Progress Towards an International Image Quality Monitoring Framework for Quantitative Imaging

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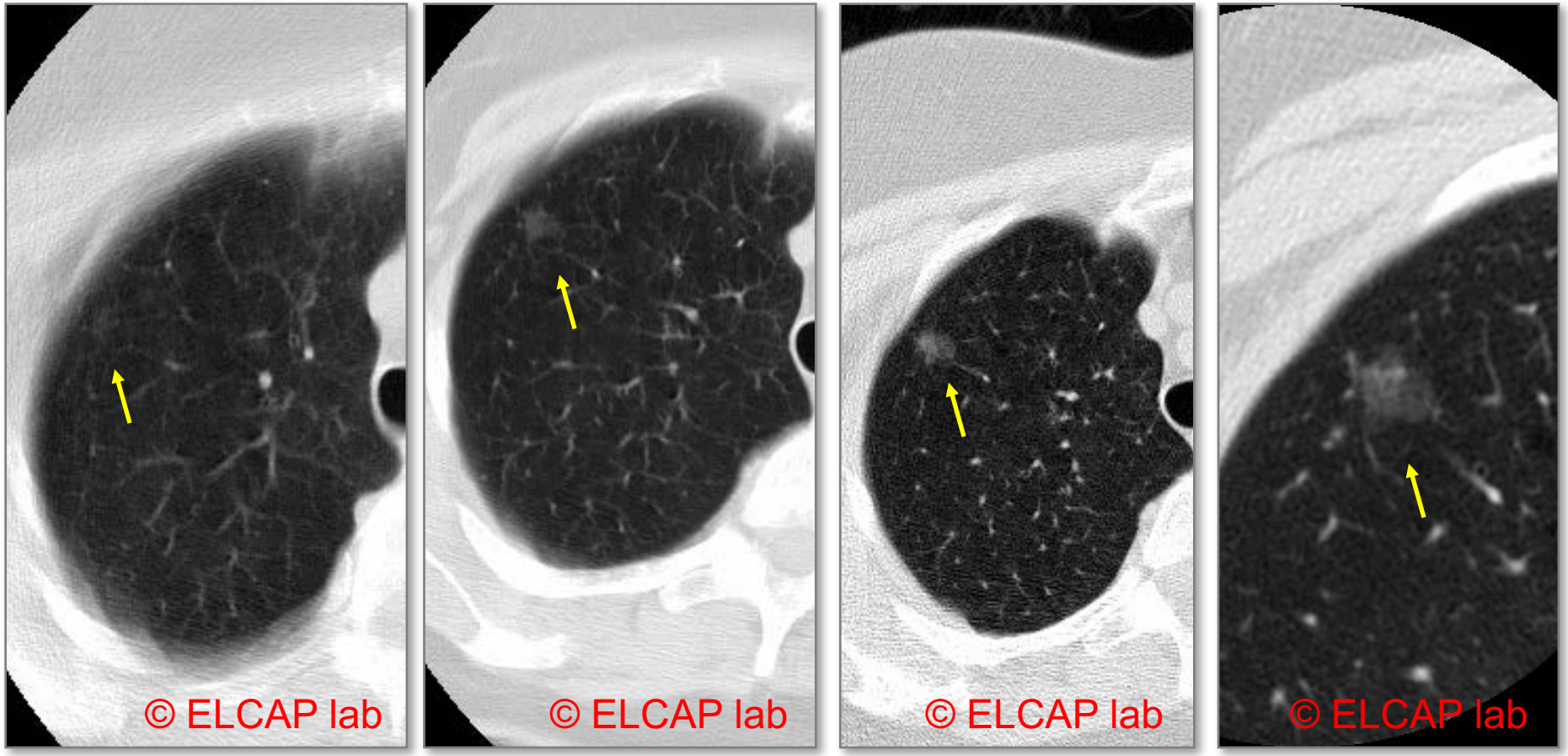
October 2, 2017

Hubble Space Telescope

1990

1993

CT Image Quality



10.0 mm **5.0 mm** **2.5 mm** **1.25 mm**

[Dr. David Yankelevitz, Mount Sinai]

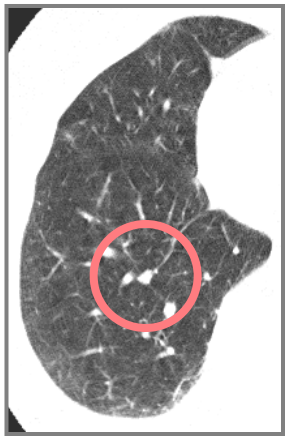
Lung Cancer Decision Support Landscape

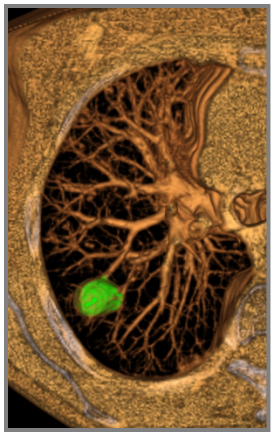
Pipeline

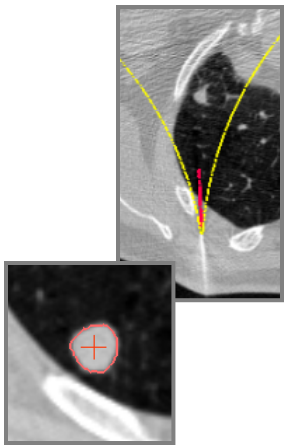
Individual Risk Assess, Δ, Monitor → Personalized Early Detection → Differential Diagnosis → Intervention & Therapy

Imaging Opportunities

Image+ Based Risk Analysis	Computer Aided Detection (CAD) + Δ Analysis	Δ Analysis & IG Biopsy	CAD + Δ Analysis







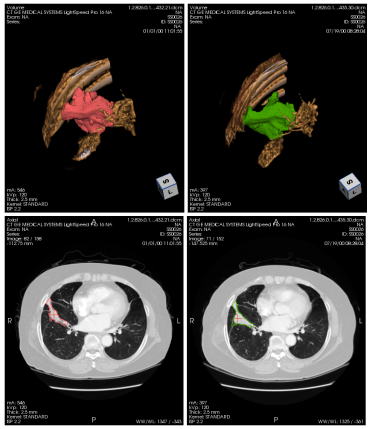
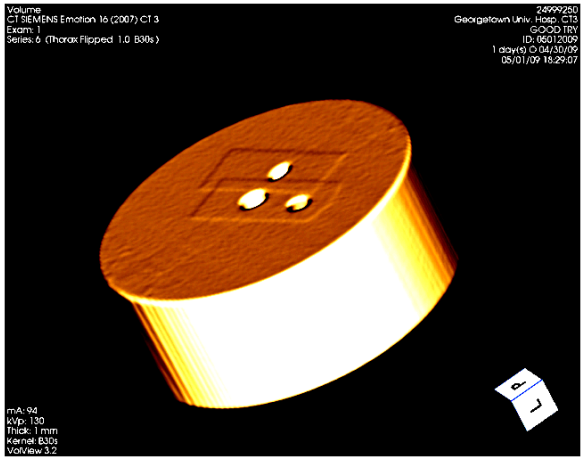
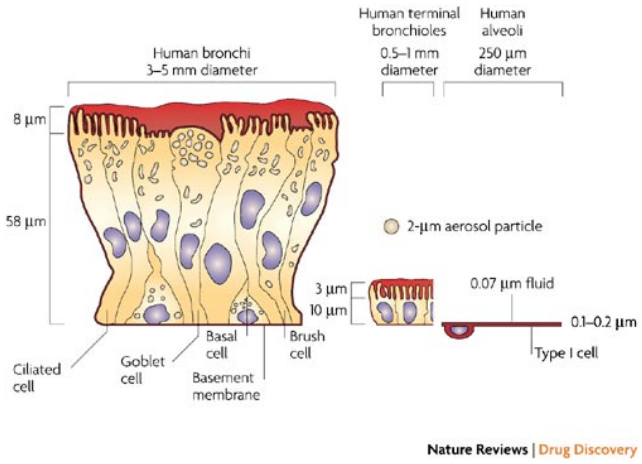
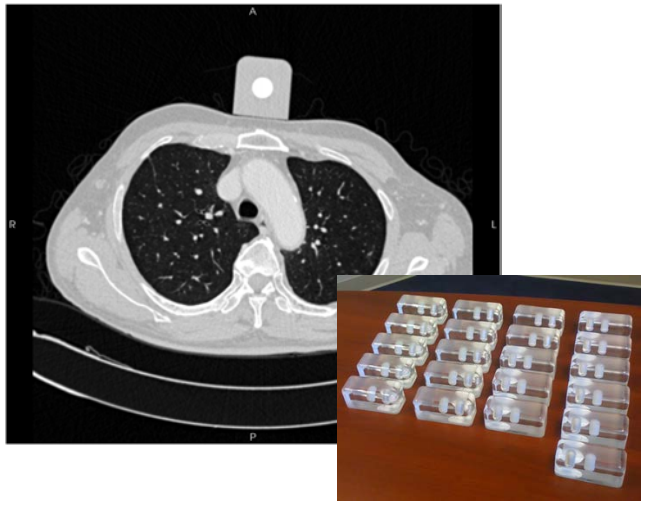


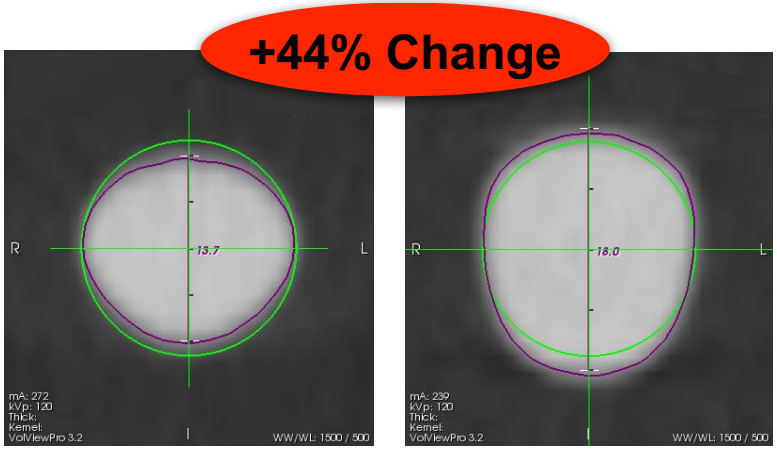
Image Quality Assessment Is Highly Task and Equipment Specific





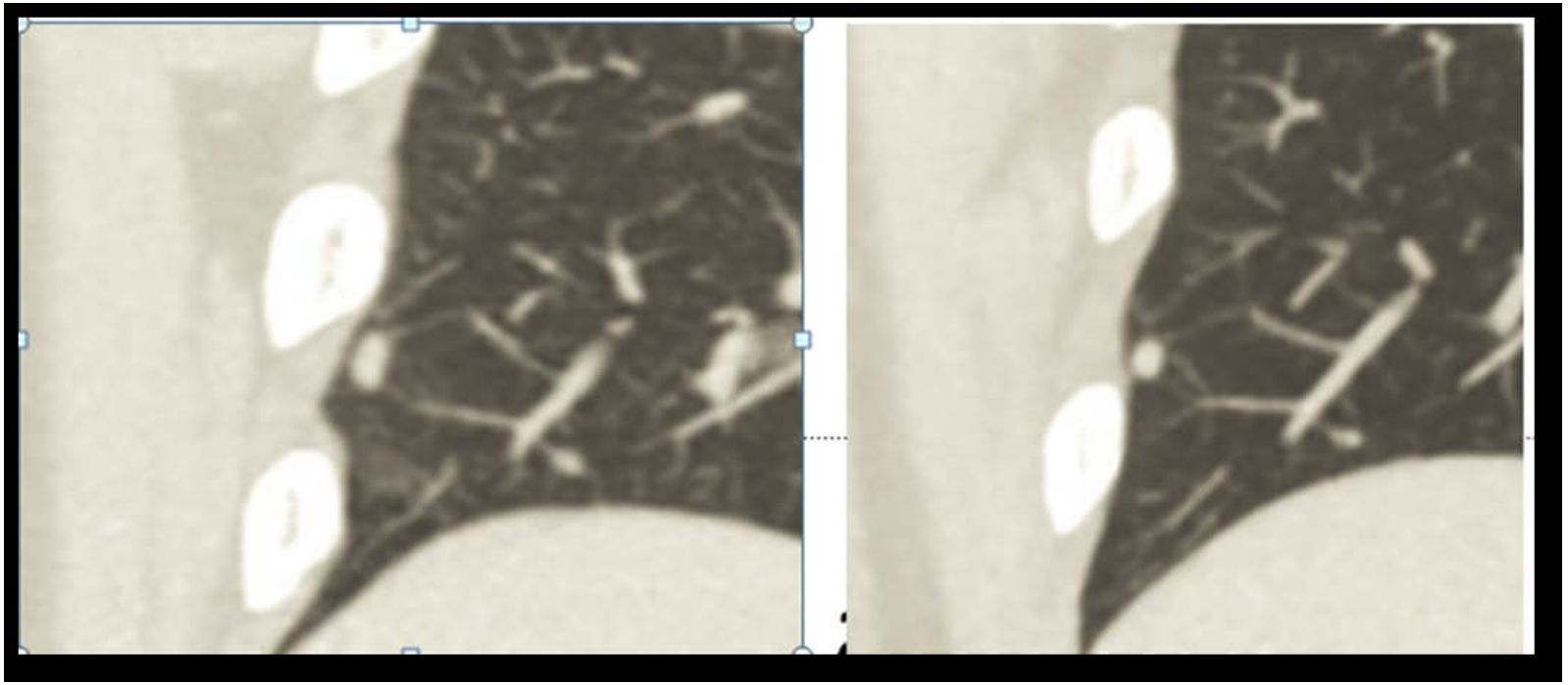
Patton and Byron *Nature Reviews Drug Discovery* 2007



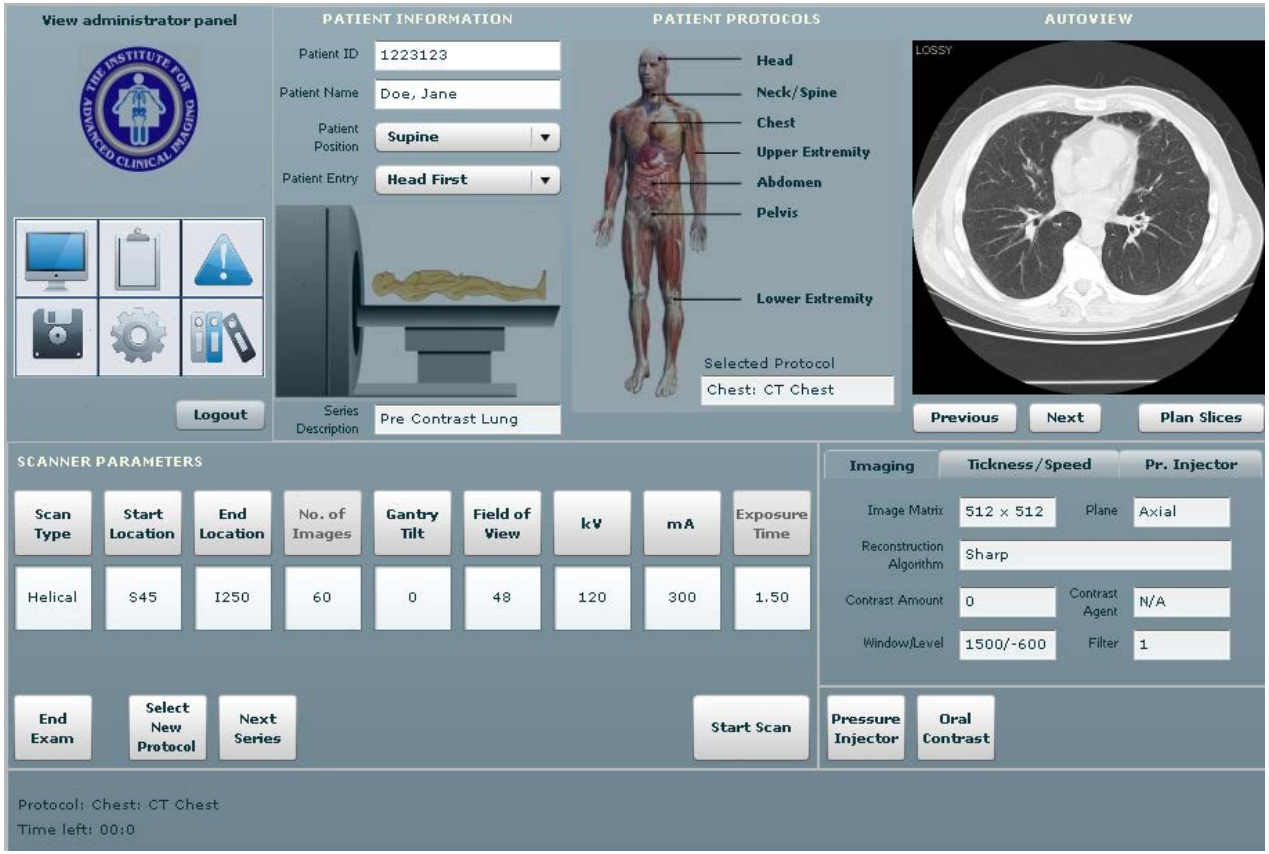


Henschke *Journal of Medical Imaging 2016*

Spatial Warping Example



Fundamental Quantitative Imaging Problem



http://www.iacionline.com/simulators.da

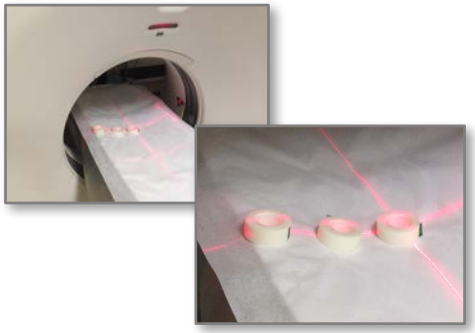
CT Scanners Have Too Many Parameter Settings And Their Tradeoffs Are Not Known

Free CT Image Quality Report

Can Be Replaced With Calibrated Object

Accumetra.com

Email



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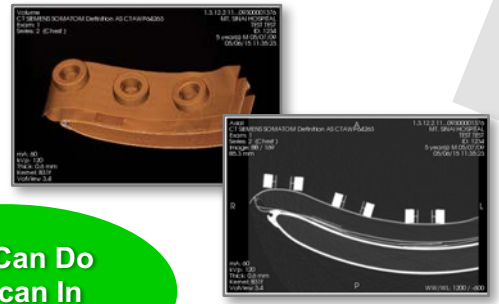
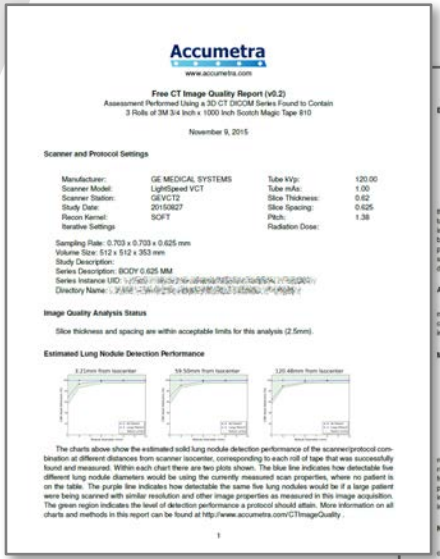


Tech Can Do The Scan In < 5 Minutes


Accumetra

Free CT Image Quality Report (v0.2)

Assessment Performed Using a 3D CT DICOM Series Found to Contain 3 Rolls of 3M 3/4 Inch x 1000 Inch Scotch Magic Tape 810

November 9, 2015

Scanner and Protocol Settings

Manufacturer:	GE MEDICAL SYSTEMS	Tube kVp:	120.00
Scanner Model:	LightSpeed VCT	Tube mAs:	1.00
Scanner Station:	GEVCT2	Slice Thickness:	0.62
Study Date:	20150827	Slice Spacing:	0.625
Recon Kernel:	SOFT	Pitch:	1.38
Iterative Settings		Radiation Dose:	

Sampling Rate: 0.703 x 0.703 x 0.625 mm
Volume Size: 512 x 512 x 353 mm
Study Description:
Series Description: BODY 0.625 MM
Series Instance UID:
Directory Name:

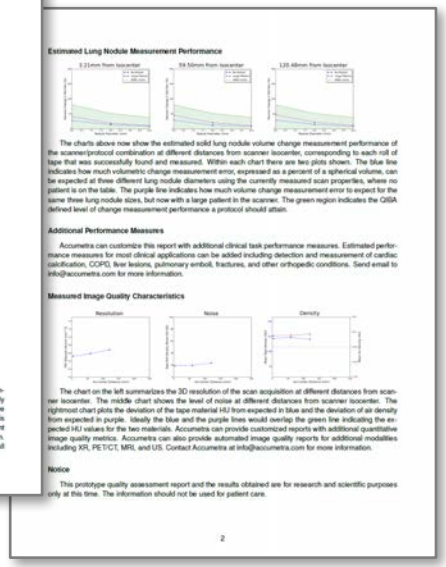
Image Quality Analysis Status

Slice thickness and spacing are within acceptable limits for this analysis (2.5mm).

Estimated Lung Nodule Detection Performance

The charts above show the estimated solid lung nodule detection performance of the scanner/protocol combination at different distances from scanner isocenter, corresponding to each roll of tape that was successfully found and measured. Within each chart there are two plots shown. The blue line indicates how detectable five different lung nodule diameters would be using the currently measured scan properties, where no patient is on the table. The purple line indicates how detectable the same five lung nodules would be if a large patient were being scanned with similar resolution and other image properties as measured in this image acquisition. The green region indicates the level of detection performance a protocol should attain. More information on all charts and methods in this report can be found at http://www.accumetra.com/CTImageQuality .

1


Estimated Lung Nodule Measurement Performance

The charts above now show the estimated solid lung nodule volume change measurement performance of the scanner/protocol combination at different distances from scanner isocenter, corresponding to each roll of tape that was successfully found and measured. Within each chart there are two plots shown. The blue line indicates how much volumetric change measurement error, expressed as a percent of a spherical volume, can be expected at three different lung nodule diameters using the currently measured scan properties, where no patient is on the table. The purple line indicates how much volume change measurement error to expect for the same three lung nodule sizes, but now with a large patient in the scanner. The green region indicates the QIBA defined level of change measurement performance a protocol should attain.

Additional Performance Measures

Accumetra can customize this report with additional clinical task performance measures. Estimated performance measures for most clinical applications can be added including detection and measurement of cardiac calcification, COPD, liver lesions, pulmonary emboli, fractures, and other orthopedic conditions. Send email to info@accumetra.com for more information.

Measured Image Quality Characteristics

The chart on the left summarizes the 3D resolution of the scan acquisition at different distances from scanner isocenter. The middle chart shows the level of noise at different distances from scanner isocenter. The rightmost chart plots the deviation of the tape material HU from expected in blue and the deviation of air density from expected in purple. Ideally the blue and the purple lines would overlap the green line indicating the expected HU values for the two materials. Accumetra can provide customized reports with additional quantitative image quality metrics. Accumetra can also provide automated image quality reports for additional modalities including XR, PET/CT, MRI, and US. Contact Accumetra at info@accumetra.com for more information.

Notice

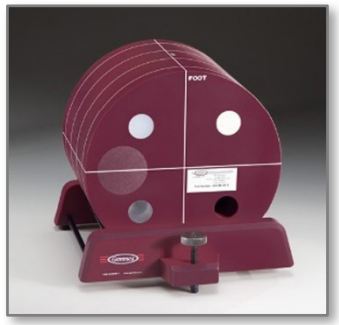
This prototype quality assessment report and the results obtained are for research and scientific purposes only at this time. The information should not be used for patient care.

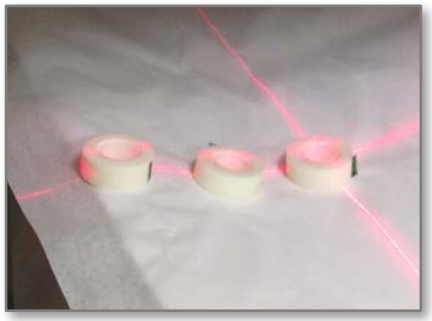
2

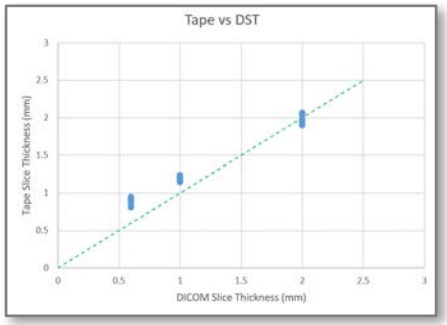
Optimize

Validation Studies

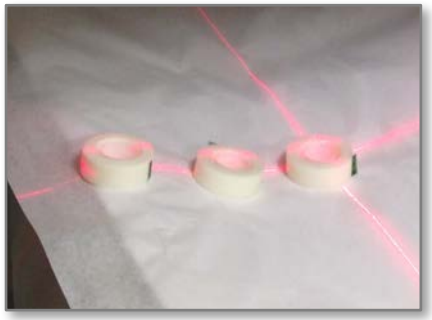
- ACR Phantom and Tape Comparison

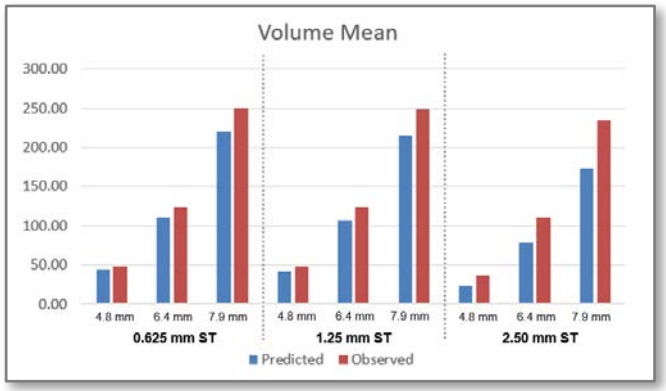






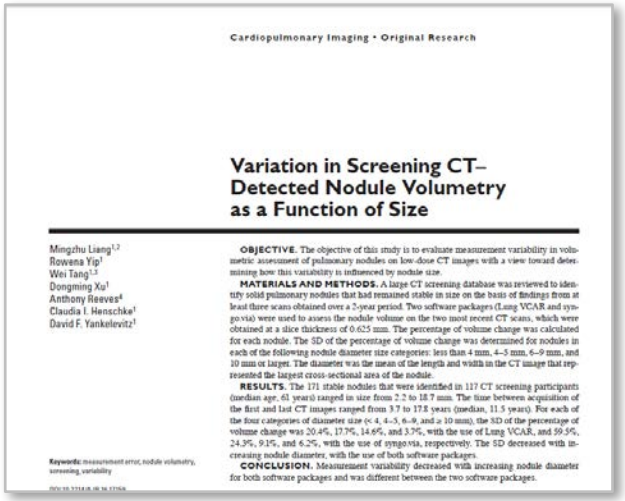
- Clinical Task Prediction Performance





Avila SPIE Medical Imaging 2017

Prediction Data Point



Cardiopulmonary Imaging • Original Research

Variation in Screening CT–Detected Nodule Volumetry as a Function of Size

Mingzhu Liang[1,2]
Rowena Yip[1]
Wei Tang[1,3]
Dongming Xu[1]
Anthony Reeves[4]
Claudia I. Henschke[1]
David F. Yankelevitz[1]

OBJECTIVE. The objective of this study is to evaluate measurement variability in volumetric assessment of pulmonary nodules on low-dose CT images with a view toward determining how this variability is influenced by nodule size.

MATERIALS AND METHODS. A large CT screening database was reviewed to identify solid pulmonary nodules that had remained stable in size on the basis of findings from at least three scans obtained over a 2-year period. Two software packages (Lung VCAR and syngo.via) were used to assess the nodule volume on the two most recent CT scans, which were obtained at a slice thickness of 0.625 mm. The percentage of volume change was calculated for each nodule. The SD of the percentage of volume change was determined for nodules in each of the following nodule diameter size categories: less than 4 mm, 4–5 mm, 6–9 mm, and 10 mm or larger. The diameter was the mean of the length and width in the CT image that represented the largest cross-sectional area of the nodule.

RESULTS. The 171 stable nodules that were identified in 117 CT screening participants (median age, 61 years) ranged in size from 2.2 to 18.7 mm. The time between acquisition of the first and last CT images ranged from 3.7 to 17.8 years (median, 11.5 years). For each of the four categories of diameter size (< 4, 4–5, 6–9, and ≥ 10 mm), the SD of the percentage of volume change was 20.4%, 17.3%, 14.6%, and 3.7%, with the use of Lung VCAR, and 59.5%, 24.3%, 9.1%, and 6.2%, with the use of syngo.via, respectively. The SD decreased with increasing nodule diameter, with the use of both software packages.

CONCLUSION. Measurement variability decreased with increasing nodule diameter for both software packages and was different between the two software packages.

Keywords: measurement error, nodule volumetry, screening, variability

TABLE 2: Percentage of Volume Variation Between Software Packages, by Nodule Size

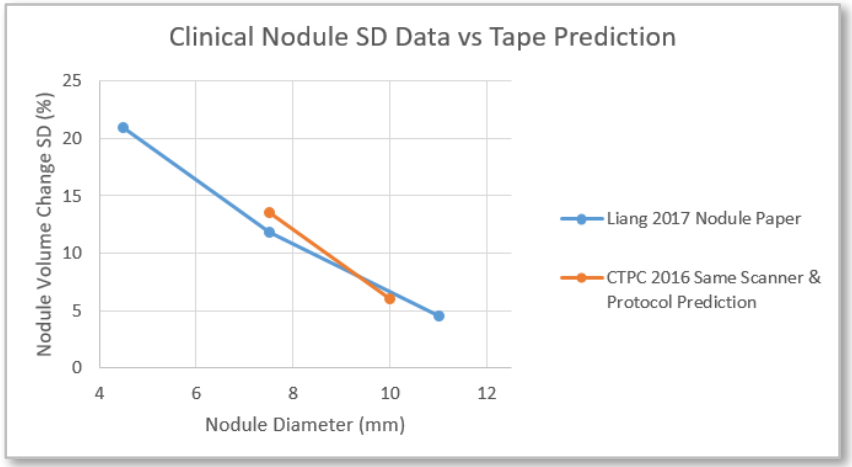
Software Package and Percentage of Volume Variation	< 4 mm (*n* = 83)	4–5 mm (*n* = 62)	6–9 mm (*n* = 20)	≥ 10 mm (*n* = 6)
Lung VCAR[a]				
Mean ± SD	−2.3 ± 20.4	4.7 ± 17.7	1.5 ± 14.6	0.3 ± 3.7
Median (IQR)	−4.8 (−18.4 to 11.1)	6.1 (−7.3 to 16.7)	1.4 (−4.5 to 9.0)	−0.2 (−0.5 to 3.7)
syngo.via[b]				
Mean ± SD	9.7 ± 59.5	−1.7 ± 24.3	−1.0 ± 9.1	4.9 ± 6.2
Median (IQR)	0.0 (−20.7 to 25.0)	−0.5 (−15.0 to 13.8)	1.0 (−5.2 to 4.2)	5.7 (0.7–8.7)

Note—IQR = interquartile range.
[a]Version 11.3–10.11, GE Healthcare.
[b]Version VA20, Siemens Healthcare.

95% CI = 1.96 * SD

Similar/Same Protocol

	6	8	10
GE Discovery CT750 HD	51.7	19.7	11.3
	46.3	22.3	11.8
	53.3	20.4	11.8
	47.8	19.8	11.9
GE LightSpeed VCT	49	18.4	12.2
	54.5	21.3	12.7
	44.3	20	11.5
GE Revolution CT	44.2	19.2	11.8
	41.9	17.9	10.4

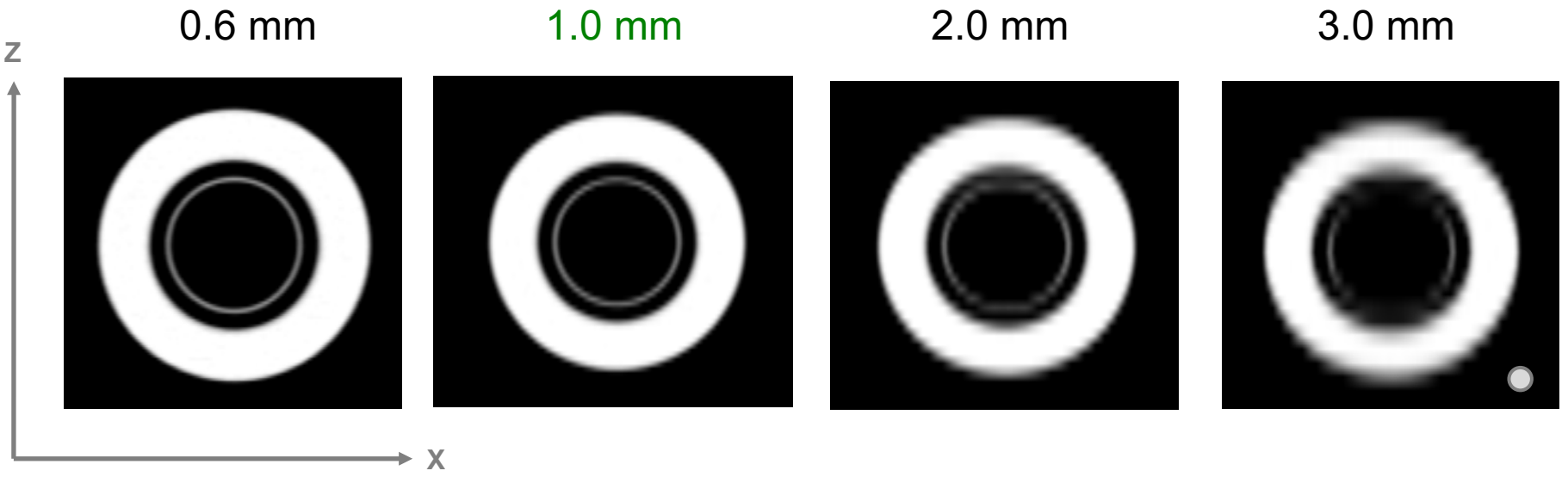


Detection Slice Thickness & Recon Kernel

Slice Thickness	Sites	Soft Recon	Medium Recon	Edge En. Recon
<= 0.625	4 (15%)	0	3	1
0.8, 1.0, 1.25	12 (46%)	6	2	4
>= 1.5	10 (38%)	6	3	1

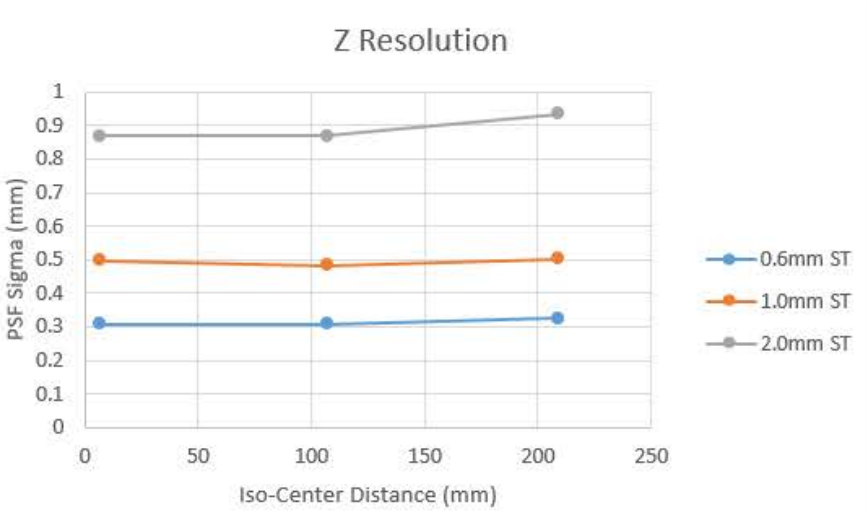
3 used 2mm ST & 1mm spacing

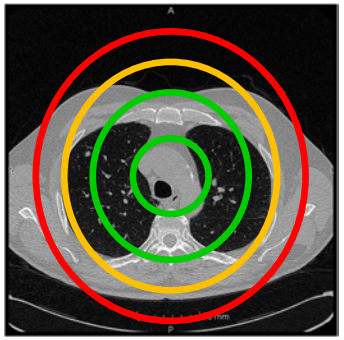
Need To Control CT Slice Thickness (Resolution)

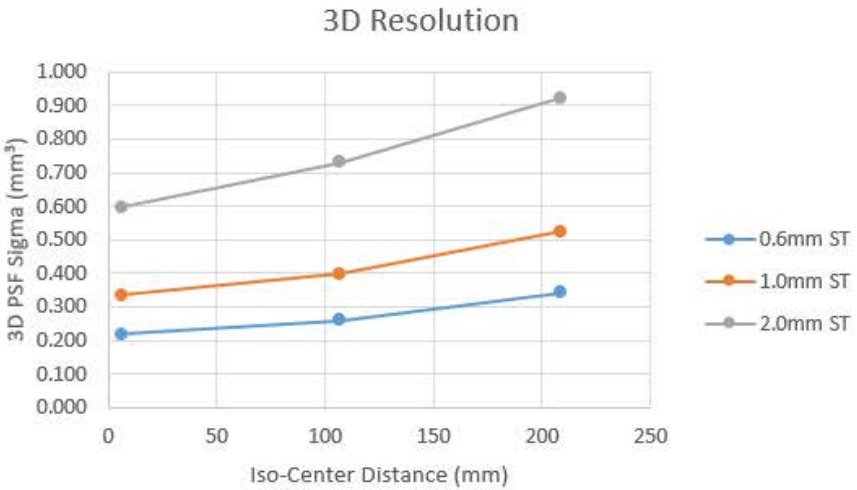


WW = 1000
WL = - 400

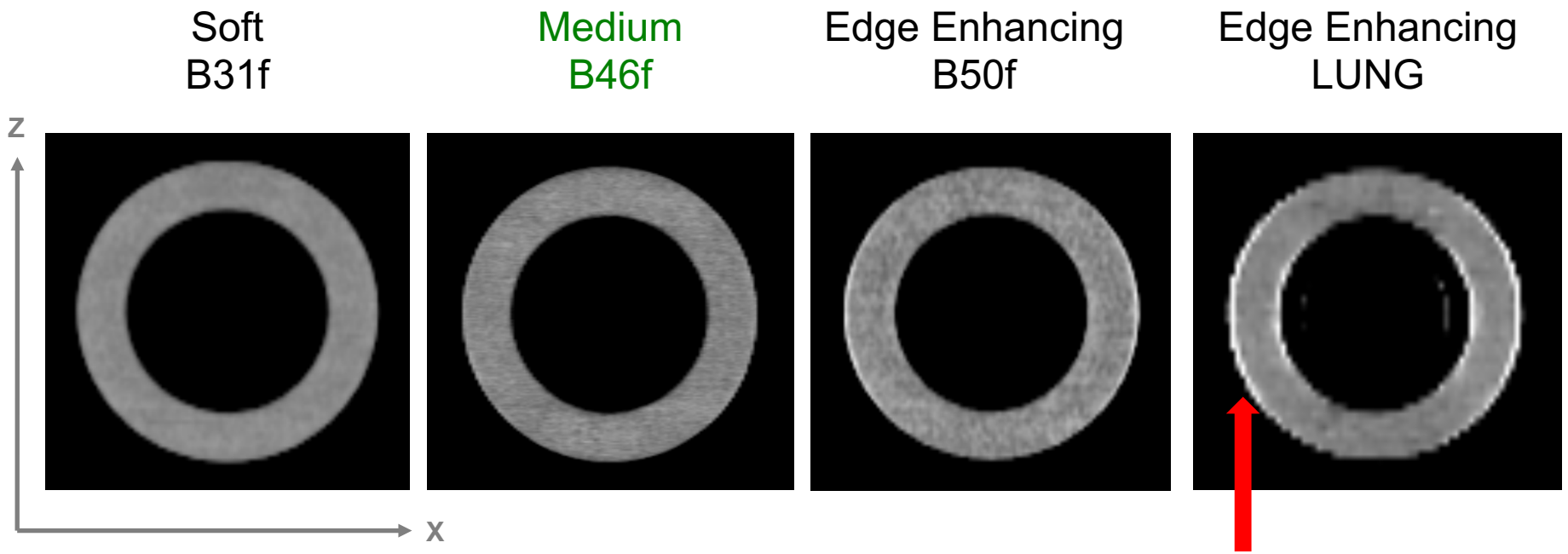
3D Resolution







Need To Control For Edge Enhancement (and Resolution)

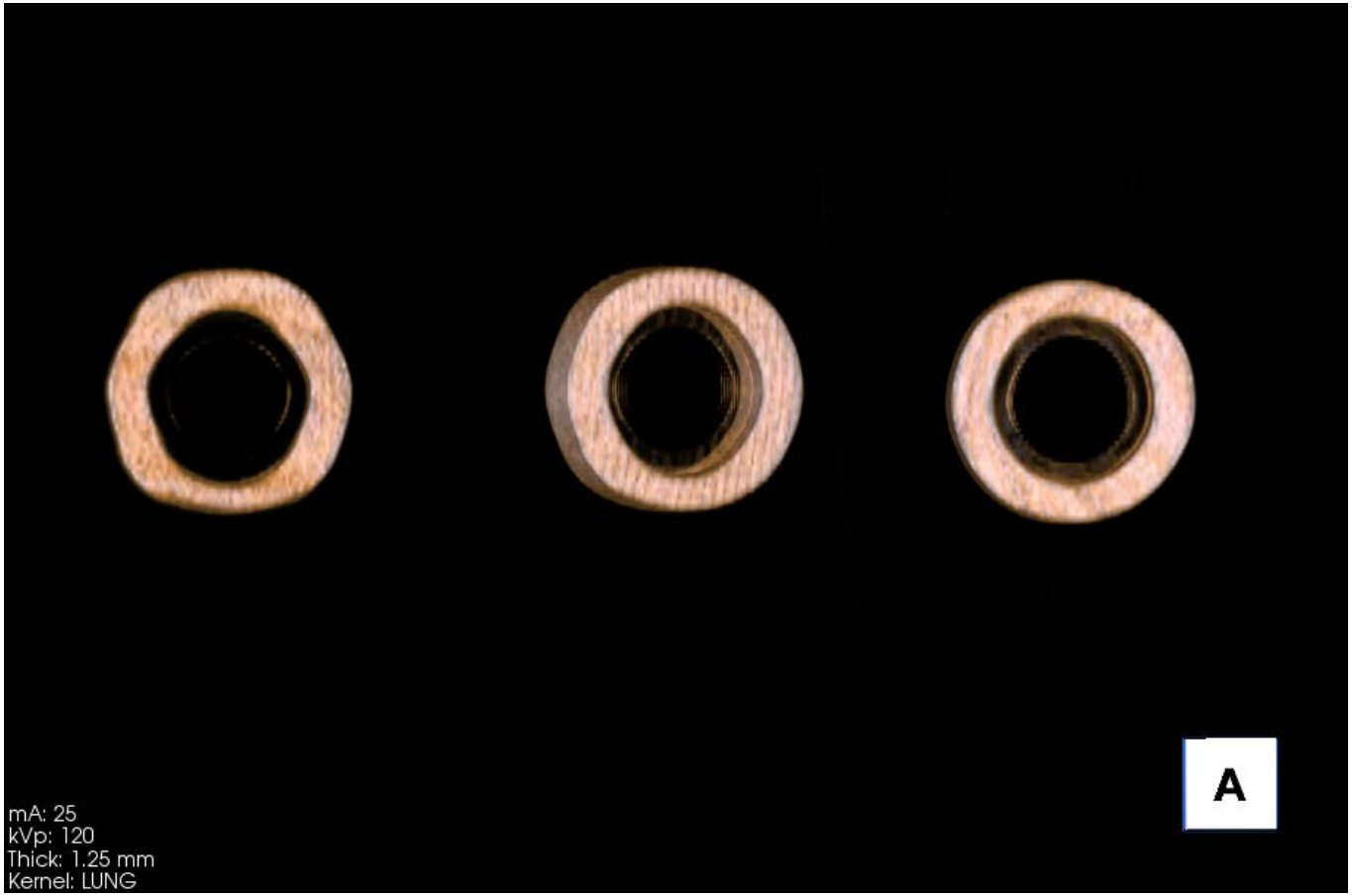


WW = 400
WL = 100

Need To Control For HU Bias - Tape

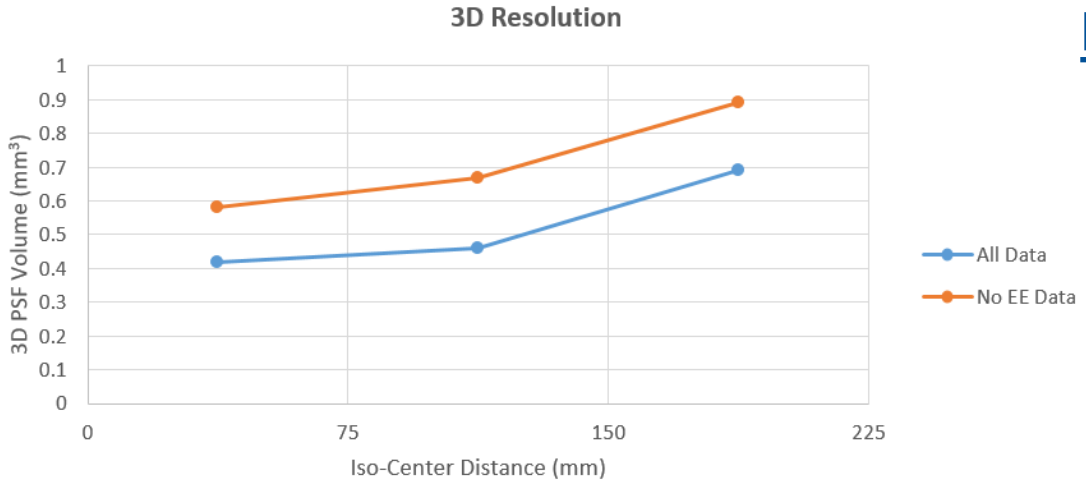
Need To Control For HU Bias - Air

Need To Control Z Spatial Warping



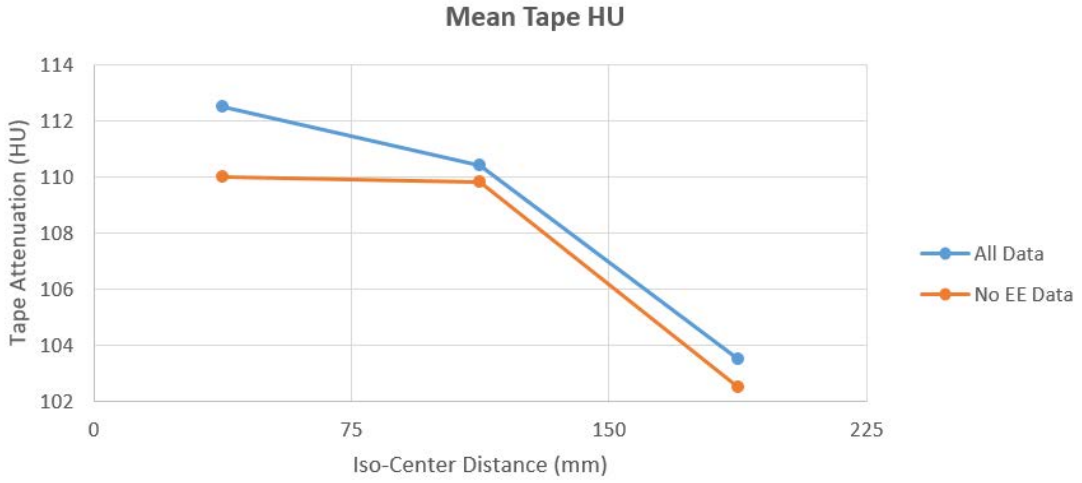
Results For <= 1.25mm Slice Thickness

2017 WCTI Hot Topic Abstract



Periphery Implications

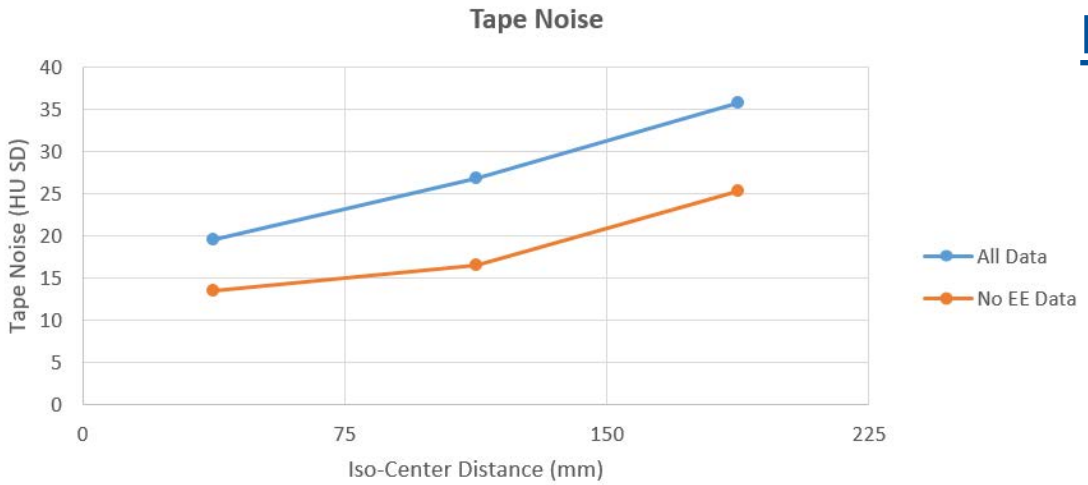
Resolution



HU

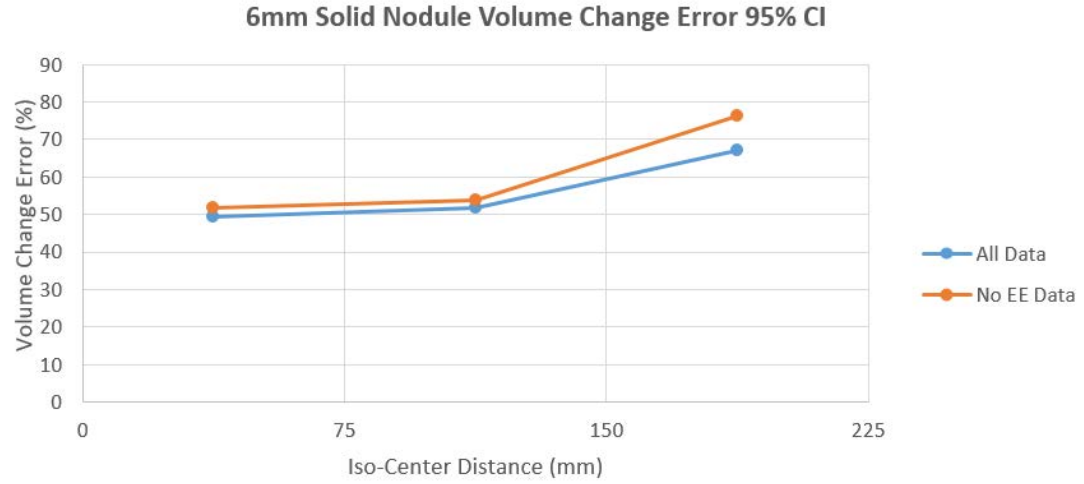
Results For <= 1.25mm Slice Thickness

2017 WCTI Hot Topic Abstract



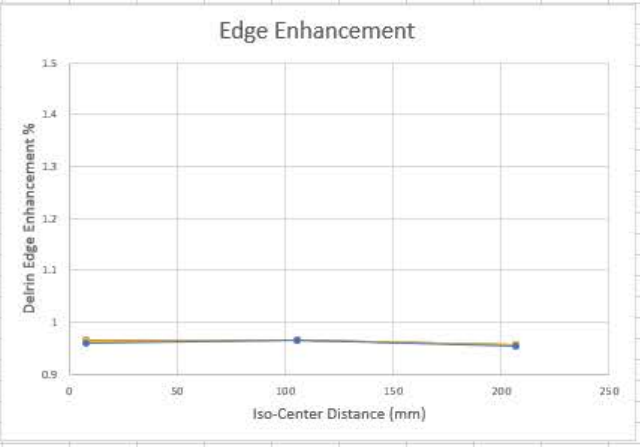
Periphery Implications

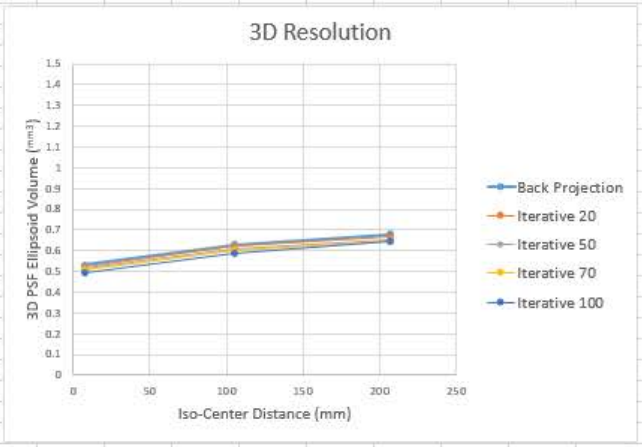
Noise

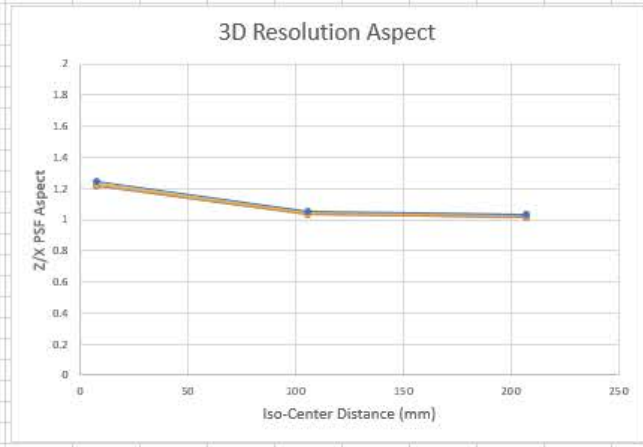


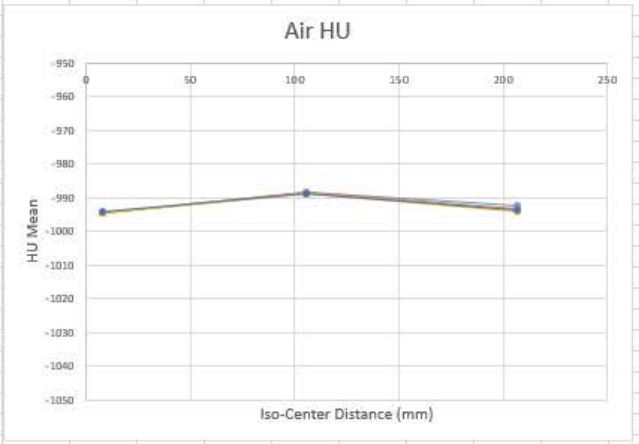
Volume Change Error 95% CI

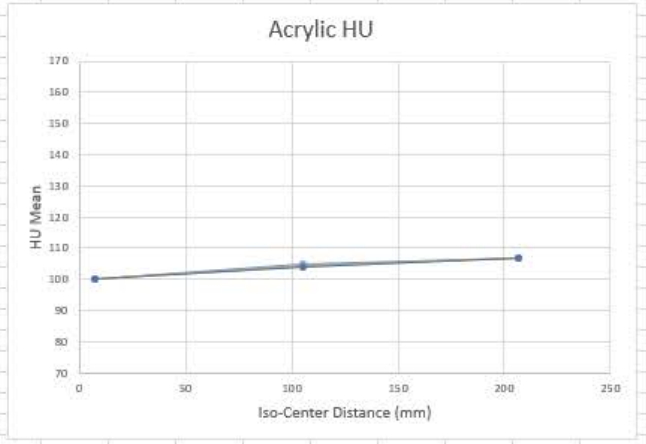
Impact of Iterative Reconstruction

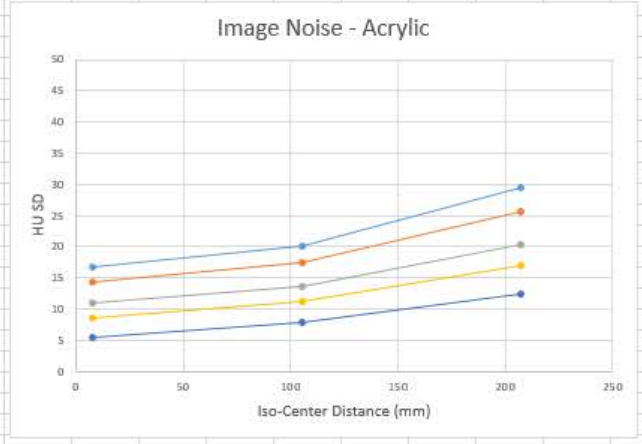












QIBA CT Lung Nodule Profile

1

2

3

4 **QIBA Profile:**

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

6 **Low Dose CT Screening**

7

8 Stage: Publicly Reviewed (draft)

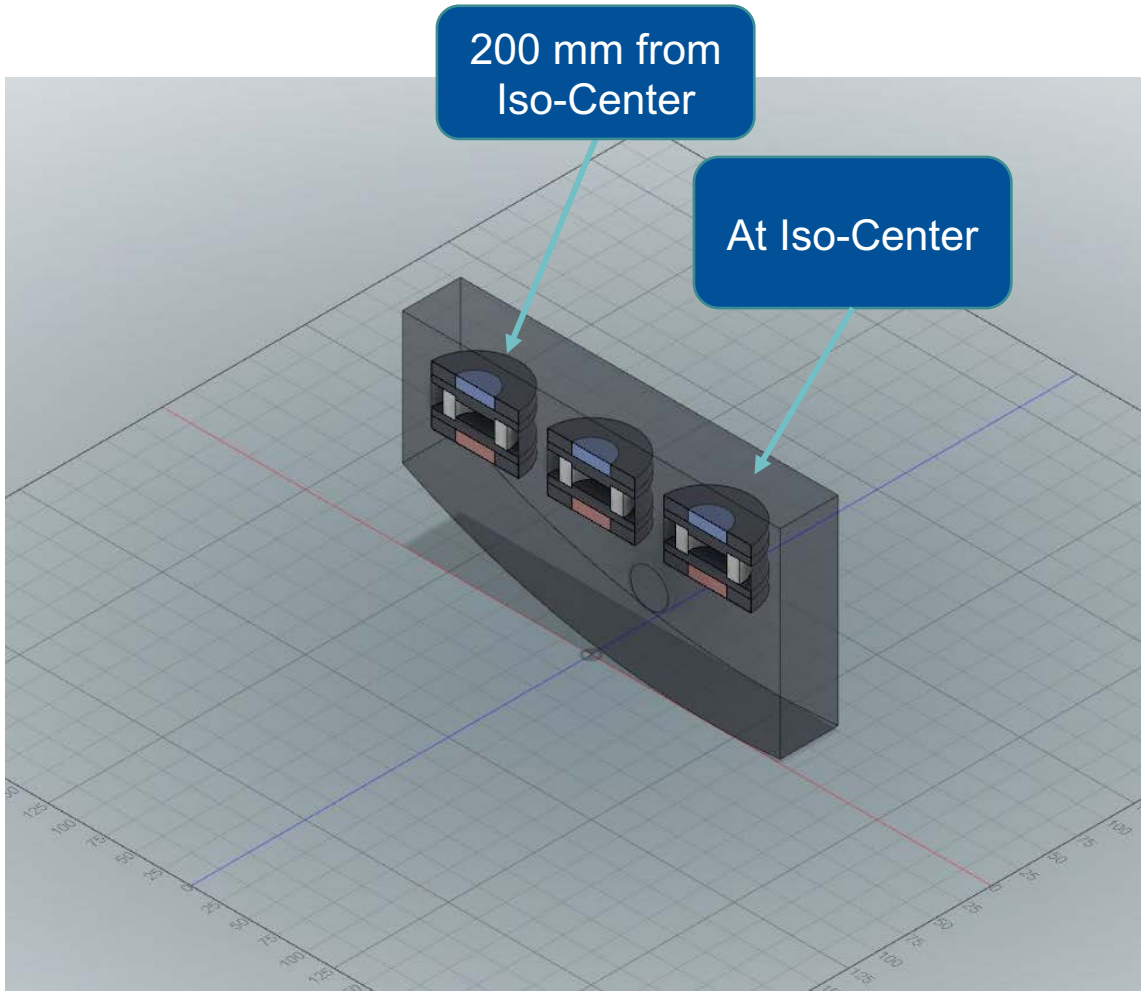
Our Smallest Target

Profile Requirements & Steps

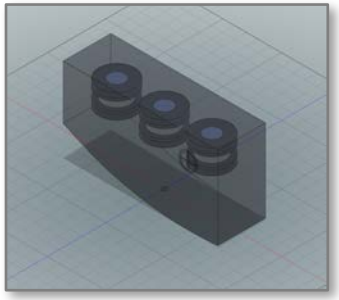
- **CT Scanner**
  - >= 16 Slice
  - Model has been verified to be QIBA Compliant
  - ACR CT accreditation
- **CT Protocol**
  - <= 1.25mm slice thickness
  - Slice spacing <= slice thickness
  - Medium reconstruction kernel
  - Pitch < 2.0
  - …
- **Fundamental Image Properties**
  - Edge Enhancement <= 5%
  - 3D PSF Ellipsoid Volume <= 1.5mm^3
  - 3D PSF Aspect <= 2.0
  - HU Bias < 35 HU
  - Spatial Warping RMSE <= 0.1 mm
  - Image Noise <= 50 HU SD
- **Nodule Analysis Software**
  - ftware has been verified be QIBA Compliant

Verification is Challenging For Many Clinical Sites

CTLX1 Phantom



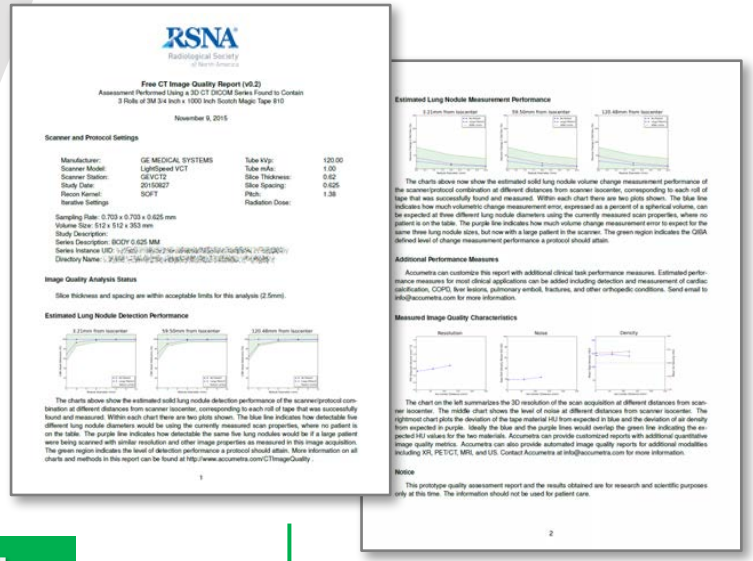
QIBA Pilot: Conformance Testing



http://quality.rsna.org

Upload

Email


RSNA
Radiological Society of North America

Free CT Image Quality Report (v0.2)

Assessment Performed Using a 3D CT DICOM Series Found to Contain 3 Rolls of 3M 3/4 Inch x 1000 Inch Scotch Magic Tape 810

November 9, 2015

Scanner and Protocol Settings

Image Quality Analysis Status

Slice thickness and spacing are within acceptable limits for this analysis (2.5mm).

Estimated Lung Nodule Detection Performance

Estimated Lung Nodule Measurement Performance

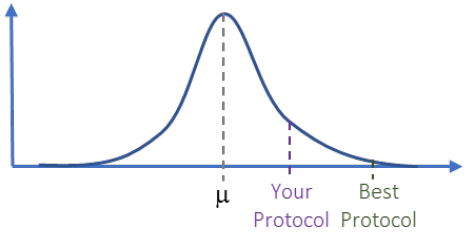
Additional Performance Measures

Measured Image Quality Characteristics

Notice

Optimize

Check Each Time Scanner or Protocol Changes and Once Per Year

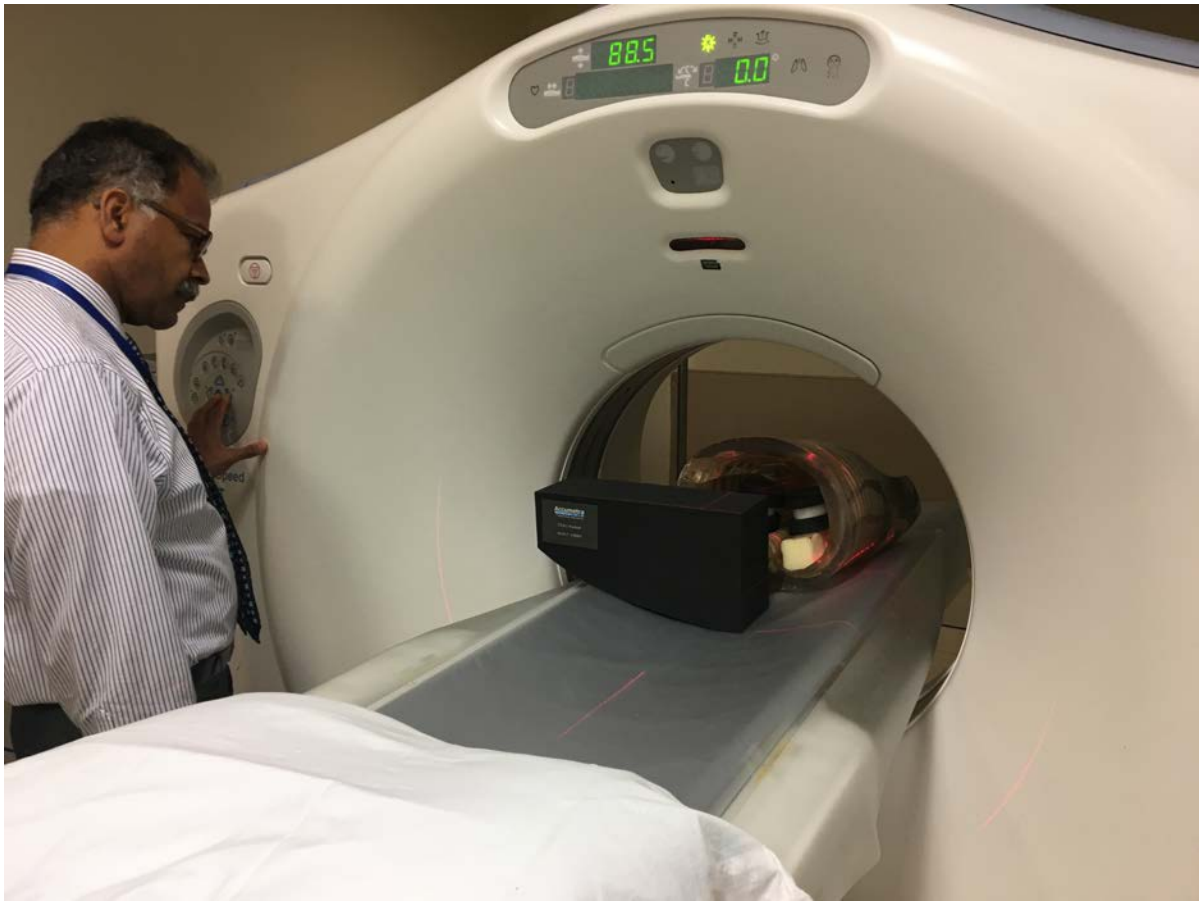


Guidance

Webpages & FAQs

Anthropomorphic Phantom Testing of the CTLX1 Phantom

Preliminary Results



CT Scanning Study - Siemens

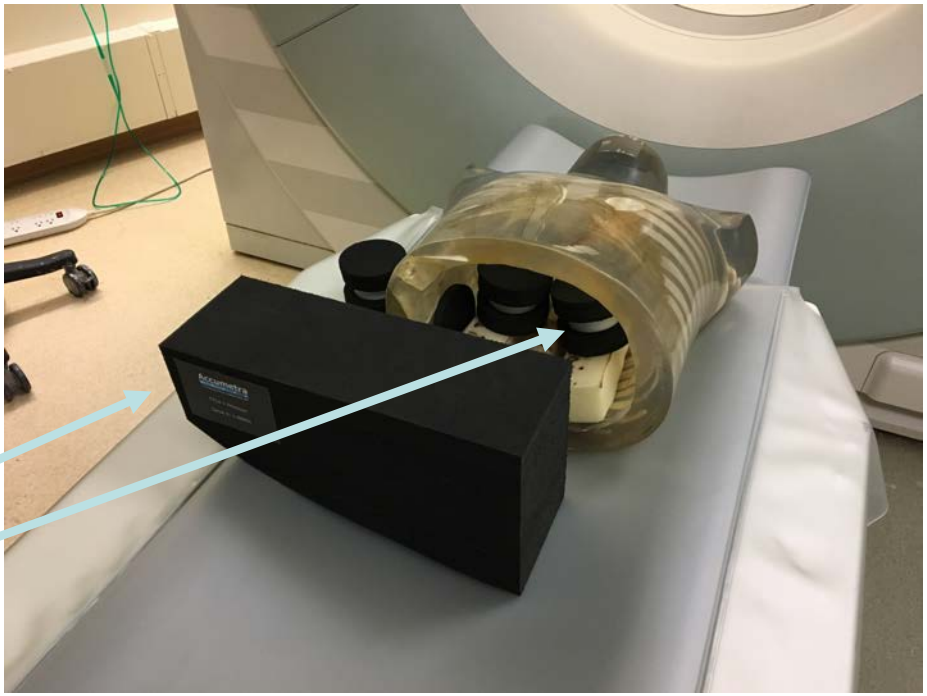
CT Scanner:
Siemens Somatom Definition AS

Main Protocol:
Low Dose Lung Cancer Screen
QIBA SN Profile Conformant

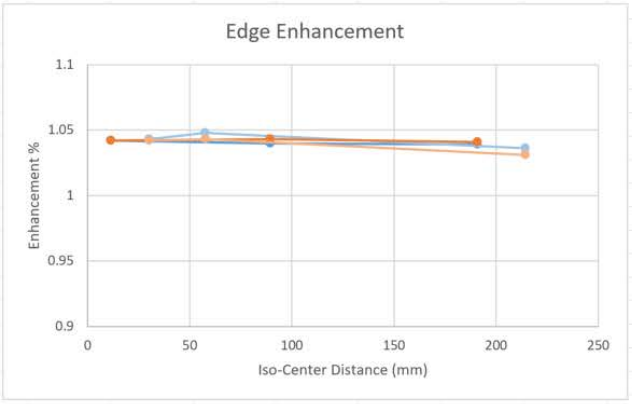
Protocol Variants:
0.6 mm B40f (blue lines)
1.0 mm B40f (orange lines)

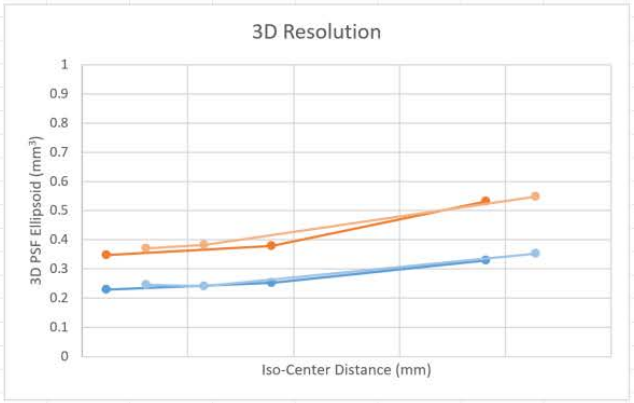
Phantoms:
1) CTLX1 Phantom (darker color)
2) Anthro Chest Phantom w/ CTLX1 Phantom modules (lighter color)

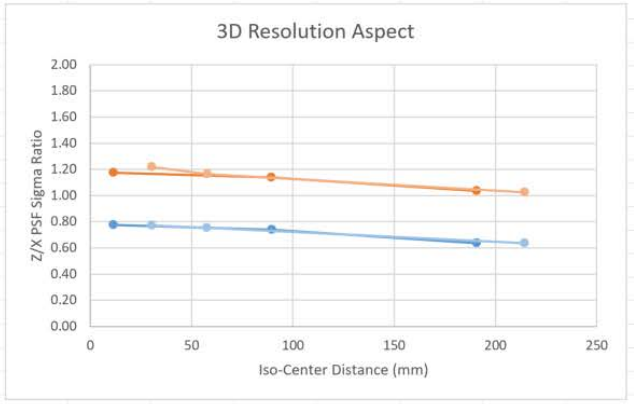
Measurement:
Fully Automated Accumetra SW

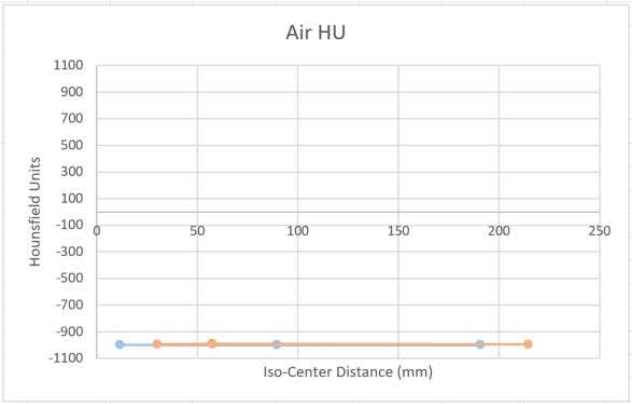


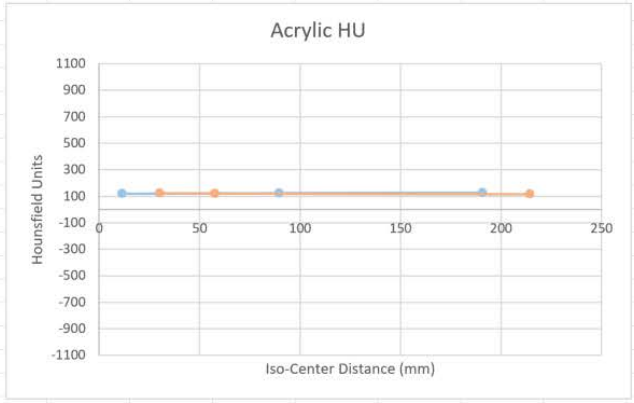
Preliminary Results - Siemens

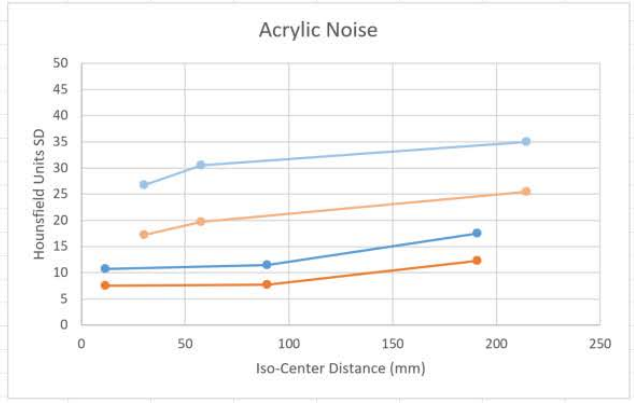




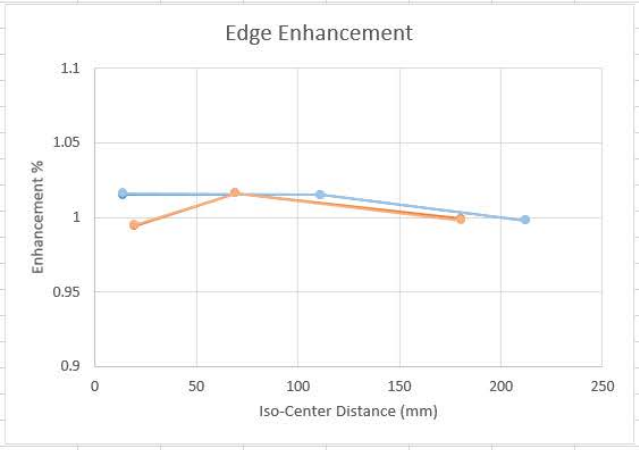


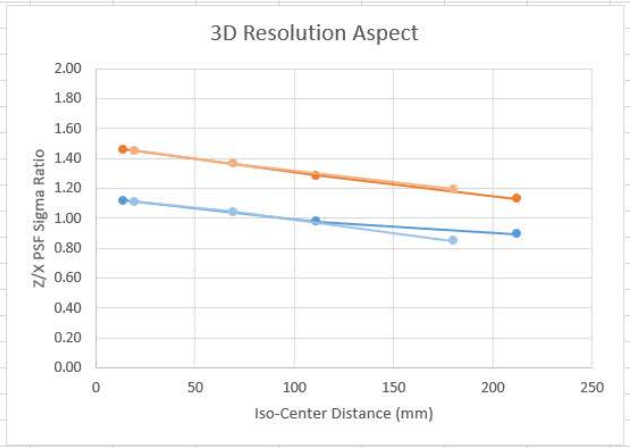


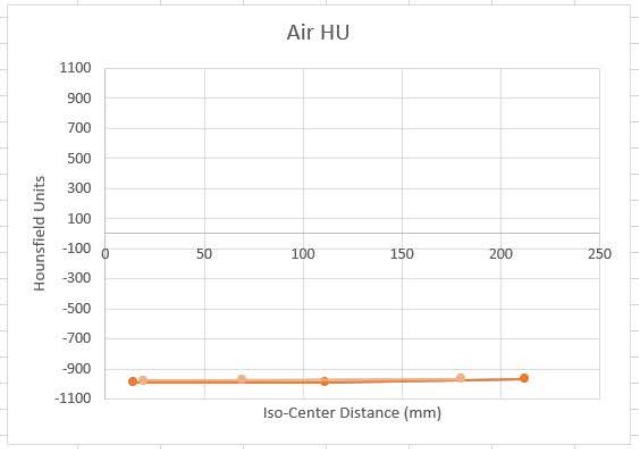


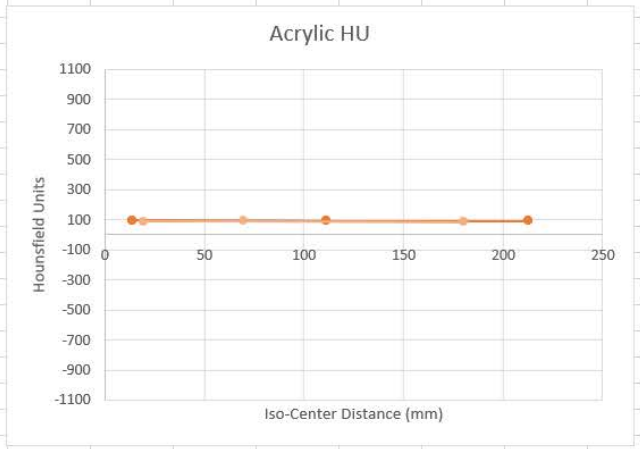


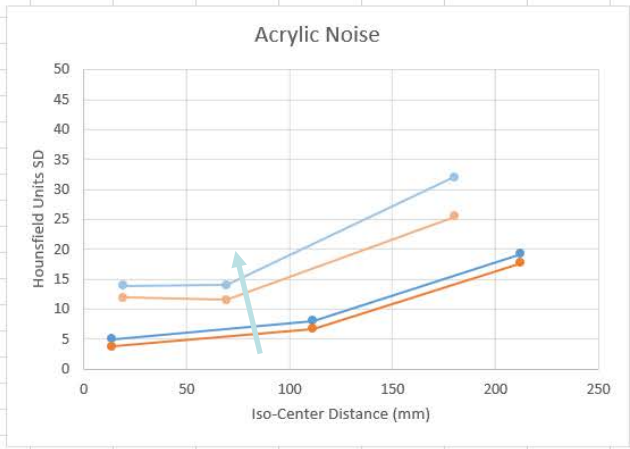
Preliminary Results - GE











CT Scanner and Software Vendors

- CT Scanner DOE

Provide Recommended CT Scanning Protocol

Test the Protocol Over an Operating Envelope

[Insert The Following As A Table

mAs	40
kVp	100
Rotation Time (s)	0.50
Filed of View (cm)	35.0
Pitch	1.50
Slice Thickness (mm)	1.00
Slice Spacing (mm)	0.75
Reconstruction Kernel	I40-4
Table Height	Centered

]

Will have a DOE with the following 19 experiments consisting of 3 repeat CT scans of the recommended CT acquisition protocol (A,B,C) and 16 CT scans that systematically vary mAs, FOV, Pitch, and an iterative reconstruction setting:

[Insert The Following As A Table

Experiment #	mAs	FOV	Pitch	Iterative Recon Setting	Notes
A	40	30.0	1.50	I40-4	Repetition 1
01	30	30.0	1.25	I40-3	[-, -. -, -]
02	30	30.0	1.25	I40-5	[-. -, -, +]
03	30	30.0	1.75	I40-3	[-. -, +, -]
04	30	30.0	1.75	I40-5	[-, -, +, +]
05	30	40.0	1.25	I40-3	[-, +, -, -]
06	30	40.0	1.25	I40-5	[-, +, -, +]
07	30	40.0	1.75	I40-3	[-, +, +, -]
08	30	40.0	1.75	I40-5	[-, +, +, +]
B	40	35.0	1.50	I40-4	Repetition 2
09	50	30.0	1.25	I40-3	[+, -. -, -]
10	50	30.0	1.25	I40-5	[+. -, -, +]
11	50	30.0	1.75	I40-3	[+. -, +, -]
12	50	30.0	1.75	I40-5	[+, -, +, +]
13	50	40.0	1.25	I40-3	[+, +, -, -]
14	50	40.0	1.25	I40-5	[+, +, -, +]
15	50	40.0	1.75	I40-3	[+, +, +, -]
16	50	40.0	1.75	I40-5	[+, +, +, +]
C	40	35.0	1.50	I40-4	Repetition 3

]

CT Scanner and Software Vendors

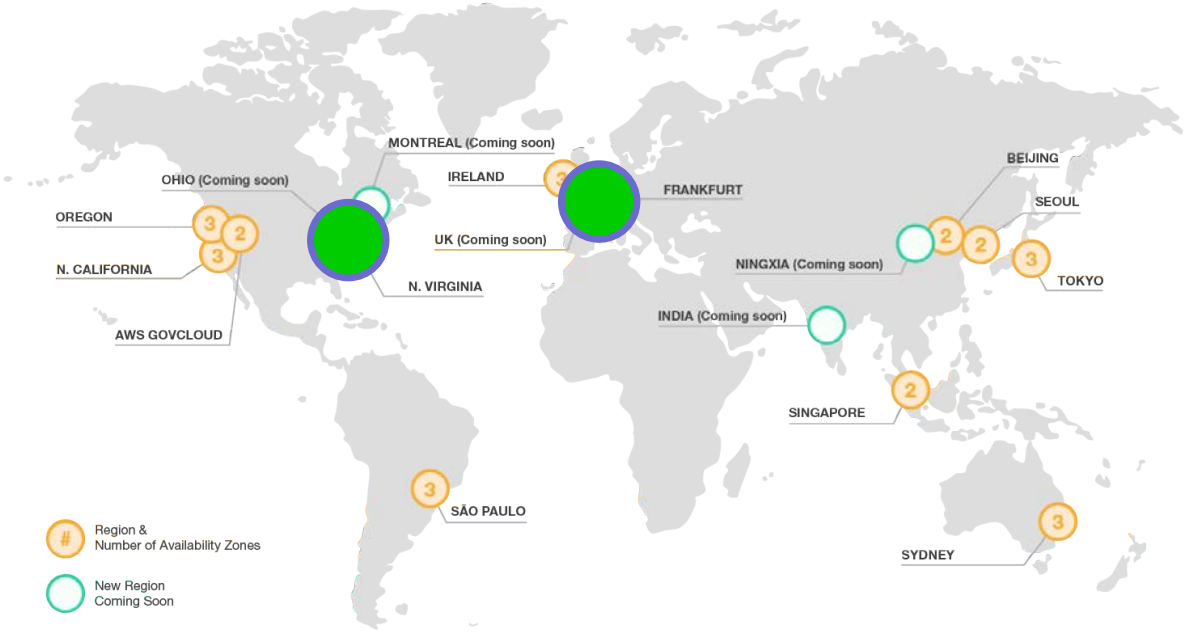
- Analysis Software Vendors
  - Scans of well characterized synthetic and clinical zero change datasets will be provided
  - We will check for near zero bias from 6mm to 12mm diameter solid lesions
  - We will check that the analysis software does not exceed the CV table provided in the profile

We Are Now Distributing 80 CTLX1 Phantoms & Launching New Quality Monitoring Services

- 40 CTLX1 Phantoms Will Be Distributed To Lung Cancer Screening Sites Outside of the United States
- Another 40 CTLX1 Phantoms Will Be Distributed To Lung Cancer Screening Sites In the United States
- Working With RSNA/QIBA We Are Piloting The 1st Small Nodule Change Measurement Conformance Service
- Launching The New 2017 CT Lung Imaging Protocol Challenge Here
- Funding Thanks To The Prevent Cancer Foundation

International CT Image Quality Monitoring

- Monitoring Infrastructure
  - Ultra-low cost CT phantoms requiring <= 5 min to scan
  - Web-based Analysis Tools and Calculator(s)
  - All Running on the Amazon Web Services (AWS) cloud



Challenges

- Getting the Word Out To Sites
  - We need champions (RSNA/QIBA, Advocacy, etc)
- International Regulations
  - Who can help navigate?
- Support For More Application Areas Increases Cost
  - More materials, higher overall mass, and added algorithms
  - Some solutions increase complexity and scanning time
- Thinner Slices = More Review Time
  - We must get Radiology to accept the routine acquisition of multiple scans with at least one high res scan for algorithms
- Continuously Changing CT Technology
  - Iterative Reconstruction Algorithms

Potential Benefits of Improving Global CT Image Quality Through Site Optimization & Correction

- Improved Earlier Lung Cancer Detection : 4mm
- Improved Differential Diagnosis: Improved Sens/Spec
- Shorter Follow-Up Times: 1 to 2 Month Follow-up
- Improvements to Existing Biomarkers: New Sub-Types
- New Biomarker Discoveries: **?**

QIW Recommendations

- Allow Clinical Sites to Acquire At Least One High Resolution CT Lung Screening Scan That Is Intended Only For Computational Analysis
- Encourage CT Scanner Manufacturers To Support 1024x1024 Matrix Size and Clinical Sites To Use It For Computational Analysis
- Enable Reimbursement For Quality Verification of Scans

Thank You

2010: Roche ABIGAIL Study

Model A
Site 1

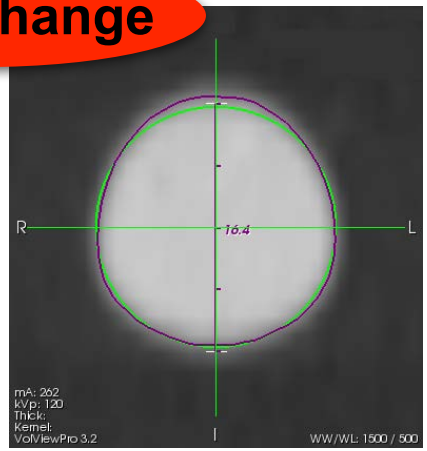
+44% Change

1654 mm^3

2379 mm^3

Model A
Site 2

+33% Change



1601 mm^3

2127 mm^3

Understanding Lung Nodule Volumetric Error

Patient Characteristics

1. Lesion Size
2. Lesion Margin
3. Patient Size
4. Attachment
5. Local Conditions
6. High HU Objects
7. Metal Implants
8. Motion
9. …

Scan Specification

1. Detector Rows
2. mAs
3. kVp
4. Slice Thickness
5. Pitch
6. Recon Kernel
7. Iterative Recon
8. Dual Source
9. Auto mA & kVp
10. …

CT Acquisition

Acquired Images

Semi-Automated Software

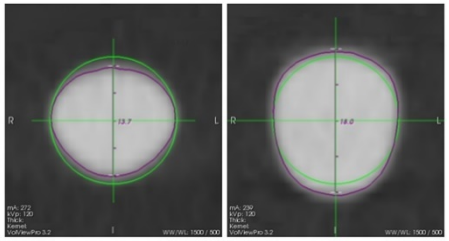
Detection & Measurement

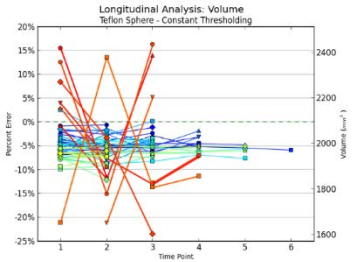
Challenges

1. Internal Structures
2. Large Complex Borders
3. Changing Presentation
4. Very Large Patients

Issues

1. Large & Growing # Parameters
2. Constantly Changing
3. Operator Preferences/Errors
4. Difficult to Fully Reproduce





Object → Scanner → Software → **Volumetric Performance**