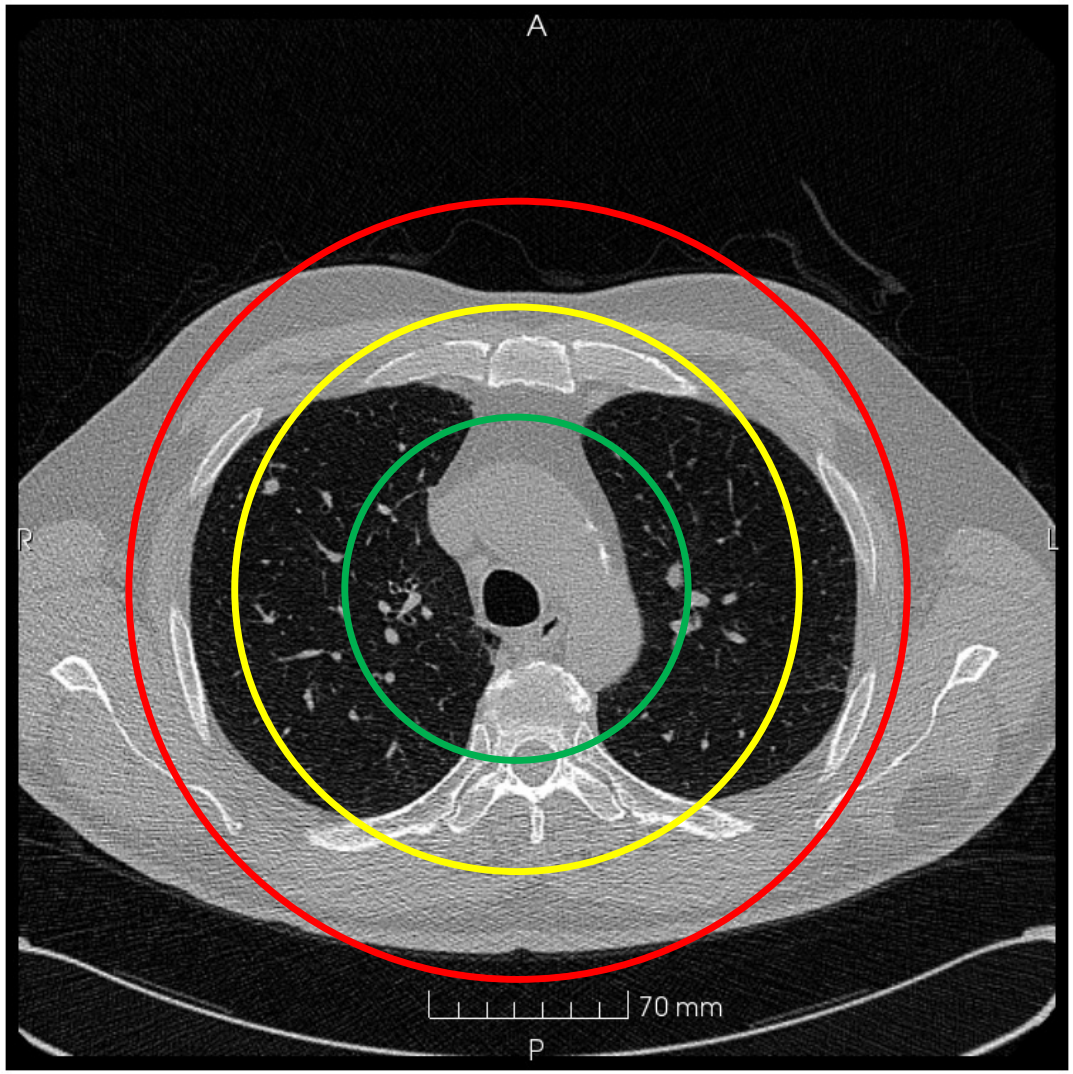
If This Is TRULY a +1.0 mm Max Diameter Increase Over 6 Months, This Is a > 250% Volume Increase Over A Year

(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

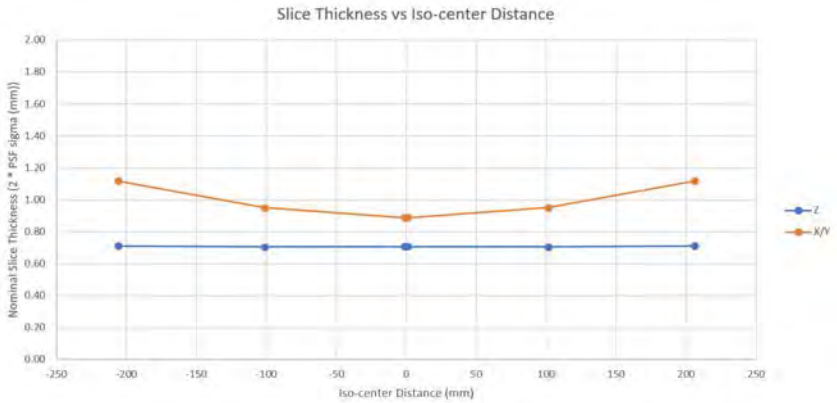


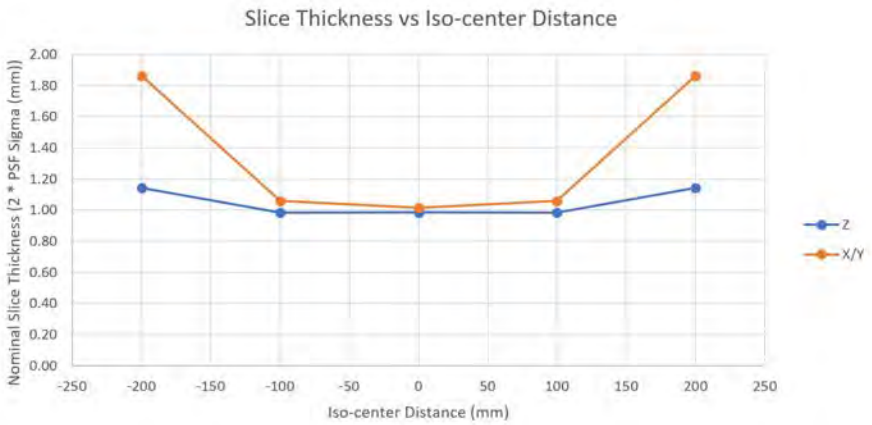
Best

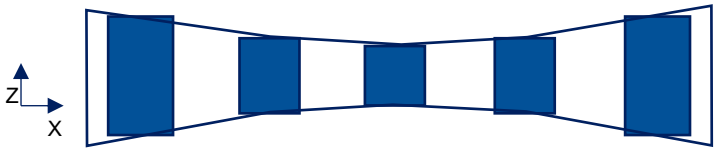
Medium

Worst

Slice Thickness In X, Y, and Z

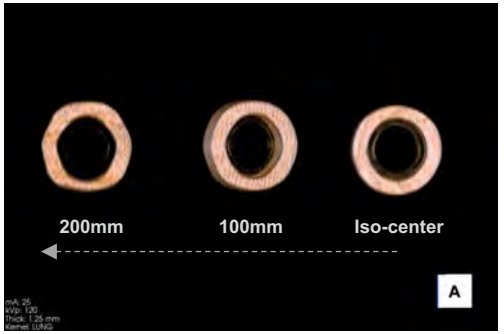




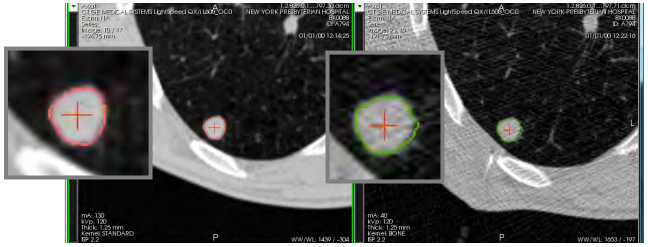


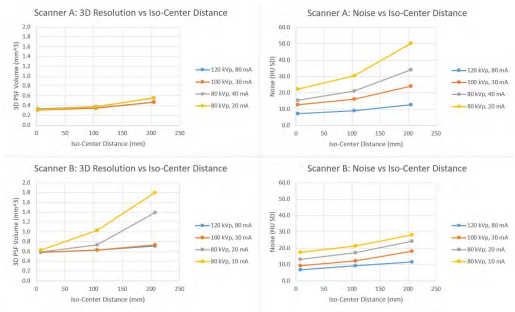
Quality of Lung Nodule Measurements: What Have We Learned Over The Last 15 years?

- 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 +- 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
  - …

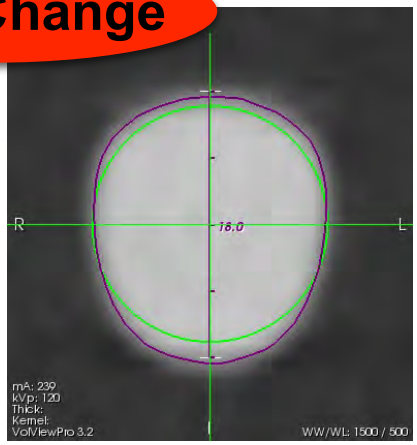




We need to constantly measure and monitor CT detection and measurement equipment

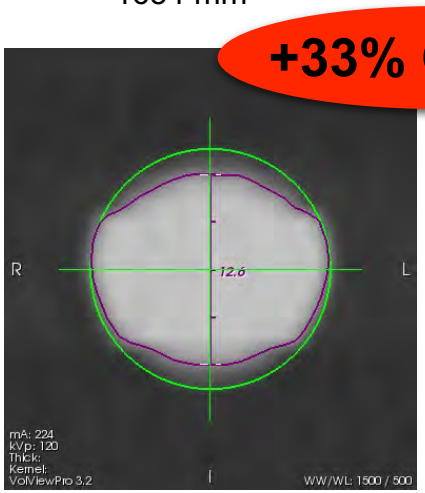
2010: Roche ABIGAIL Study

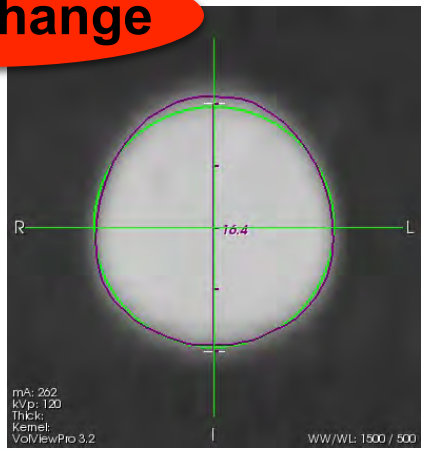
Model A
Site 1



1654 mm^3 2379 mm^3

Model A
Site 2



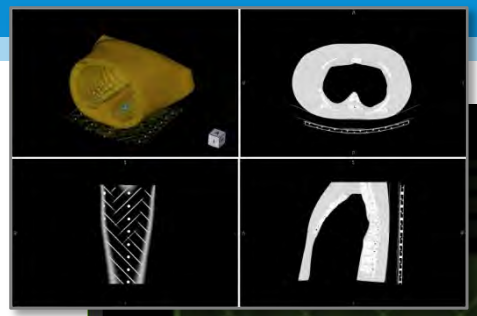


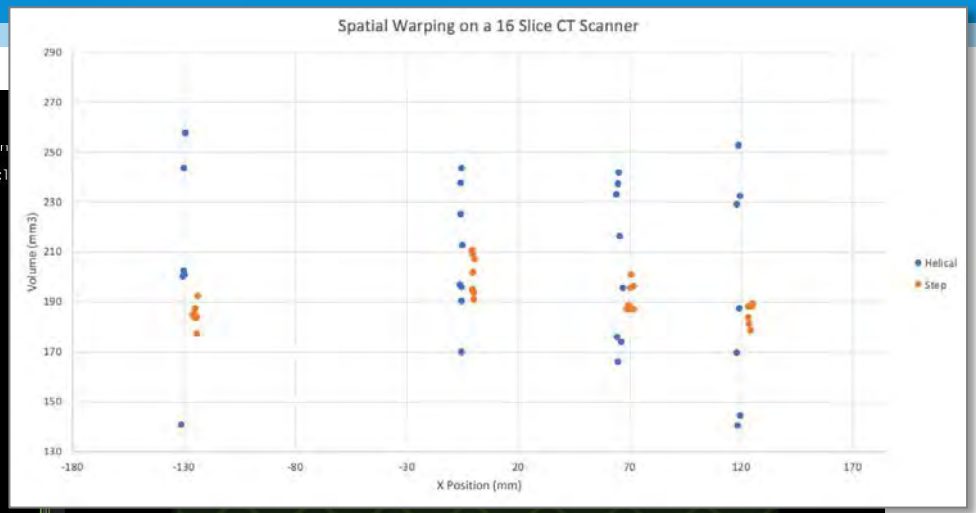
1601 mm^3 2127 mm^3

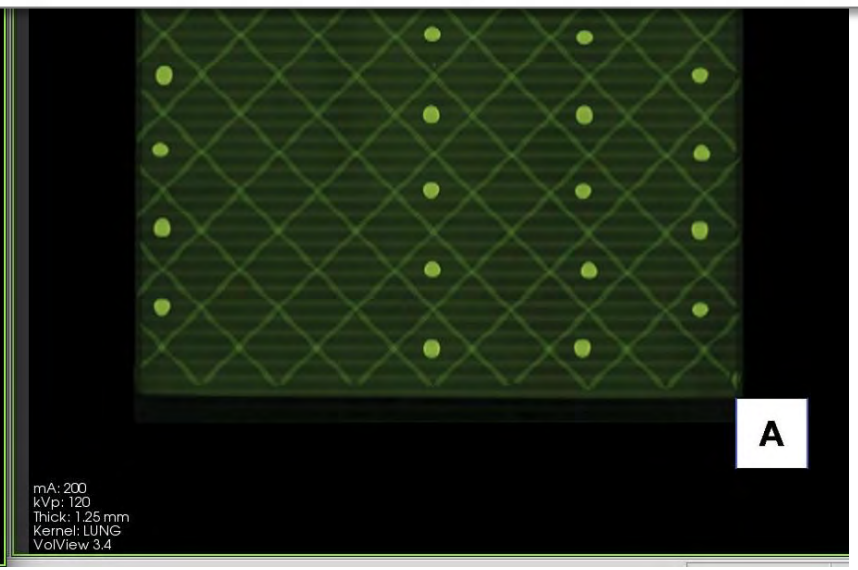
[Henschke, … Avila, J Med Imaging 2016]

Clinical Biopsy Case

Table Phantom Scanning On a 16 Slice







Step & Shoot Acquisition

Helical Acquisition

CT Scanner Spatial Warping

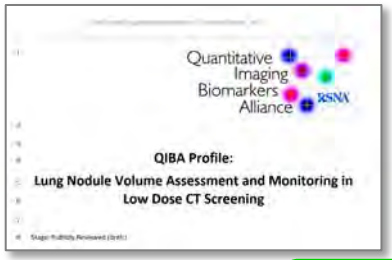
- CT spatial warping was 1st reported at meetings in 2011.
- It took > 3 years to publish spatial warping results observed on multiple scanners from a phase II clinical trial (JMI 2016).
- Numerous presentations by me and others every year from 2011 – 2021 have described this problem.
- Yet, even today 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.

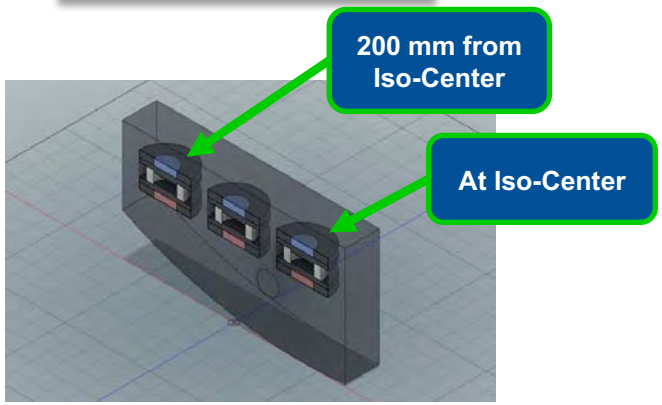
- So after > 10 years of studying and reporting on this it is long past time for the community to accept that this major CT image quality problem happened and that global CT image quality monitoring needs to be updated and running continuously so image quality lapses of this magnitude never happen again.

AAPM 2019 LCS Protocols

CTLX1 Phantom

The 1st Phantom To Build A 3D Math Model Across The Full Scanner FOV

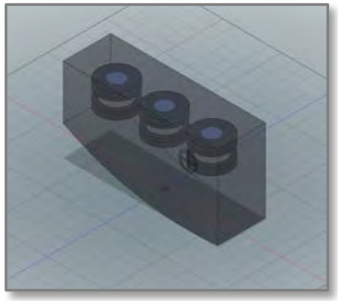


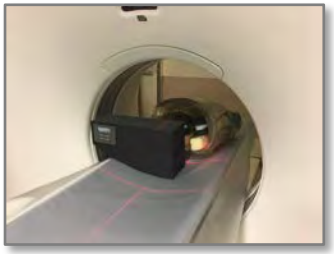


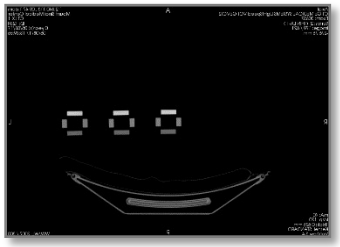
This Ellipsoid Represents The Smallest Size Lung Nodule That a CT Lung Cancer Screening Site Needs To Be Able To Reliably Measure

- **Fundamental CT Image Properties**
  - 3D Resolution:
    - 3D PSF Ellipsoid Volume <= 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

CT Image Quality Verification Using Cloud-Based Computing Services



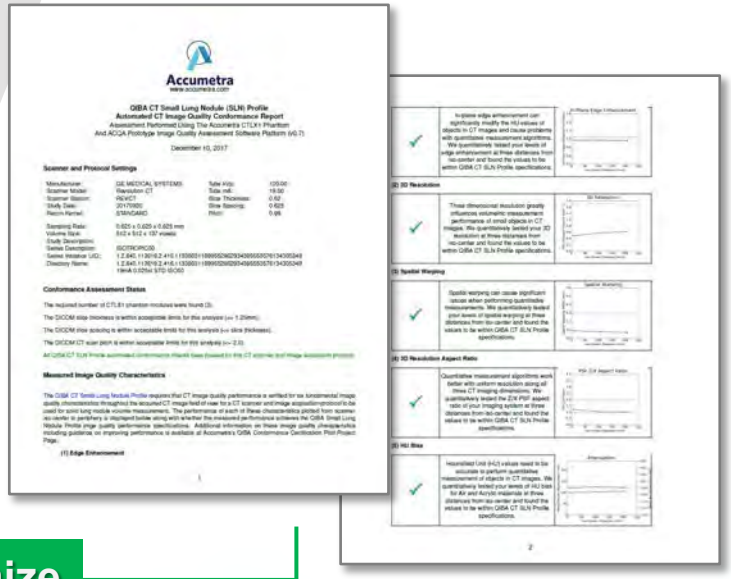




http://accumetra.com

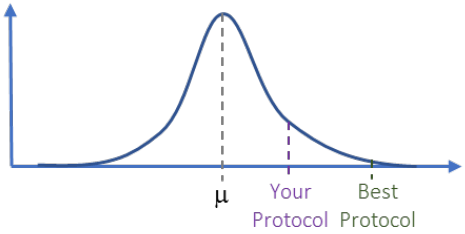
Upload

Email



Optimize

Check Each Time Scanner or Protocol Changes and Once Per Year

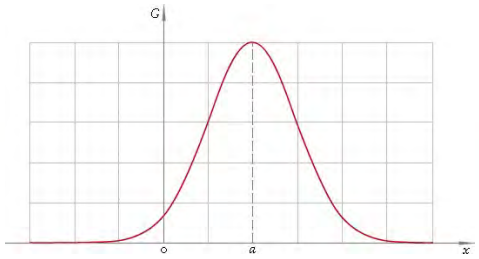


Guidance

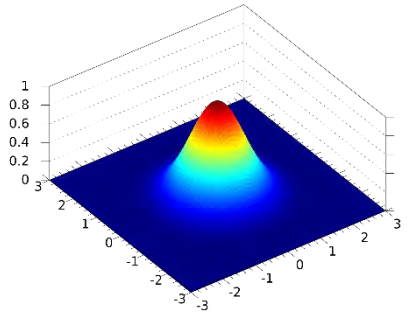
Webpages & FAQs

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

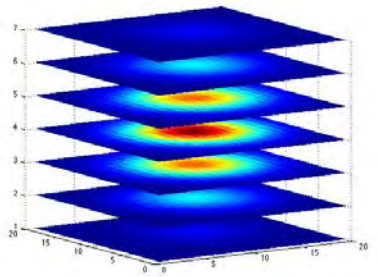
1D Gaussian

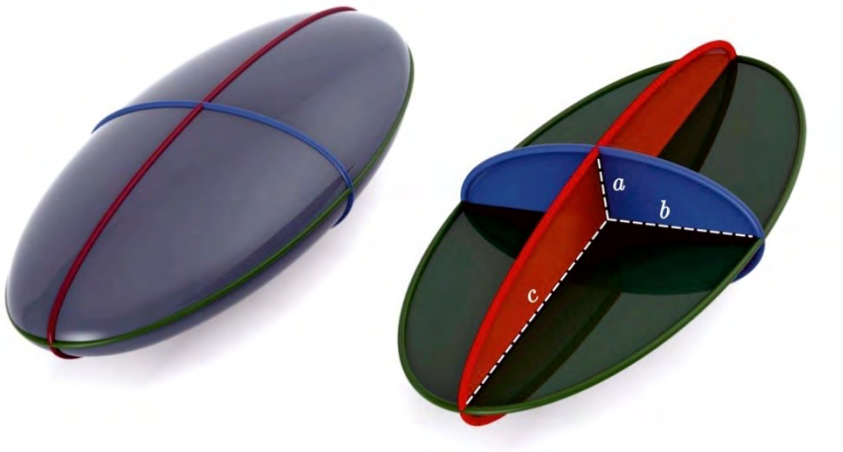


2D Gaussian



3D Gaussian





3D Gaussian PSF along with

3D sampling rate represents the resolution of the system

Ellipsoid Scanning Simulation

Simulated Object

Object Contrast	Object Position	Object Orientation
215 HU	Any	Any

Object Size

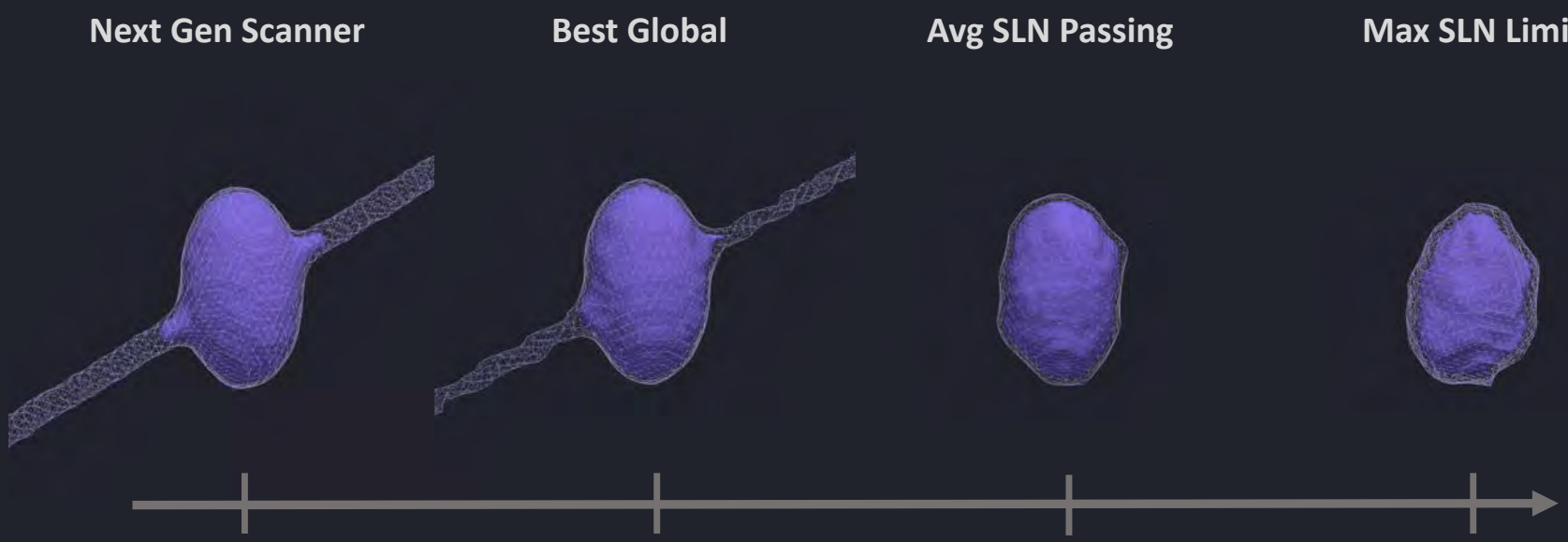
4.0 mm x 3.0 mm x 2.25 mm	6.0 mm x 4.5 mm x 3.375 mm	8.0 mm x 6.0 mm x 4.50 mm	10.0 mm x 7.50 mm x 5.625 mm	12.0 mm x 9.00 mm x 6.75 mm

Simulated Scanner

CT Linearity	Resolution (PSF σ)	Sampling Rate	Noise
Perfect	0.798 x 0.798 x 0.697	0.89 x 0.89 x 1.25	40 HU SD

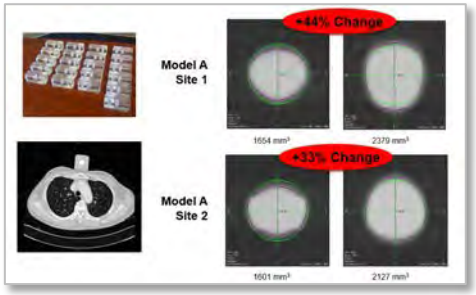
Simulated Images

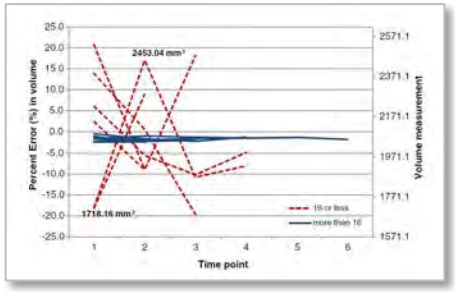
CT Image Quality:
Where Do You Want To Operate When Tracking a Nodule?

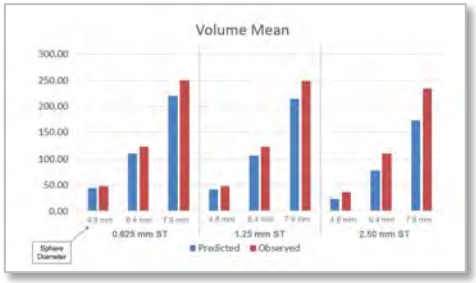


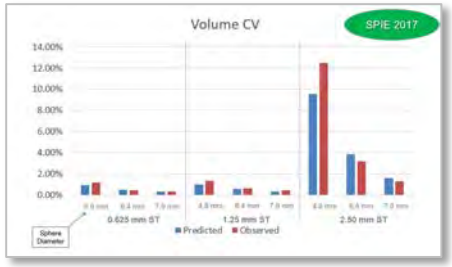
Supporting Studies

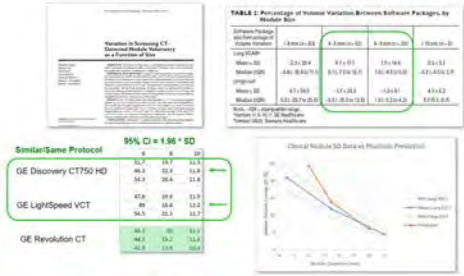
- **Volumetric Performance in a Phase II Lung Cancer Clinical Trial (N=20 sites)**
- **Anthropomorphic Phantom Prediction Study, SPIE 2017**
- **Clinical Small Lung Nodule Prediction Results**
- **2016-2017 International Performance Study (N=27+ CT scanners)**
- **2018-2019 International Performance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

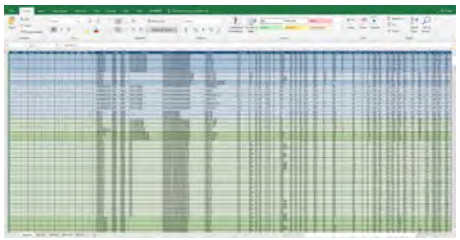




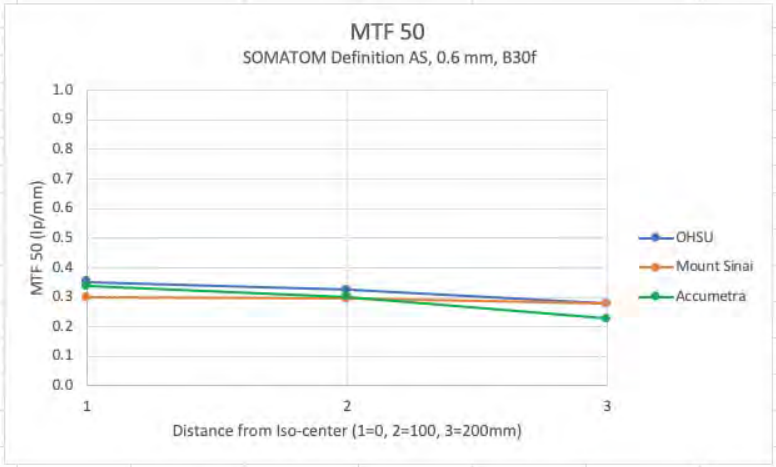


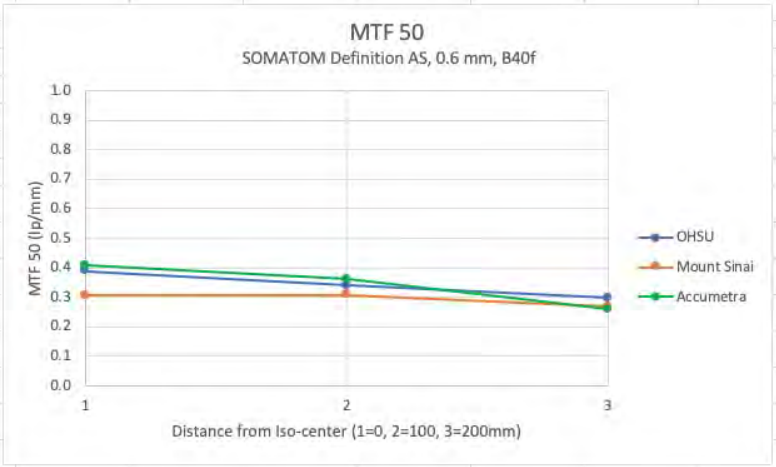


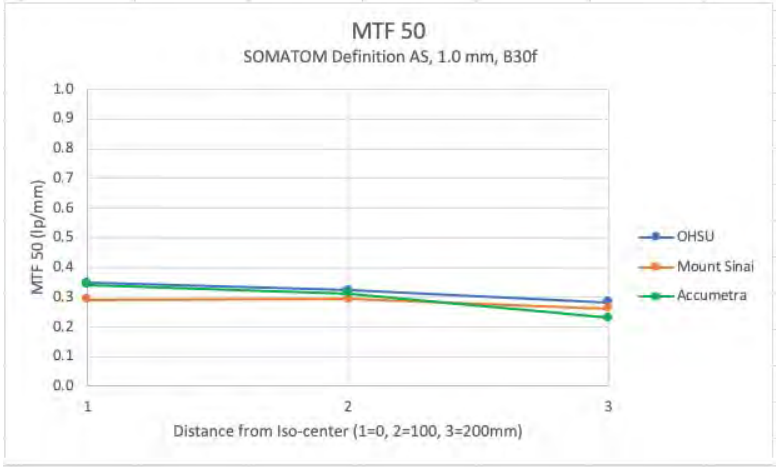


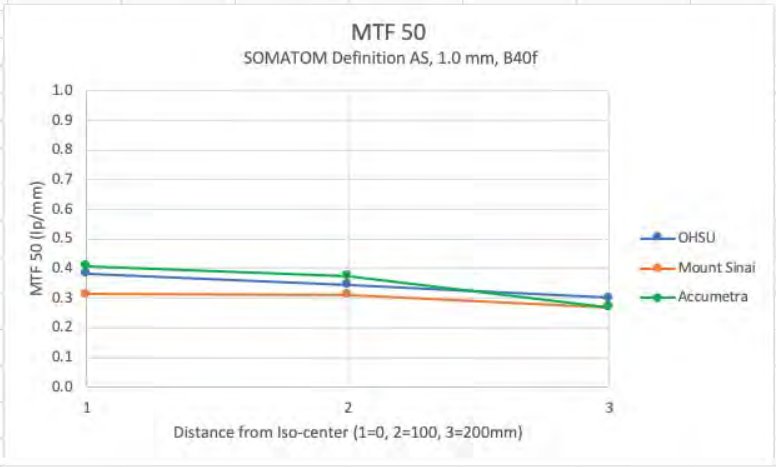


OHSU, Mount Sinai, and Accumetra : MTF 50





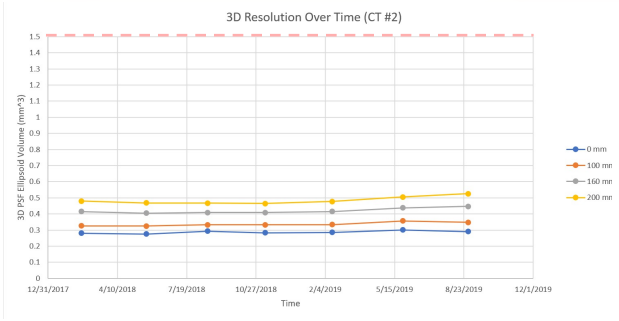




Problem: There is NO Accepted Standard For Measuring CT Resolution

CT Image Quality Properties Over Time (1.5 Years)
Fully Automated Analysis of Phantom Data : Scanner 1

3D Resolution



3D Resolution Aspect Ratio

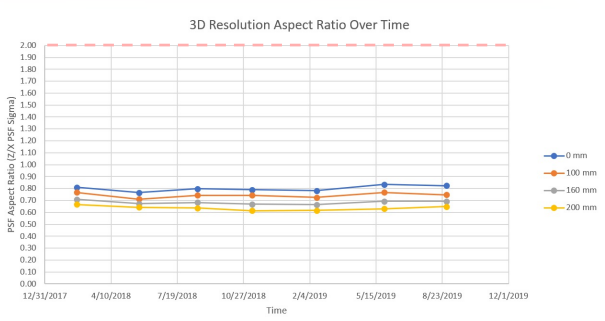
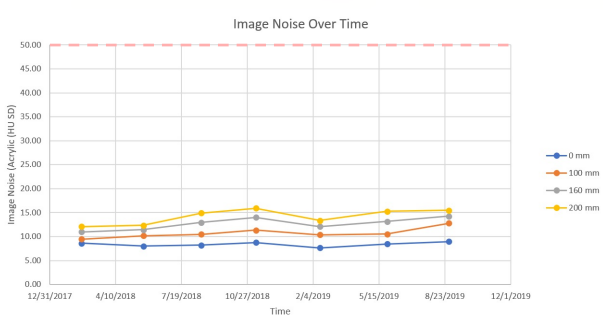
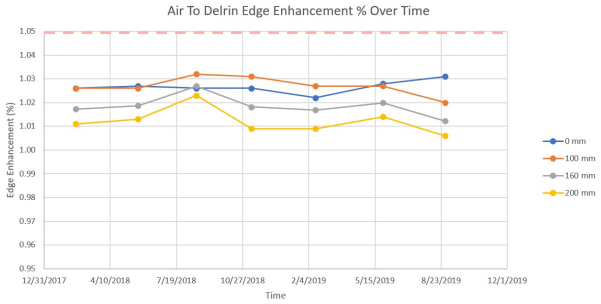


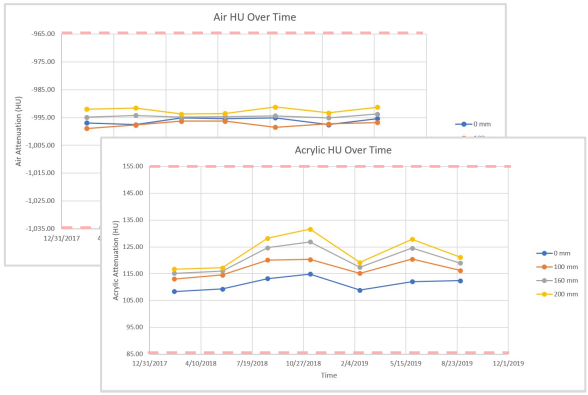
Image Noise (Acrylic)



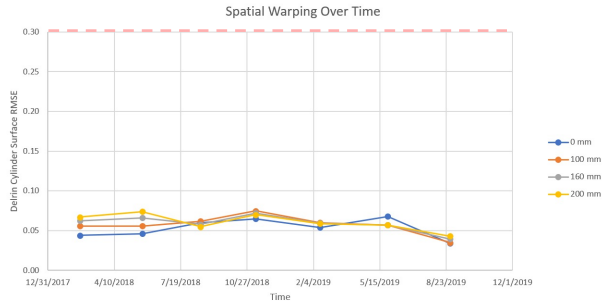
Edge Enhancement %



HU Bias (Air & Acrylic)



3D Spatial Warping



CTLX1 Phantom Distribution

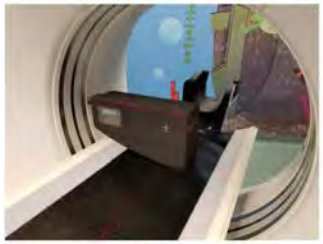
115 New CTLX1/2 Phantoms Distributed As Of 10/26/2021

Many Thanks to The Prevent Cancer Foundation

CTLX1 In Use Throughout The World

ACCUMETRA IQ PHANTOM

FDA



Children's hospital

NIH

CTLX1 phantom scan

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

Curtesy Rick Avila, Accumetra

27

NHS The Leeds Teaching Hospitals NHS Trust

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

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ucts20

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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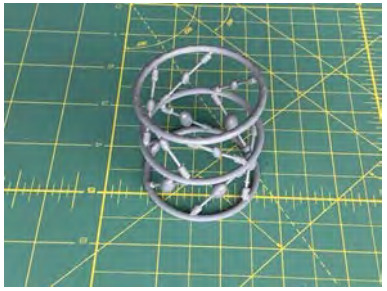
To link to this article: https://doi.org/10.1080/24745332.2020.1819175

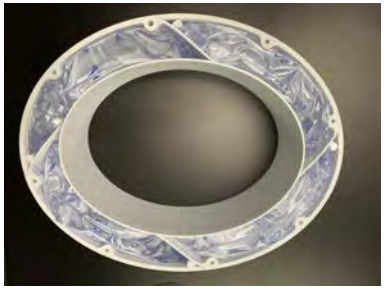
The New CTLX2 Phantom

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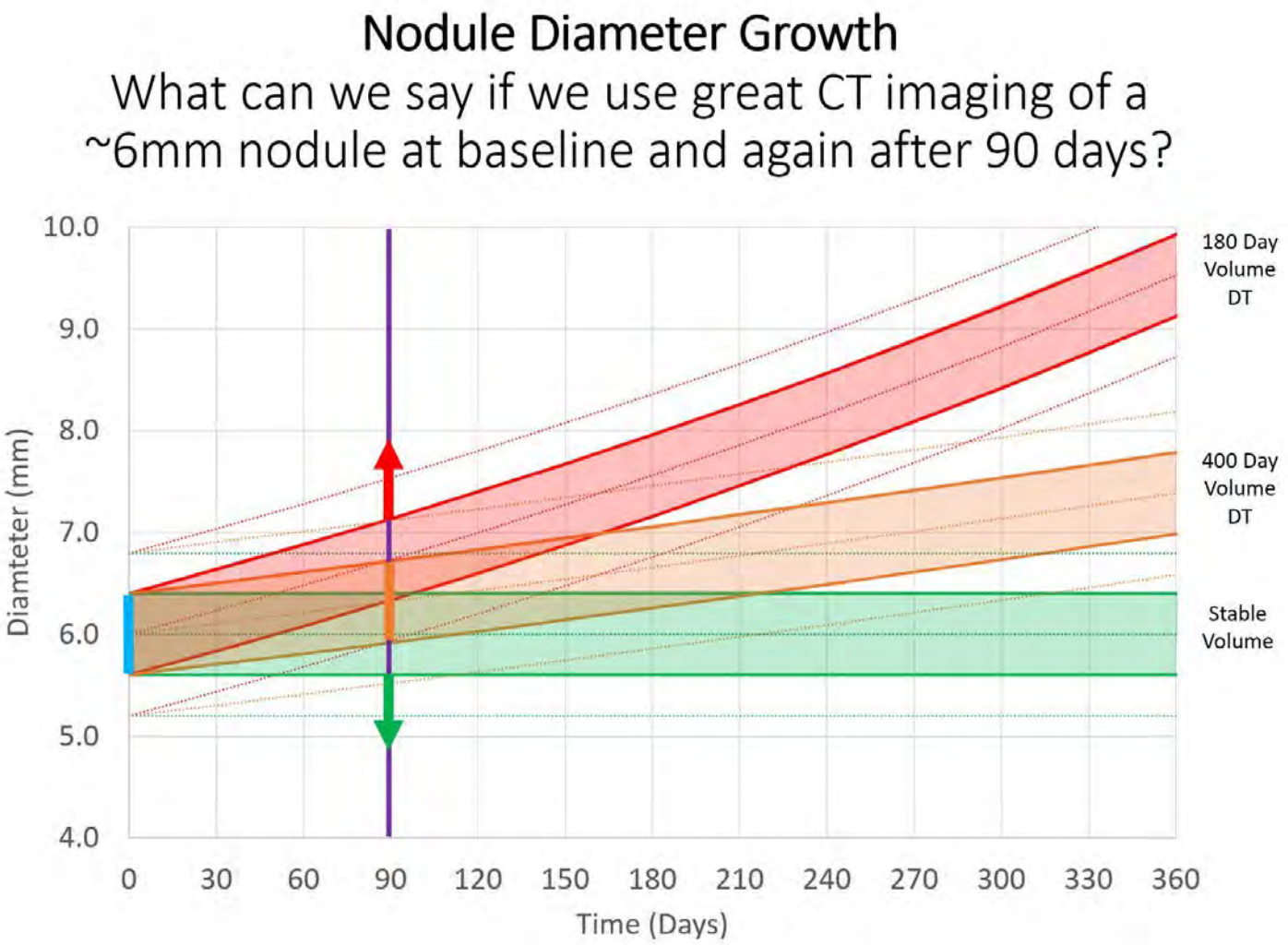
Table 1: Recommended reconstruction kernels for quantitative CT COVID-19 applications.

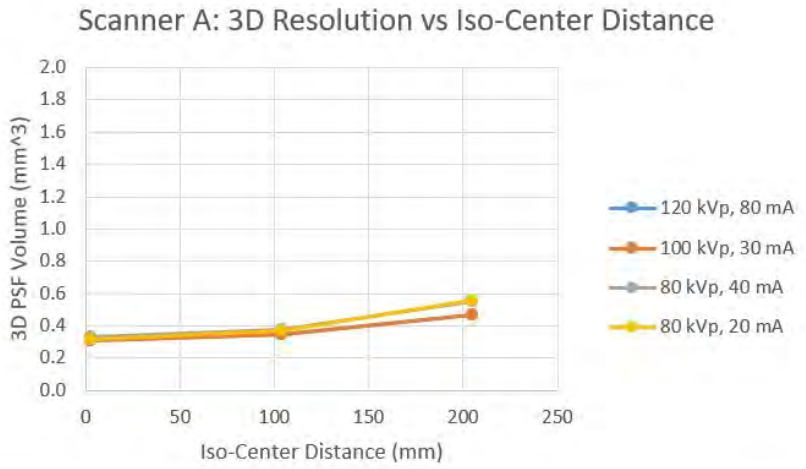
CT Scanner Manufacturer	Models	Recommended Reconstruction Kernels
Canon/Toshiba	All	FC05
General Electric	All	STANDARD
Philips	All	F, L
Siemens	Force	Br40
	All Others	B40, I40

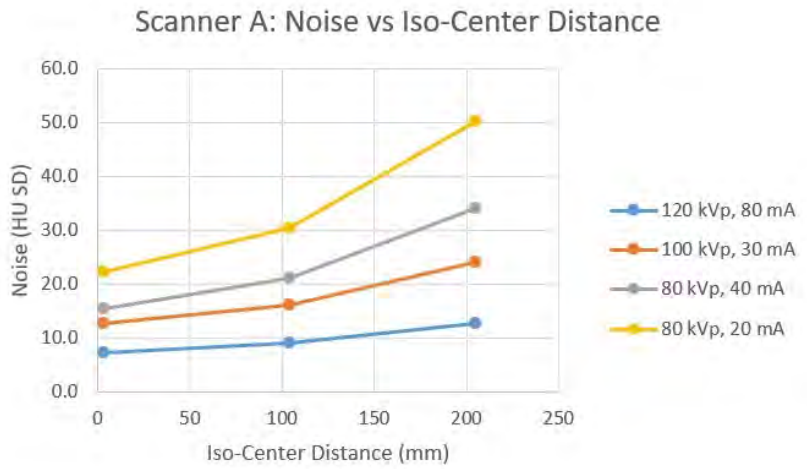
We Are Preparing Similar Guidance
For Combined CT Lung Screening and COPD Imaging

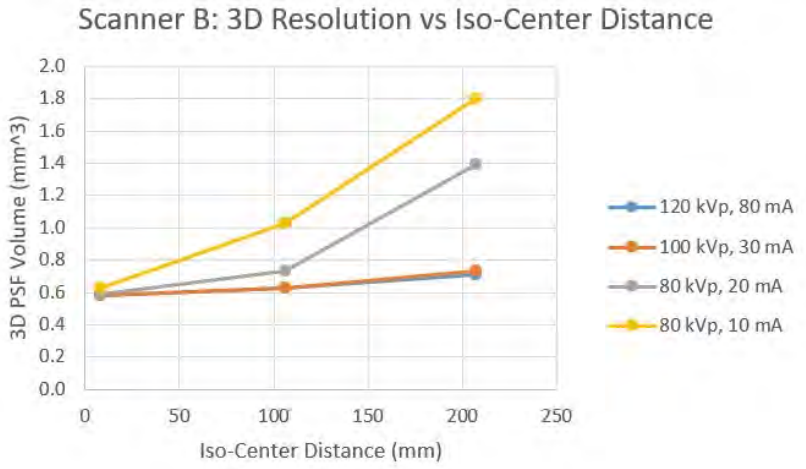
Precision Follow-up Time

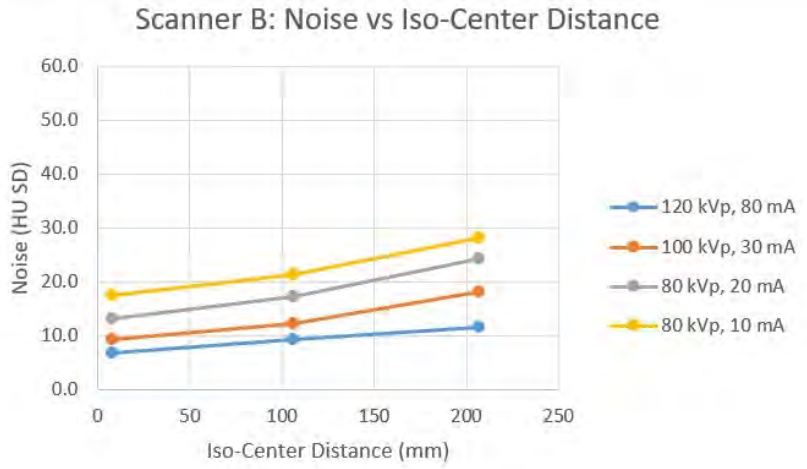


Optimizing Radiation Dose and Resolution



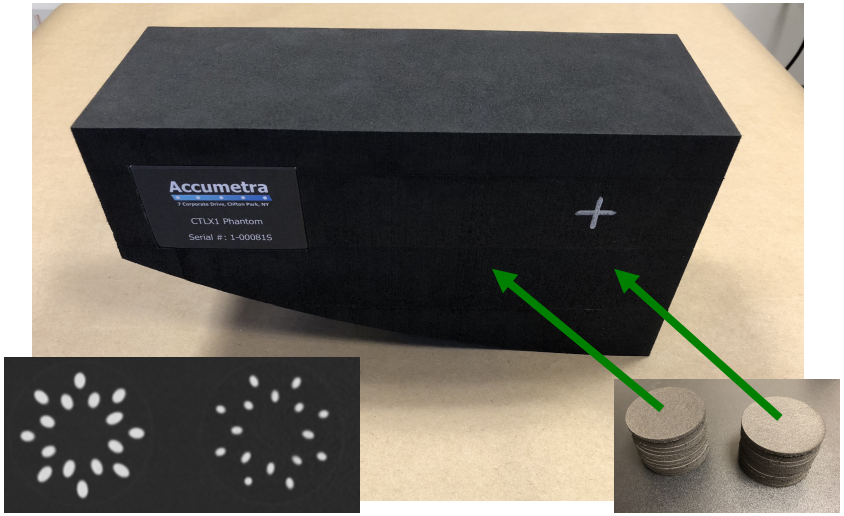


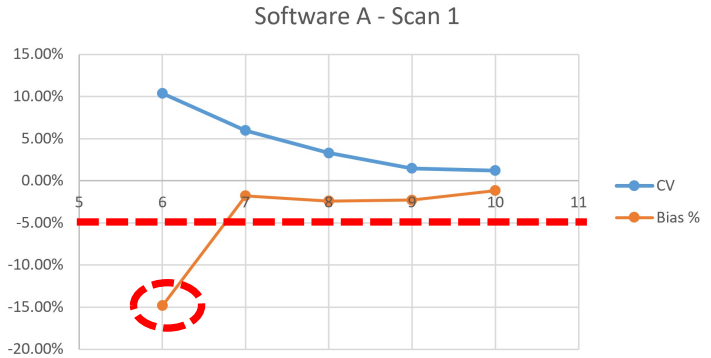


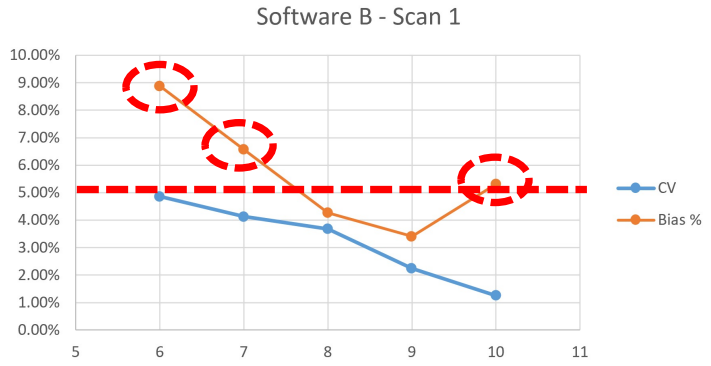


Lung Nodule Software Bias

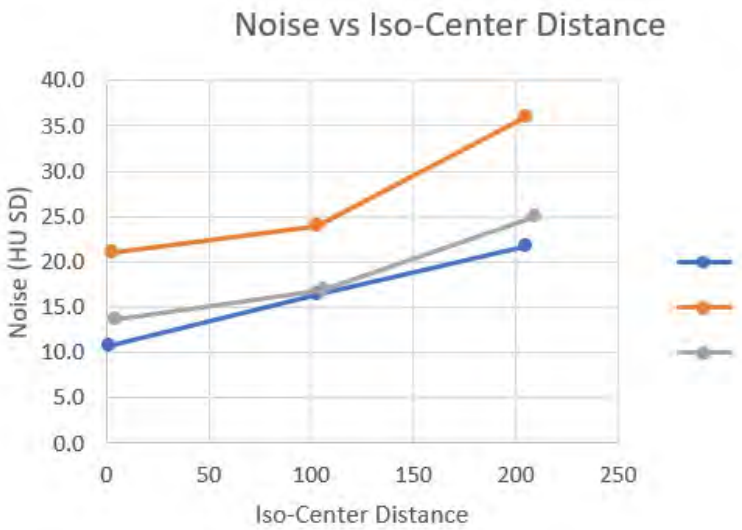
- The CTLX1S Contains 80 Acrylic Ellipsoids Ranging In Size From 6mm To 10mm
- Scanning And Measurement Using Two Software Systems Revealed High Bias







Using Different CT Scanners To Follow-up



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