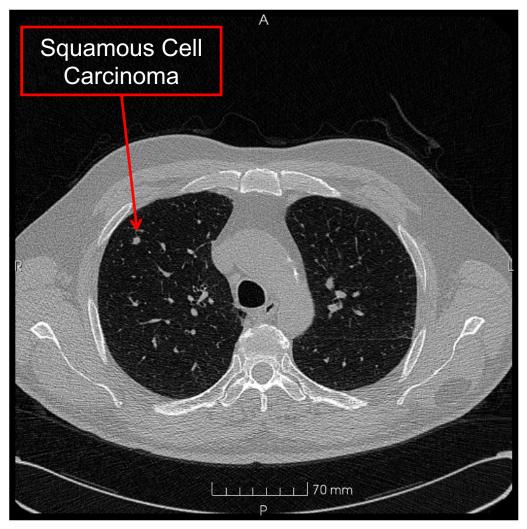
Towards an International Image Quality Monitoring Framework for Quantitative Imaging: Plan for Global Sharing and Progress

> Ricardo S. Avila rick.avila@accumetra.com

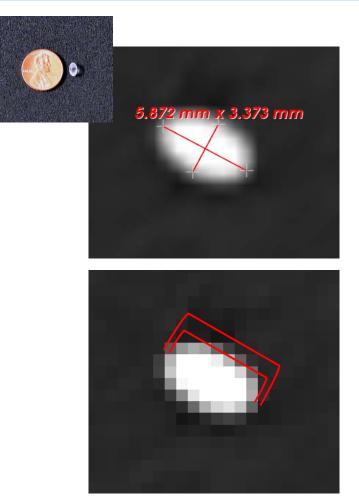
> > November 5, 2018

Follow-Up Measurement of Small Lung Nodules



[Dr. Javier Zulueta, University of Navarra]

Small Lung Nodule Measurement



For a 6.0 x 3.6 x 3.6 mm Lung Nodule:

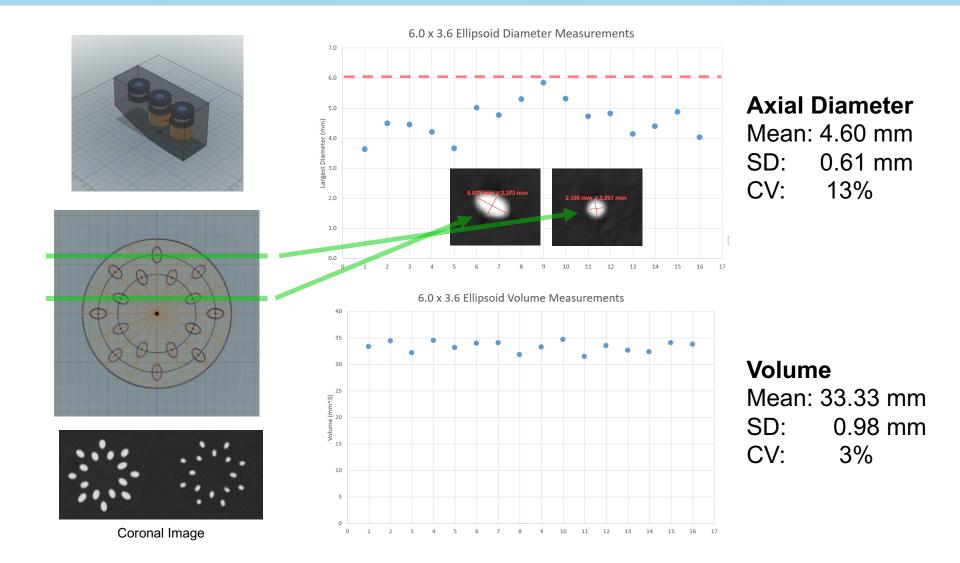
We are working with axial CT images with a maximum nodule diameter of between 6 and 9 pixels

+1mm Max Diameter Increase

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

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

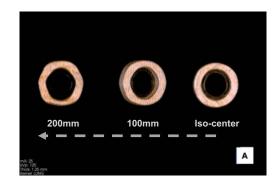
Small Lung Nodules

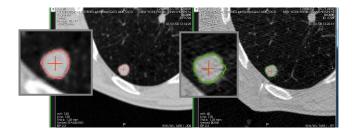


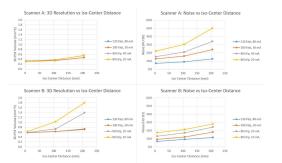
Quality of Lung Nodule Measurements: What Have We Learned Over The Last 15 years?

- 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
 - ...

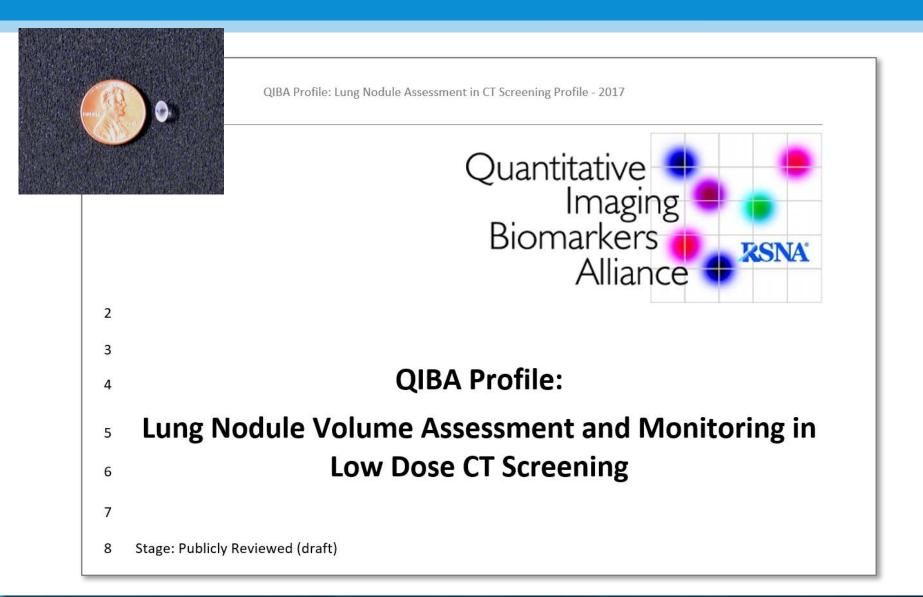
We need to constantly measure and monitor CT detection and measurement equipment







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



CTLX1 Phantom

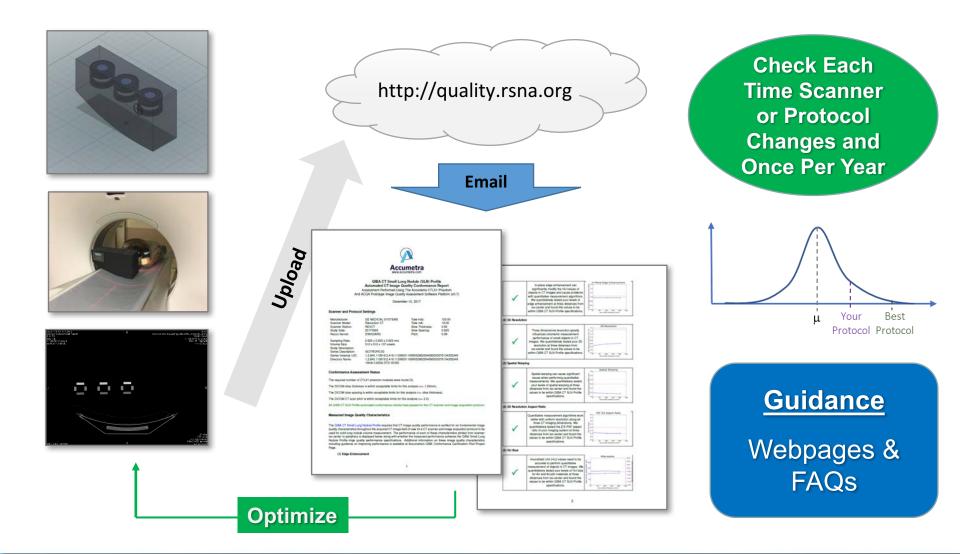
The First Image Quality Phantom To Measure The Full CT Scanner Field of View



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 <= 1.5mm³
- 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



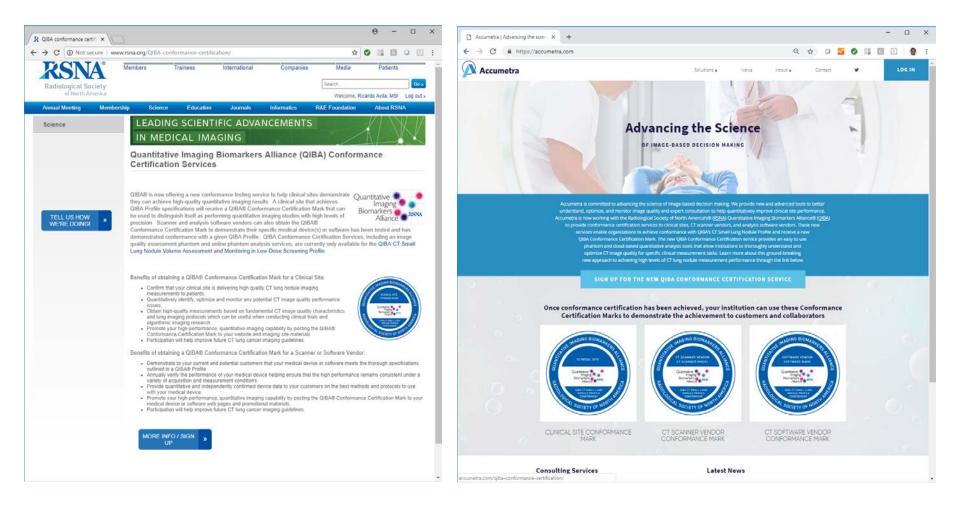
International CT Image Quality Monitoring Thanks to the Prevent Cancer Foundation



Quantitative Conformance Data

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1 Saflwar Hada	IF CTU	(H last. Hadel	Slady D. Slady Ti Slady D. Series I Series E 1	SlierTh Pileb b	Ve ExeTia a	A alla Krearl	Xaiar Yaiar	Zaine XSample VSample 2	Sample Palicul	Palical' Table H. InsC.s	lesC.s Air.HU	Rir.HU Dr.3	X Dr.Y Dr.2	Dr.lasD Dr.Asia	De.Rais De.Rais De.HU De.HU	S Dr.EE Dr.S. E	ins HS	Dr.A., Dr.SV Dr.HSE Dr	.2WR Dr.CTV	De.CTS De.CTR D.	.CTX Dr.CTY	De.CT2 De.RTV I	Dr.ATS Dr.ATR	Dr.ATX Dr.ATY	De.AT2 Te.HU	Tr.HUS AHU	R 🔺
2 Anner		1 MIN CIL SOMAT	2E-17 2E-17 Thereof 1.3.12.2 128KV	14 14	128 258	320 100 P+404	542 54	2 451 1.701 1.701	8.5 B26Y	155	1 -155 -335.55	1.74 -2	2.88 -467.44 -4425.8	2.35 -1.815	1 -8.883 555.555 5.51	7 1.83 8.445	1.445 1.314	1.785 1.261 1282.4	1.162 1			1 1			1 164.43	18.83 117.88	
3 Assart	1	1 NIN CIL SOMAT	2E-17 2E-17 Thereof 1.5.12.2 128KV_ 2E-17 2E-17 Thereof 1.5.12.2 128KV_		121 251	528 - 188 (0,482) 528 - 188 (0,482)	542 54 542 54		1.5 126Y	166	1 -166 -1011.5 1 -166 -356.50		1.51 -165.21 -1126.2		1 -0.017 555.476 11.56		1.462 1.524		LIS		1 1				351.4	16.11 124.14	
5 Assaul	2	1 NINCE, SOMAT	2E-87 2E-87 Thereof 1.5.12.2 LUNG	1.5 1.1	148 258	328 188 P+324	542 54	2 31 8.781 8.781	1.5 8254	166	1 -155 -1883.5	5.88 -	-2.1 -166.58 -1125.8	2.14 -8.815	1 -0.01 350.043 10.40	7 1.855 8.58	1.51 1.547	1.114 8.512 1515	1.175 1	- i i	1 1	- 1 - 1	- 1 - 1	- 1 - 1	8 383.54	3.25 146.44	
5 Assarl	1	1 HINCE SOMAT	2E-17 2E-17 Theread 1.5.12.2 LUNG 2E-17 2E-17 Theread 1.5.12.2 LUNG	1.5 1.1	141 251	321 101 P+324 321 101 P+324	542 54 542 54	2 31 1.701 1.701 2 31 1.701 1.701	1.5 B26Y	166	1 -166 -106.7		1.83 -165.11 -1126.7	55.15 -1.101 211.5 -1.111	1 -0.017 555.402 5.75	1.033 0.602 7 1.003 0.632			1.051 1						375.87	E.31 148.42 11.32 158.41	
7 Assarl B Assarl	;		2E-17 2E-17 Thereof 1.3.12.2 LUNG 2E-17 2E-17 Thereof 1.3.12.2 LUNG	1.5 1.1	14 21	21 6 0-414	512 51	2 31 1.711 1.711 2 31 1.711 1.711	1.5 8254	166	1 -166 -110.3		1.53 -164.46 -1126.5	2.15 -0.11	1 -0.011 100.001 1.75				1.155 1						1111.52	11.32 158.41	
3 Assard	÷ .	1 NINCE, SOMAT	2E-87 2E-87 Thereof 1.3.12.2 LUNG	1.5 1.1	81	21 6 8-484	542 54	2 31 8,781 8,781	1.5 8254	166	1 -155 -335.51	15.48 5	13.5 -165.85 -1126.7	33.3 -4.81	1 -8.815 515.545 22.85	2 1.82 8.457	1.457 1.675	1.477 8.531 1252.5	1.165	- i i	- i - i	i i	i i	- i i	1 335.87	28.55 184.58	
18 Assarl	:		2E-87 2E-87 Theread 1.5.12.2 LUNG 2E-87 2E-87 Theread 1.5.12.2 LUNG	1.5 1.1		21 E D.484 54 45 D.484	542 54 542 54		1.5 B26Y	166	1 -155 -312.00		1.53 -164.44 -1126.3	201.5 -0.017	1 -0.005 255.660 55.76				1.166 1						331.24	41.75 103.03	
12 Annual			2E-17 2E-17 Thereof 1.3.12.2 LUNG	13 13	141 251	54 15 0-324	542 54		1.1 1257	155	1 466 4002.2		1.81 (165.65 (1126.7												173.45	11.12 147.71	
13 Assard	2		2E-87 2E-87 Thereof 1.5.12.2 LUNG	1.6 1.1	148 258	54 15 P+324	512 51		8.5 B25Y	166	1 466 400.4			281.6 -0.818	1 -8.81 545.857 14.55	1 1.000 0.607	1.517 1.541	1.516 1.683 1833.4	1.133	i i	i i	i i	i i	i i	\$ \$\$7.65	14.51 147.84	
14 Assault 15 Assault	:		2E-17 2E-17 Thereof 1.5.12.2 BKV_A 2E-17 2E-17 Thereof 1.5.12.2 BKV_A		11 21	21 E D-414 21 E D-414	542 54	2 451 L201 L201 2 451 L201 L201	1.1 125Y	155	-166 -333.74		2.88 -167.29 -1125.8	2.42 -0.015	1 -0.003 525.425 55.07	1 1.011 0.454 1 1.02 0.424	1.634 1.315	1.672 1.263 1947.4	1.165						1121.05	51.65 55.52	
15 Assaul	i i	1 HINCL: SOMAT	2E-87 2E-87 Thursd' 1.5.12.2 BKV_A	1.5 1.1	11 21	24 6 0.484	542 54	451 1.781 1.781	8.5 B25Y	155	1 466 483.55	41.55 281	1.55 -164.25 -1126.5	201.5 -0.010	1 -8.812 254.645 55.44	1.557 1.552	1.652 1.462	1.751 1.774 4550.1	1.162 1	- i i	- i - i	- i i	- i i	- i i	1 16.0	\$1.11 181.75	
17 Annual	2	1 HIH CIL SOMAT	2E-87 2E-87 Thereof 1.3.12.2 SOPT 2E-87 2E-87 Thereof 1.3.12.2 SOPT	2 1.55	121 251	41 E P+41A2 41 E P+41A2	542 54	2 67 6.714 6.714 2 67 6.714 6.714	2 826Y 2 826Y	166	466 497.99	6.00 -2	2.84 -167.25 -1125.8 3.87 -164.88 -1126.7	2.55 -8.845	1 -0.007 546.636 0.05	6 1.85 E.425	1.425 1.157	2.845 8.645 1445.4 2.492 8.784 5954.5	1.113 1	1 1	1 1	1 1	1 1	1 1	371.11	3.61 125	
18 Annual 13 Annual		1 HINCL: SOMAT	2E-07 2E-07 Thereof 1.3.12.2 SOFT	2 1.55	12 23	G 5 5-662	512 51		2 1257	166	1 466 491.57	21.25 214	1.51 -164.48 -1126.7	214.51 -1.111	1 -0.021 343.101 13.15	2 1.00 1.420 5 1.11 1.524	1.621 1.114	2.132 1.714 5334.5							174.11	15.63 196.37	
28 Annual			2E-87 2E-87 Thereof 1.5.12.2 LUNG	1.5 1.1	121 251	328 488 P+324	542 54		8.5 B26Y	155	466 -402.4		2.83 -467.84 -4425.8						1.64						1 101.51	3.83 133.8	
21 Annual 22 Annual	1		2E-17 2E-17 Thereaf 1.5.12.2 LUNG 2E-17 2E-17 Thereaf 1.5.12.2 LUNG	LI LI LI LI	121 231	528 188 P+524 528 188 P+524	542 54 542 54		1.3 126Y	155	1 -166 -106.5 1 -166 -100.6		1.81 -165.71 -1126.7						1.161 1						1 107.50	10.75 145.64	
23 Annual	;	1 HINCL SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 148KV	1.6 1.1	141 251	121 111 P114	542 54	451 8.781 8.781	1.1 125Y	166	-166 -597.21	1.45 -2	2.88 -167.25 -1125.8	2.42 -1.115	1 -8.81 341.648 8.31	5 1.852 8.444	1.444 1.525	1.755 1.265 1248.1	1.165						151.25	18.52 125.11	
24 Annual 25 Annual	1		2E-87 2E-87 Thursd 4.3.42.2 108KV 2E-87 2E-87 Thursd 1.3.42.2 108KV	LS L. LS L.	141 251	521 101 D404 521 101 D404	542 54 542 54	2 451 1.701 1.701 2 451 1.701 1.701	1.1 126Y	166	1 -166 -1011.0 1 -166 -190.26		1.53 -165.6 -1126.7	33.00 -0.01	1 -0.010 554.605 10.55				1.10						1 11.71	11.62 121.41	
25 Annel	1	1 NIN CIL SOMAT	2E-87 2E-87 Thereof 1.3.12.2 UHG	1.5 1.1		21 6 8-324	512 51	2 11 1.211 1.211	1.5 8269	166	1 -155 -1882.5	18.62 -	-2.1 -166.33 -1125.8	2.14 4.111	1 -8.811 343.745 15.53	6 1.836 8.532	1.552 1.655	1.184 8.557 1254.7	1.171						1057.2	14.50 113.01	
27 Annual	1	1 NIN CIL SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 LUNG	1.5 1.1	11 251	21 E P-324	542 54	2 11 1.701 1.701	1.5 8254	166	1 46 404.0	18.42 5	11.1 -165.27 -1126.7	33.3 -8.81	1 -8.816 337.58 16.51	7 1.825 8.615	1.645 1.656	1.855 1.84 381.4	1.167		1 1		1 1		8 1835.41	28.82 124.87	
28 Anneri 25 Anneri		1 NINCE, SOMAT	2E-87 2E-87 Thursd 4.5.42.2 LUNG 2E-87 2E-87 Thursd 1.5.42.2 LUNG	1.5 1.1		24 E D-524 24 E D-524	542 54 542 54		1.5 8264	166	-166 -333.31		1.55 464.4 4126.5	201.6 -0.017	1 -0.00 040.007 20.02		1.512 1.245		1.161 1						1023.31	25.84 425.74	
38 Assaul	1	1 NINCE, SOMAT	2E-17 2E-17 Thereof 1.3.12.2 LUNG	2 1.1	11 251	21 6 8-524	512 51	2 135 8.781 8.781	1 8257	155	1 -166 -1886.6	3.82 3	13.1 -165.6 -1126.7	33.3 -4.81	1 -8.818 537.171 14.54	1.828 8.687	1.617 1.125	1.555 1.274 887.2	1.155 1		- i - i		- i i		1 1014.04	17.35 124.5	
31 Assault	:		2E-87 2E-87 Theread 1.5.12.2 LUNG 2E-87 2E-87 Theread 1.5.12.2 SOFT	1 11	121 251	21 E 0-524 521 111 0-414	542 54 542 54		1 8257	155	1 466 495.49		1.55 -164.17 -1126.5	201.6 -0.010	1 -0.011 010.760 20.0				1.154 1	1 1	1 1	1 1	1 1		1025.76	25.6 122.55	
32 A	-	1 HINCL: SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 SOFT	2 1.1	121 251	121 111 P-414	542 54		1 8254	166	1 -155 -1881.5	5.12 33	1.88 -165.61 -1126.7	33.88 -4.883	1 -8.818 555.285 7.84	1 1.825 8.445	1.445 1.127	1.854 8.631 753.4							1 150.71	5.74 124.51	
34 Assaul	2	1 HINCL: SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 SOFT	1 11	121 251	121 111 P+414	542 54	2 135 8.781 8.781	1 8254	155	1 -166 -334.51	15.86 281	1.55 -164.16 -1126.5	201.53 -0.010	1 -0.01 010.546 10.50	1 1.546	1.546 1.155	1.64 1.118 1833.2	1.10 1		- i - i		1		348.51	25.12 125.72	
35 Annual	1	1 HINCE, SOMAT	2E-17 2E-17 Thereof 1.5.12.2 HKV_1 2E-17 2E-17 Thereof 1.5.12.2 HKV_1		8	521 - 101 D404 521 - 101 D404	542 54	2 451 L201 L201 2 451 L201 L201	1.5 125Y	155	1 -166 -196.04 1 -166 -1001.6		2.88 467.86 4425.8	2.54 -8.846	1 -0.003 525.445 11.50		1.467 1.344		1.165 1						1014.01	14.51 55.54	
37 Assessed	2	1 HINCL: SOMAT	2E-87 2E-87 Thurson 1.3.12.2 BKY_1	1.6 1.1	11 231	320 100 P-404	542 54	2 451 1.201 1.201	1.1 125Y	155	155 -151.22	21.45 281	1.58 464.49 4126.9	281.55 -8.815	1 -0.01 256.540 26.26	2 1.317 1.575	1.575 1.364	1.633 1.583 2278.6	1.10 1	- i i	- i - i	- i i	- i i	- i i	1 171.62	33.83 181.33	
38 Assart 33 Assart	:	1 HINCL: SOMAT	2E-17 2E-17 Thereaf 1.5.12.2 SOFT	;	121 251	11 12 P-414	542 54		1 8254	166	466 - 496,79	6.56 -2	2.88 -167.21 -1125.8		1 4.01 333.405 0.24	1.135 L.462	1.462 1.114	1.12 1.657 111.3 1.126 1.62 111.2	1.151 I 1.166 I	1 1	1 1	1 1	1 1		162.26	10.20 117.75	
41 Annual	2		2E-17 2E-17 Thereof 1.5.12.2 SOFT	1	121 251	11 12 P-484	512 51		1 8254	166	1 465 491.5		11.6 -164.62 -1126.5		1 4.00 121.05 10.05				1.16 1						1 10.72	12.16 111.5	
41 Annual			2E-87 2E-87 Thereof 1.3.12.2 LUNG	2 1.1	141 231	54 15 P+324	542 54		1 8254	166	466 -4002.2		2.00 -467.09 -4425.0		1 -0.003 353.610 10.3				1.161						1 115.41	7.53 145.87	
42 Annual	1		2E-87 2E-87 Thereof 1.5.12.2 LUNG 2E-87 2E-87 Thereof 1.5.12.2 LUNG	1 1	14 25	54 16 P+324 54 16 P+324	512 51		1 8254	165	1 -166 -1007.1 1 -166 -333.04		1.85 -165.66 -1126.8 11.6 -164.15 -1126.3	55.85 -8.885 211.5 -8.811	1 -0.017 354.402 3.20	1.027 0.507	1.517 1.115	1.363 1.153 868.5 1	1.16 1						375.55	11.51 146.1	
44 Annual	2		2E-87 2E-87 Thereof 1.5.12.2 LUNG	1.5 1.1	141 251	121 111 P-414	542 54	2 11 L.201 L.201	1.5 8254	155	466 -338.3		2.83 -166.48 -1125.8	2.15 -8.815	1 -8.883 541.757 5.44	2 1.851 8.455	1.655 1.651	1.512 8.522 1999.2	1.172	i i	1 1	i i		- i i	1 141.68	7.12 125.12	
45 A	:	1 MIN CI. SOMAT	2E-17 2E-17 Thered 1.5.12.2 LUNG 2E-17 2E-17 Thered 1.5.12.2 LUNG	1.5 1.1	141 251	521 101 Pr464 521 101 Pr464	542 54	2 31 1.201 1.201 2 31 1.201 1.201	1.5 826Y 1.5 826Y	166	1 -166 -1011.0 1 -166 -192.50		1.83 -165.7 -1126.7 1.53 -163.73 -1126.3	55.85 -4.887 284.6 -4.822	1 -0.017 554.625 7.0 1 -0.011 525.557 16.0		1.663 1.657		1.155 1						1111.75 117.72	7.85 125	
47 Assaul		1 NIN CIL SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 LUNG	2 1.1	121 251	33 12 P-524	542 54	2 135 8,781 8,781	1 8254	155	1 466 4882.4	E.52 -2	2.88 -467.48 -4425.8	2.33 -8.815	1 -8.81 557.685 18.45	2 1.845 8.585	1.585 1.786	1.343 1.117 1838.7	1.165 1	- i i		- i i			1 338.83	1.14 133.58	
41 Assaul	1		2E-17 2E-17 Thered 1.5.12.2 LUNG 2E-17 2E-17 Thered 1.5.12.2 LUNG	1 1	121 251	11 12 0-524 11 12 0-524	542 54 542 54		1 8254	166	1 -166 -1065.7		1.81 -165.68 -1126.7	13.5 -8.81	1 -0.017 351.301 3.27		1.585 1.882		1.152 1						1 104.52	1.41 144.45	
43 Anneri 58 Anneri	;		2E-87 2E-87 Thereof 1.3.12.2 LUNG	1 11	141 81	54 15 P-484	512 51		1 8257	155	1 -166 -336.72		2.00 -167.00 -1125.0		1 4.00 54.00 7.25		1.44 1.003		1.151						347.47	13.82 143.54	
51 Assaul	1		2E-87 2E-87 Thursd' 1.3.12.2 SOPT	2 1.1	141 251	54 15 D-484	512 51		1 8257	166	-155 -100.3		1.81 -165.58 -1126.7		1 -8.816 335.83 3.16		1.44 1.125	1.863 8.668 782	1.144 1	1 1					\$15.75	3.34 127.1	
52 A	;		2E-87 2E-87 Thereof 1.5.12.2 SOFT 2E-87 2E-87 Thereof 1.5.12.2 LUNG		141 251	54 15 D.484 328 188 D.484	542 54 542 54	2 196 0.701 0.701 2 31 0.701 0.701	1 8254	166	1 -166 -552.78		1.61 -164.59 -1126.9	201.01 -0.010	1 -0.011 525.525 15.5				1.14						357.14	1.11 121.41	
54 Assaul	÷ .	1 HINCL: SOMAT	2E-87 2E-87 Thereof 1.3.12.2 LUNG	1.5 1.1	121 251	121 111 P+414	512 51	2 31 8.781 8.781	1.5 8254	166	1 -155 -1881.2	5.86 5	11.1 -165.88 -1126.7	33.3 -4.883	1 -0.014 333.367 0.03	1.125 1.451	1.451 1.657	1.455 8.561 368.4	1.161 1	- i i	- i - i	i i	i i	- i i	1 152.11	18.15 125.56	
SS Assarl	:		2E-17 2E-17 Thered 1.5.12.2 LUNG 2E-17 2E-17 Thered 1.5.12.2 LUNG	1.5	121 251	521 101 D-464 521 101 D-524	542 54	2 31 L201 L201 2 135 L201 L201	1.5 B25Y 1 B25Y	155	1 -166 -554.55 1 -166 -1882.5		1.55 -164.48 -1126.5	284.6 -8.846 2.54 -8.846	1 -0.000 540.504 45.54	7 1.00 1.545	1.545 1.786		1.153 1						945.42 1051.65	31.48 431.53	
57 Annual		1 HINCL: SOMAT	2E-87 2E-87 Thurson' 1.3.12.2 LUNG	2 1.1	11 231	328 188 P+324	542 54	2 155 8.781 8.781	1 8254	166	1 466 406.0	5.58 33	1.81 -165.61 -1126.7	33.83 -8.81	1 -8.817 335.332 3.43	4 1.822 8.685	1.615 1.122	1.354 1.25 534.4	1.63						1 1031.10	18.35 125.72	
SI Assaul	2	1 HIRCE, SOMAT	2E-17 2E-17 Thereaf 1.5.12.2 LUNG 2E-17 2E-17 Thereaf 1.5.12.2 LUNG	2 1.1	1 8	521 101 P+524 521 101 P+524	542 54		1 8257	155	1 -166 -197.69 -166 -1011.3		1.50 -164.14 -1126.5		1 4.01 515.0 19.75	7 8.331 8.728	1.721 1.3	1.235 2.001 331.0	1.146 1	1 1					1125.06	16.26 121.76	
53 Assaul	;		2E-17 2E-17 Thereof 1.3.12.2 LUNG	13 13	8	10 10 P-524	512 51		1.3 126Y	165	1 465 4006,0		1.81 -165.68 -1126.7		1 -0.012 040.005 12.15				1.151 1						1031.41	13.51 123.75	
E1 Assaul	2		2E-87 2E-87 Thereof 1.5.12.2 LUNG	1.5 1.1	11 21	121 111 P+324	542 54		8.5 B26Y	155	466 -457.85		1.58 -164.16 -1126.5		1 -8.81 514.571 17.55				1.144 1						1 1125.16		
52 Annual	1		2E-17 2E-17 Theraf 1.5.12.2 LUNG 2E-17 2E-17 Theraf 1.5.12.2 LUNG	1.5 1.1	121 251	528 188 P+524 528 188 P+524	542 54		1.5 B26Y	166	1 -166 -1003		2.11 -166.33 -1125.3	2.45 -0.047	1 -0.011 557.506 10.55 1 -0.014 552.152 10.2				1.116 1						1 103.04	1.11 101.01	
E4 Annual		1 HINCE, SOMAT	2E-87 2E-87 Thursd' 1.5.12.2 LUNG	1.5 1.1	121 251	328 188 P+324	512 51	2 11 1.781 1.781	1.5 8254	155	1 465 400.0	7.2 281	1.55 -164.41 -1126.5	201.5 -0.010	1 -0.01 557.254 10.05	1.883 8.634	1.534 1.511	1.551 1.55 758.5	1.151	i i	i i	i i	i i	- i i	1 116.1	11.54 147.25	
ES Anneri	:		2E-17 2E-17 Thursd 1.5.12.2 100KV_ 2E-17 2E-17 Thursd 1.5.12.2 100KV_		141 251	54 16 D.484 54 16 D.484	542 54	2 451 1.201 1.201 2 451 1.201 1.201	1.5 826Y	166	1 -166 -196.02 1 -166 -1001		2.88 -167.25 -1125.8	2.62 4.145	1 -8.885 541.126 15.75 1 -8.817 556.117 16.16				1.153						1 341.42	15.25 122.81	
67 Assaul	ź	1 NIN CIL SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 148KV	1.6 1.1	141 251	54 15 P-484	542 54	451 8.781 8.781	8.5 B25Y	166	1 -155 -112.8	28.82 28	1.5 -154.21 -1125.5	281.51 -8.818	1 -8.811 524.556 25.65	1.551 1.552	1.552 1.544	1.641 1.411 1577.2	1.14 1	i i	- i - i		- i i		1 126.21	38.15 125.42	
ES Assart	2		2E-17 2E-17 Thered 1.5.12.2 LUNG 2E-17 2E-17 Thered 1.5.12.2 LUNG	1.5 L.I 1.5 L.I	121 251	55 12 D.464 55 12 D.464	542 54 542 54		1.5 8264	166	-166 -197.47		-2.1 -166.38 -1125.8	2.45 -0.047	1 -0.01 555.755 5.01				1.172 1	1 1	1 1	1 1	1 1		1 161.06	12.5 128.54	
78 Assessed			2E-17 2E-17 Thereof 1.3.12.2 LUNG	1.3	121 251	33 12 P-484	542 54		1.5 8267	166	-166 -339.53		1.61 -164.47 -1126.5		1 -0.003 520.552 10.55				1.153						346.84	12.33 122.83	
71 A	:		2E-87 2E-87 Theread 1.5.12.2 SOFT 2E-87 2E-87 Theread 1.5.12.2 SOFT		141 251	54 15 D.484 54 15 D.484	542 54		1 8257	155	1 466 496.9		2.88 -167.19 -1125.8		1 -0.01 041.07 7.05				1.151		1 1		1 1		1 101.41	1.81 123.13	
72 A	2	1 HINCL: SOMAT	2E-87 2E-87 Thereof 1.3.12.2 SOFT	2 1.1	141 251	54 15 D-484	542 54	2 135 8.781 8.781	1 8254	166	1 -166 -333.7	14.85 28	1.6 -164.18 -1126.5	55.85 -8.81 281.6 -8.818	1 -8.81 524.688 17.55	1.881 8.514	1.514 1.115	1.724 8.575 558.1	1.14 1						1 121.52	24.43 125.43	
74 Assaul		1 NINCEL SOMAT	2E-87 2E-87 Thereof 1.3.12.2 LUNG	1.1 1.1	128 258	33 12 P+524	542 54	451 8.781 8.781	8.5 8254	155	-166 -101.7	18.75 -2	2.88 -167.17 -1125.8	2.55 -8.816	1 4.803 557.544 49.27		1.532 1.515	1.515 1.445 1925.7	1.164 1		- i - i		- i i		101.51	12.25 148.4	
75 A	1	1 MIN CIL SOMAT	2E-87 2E-87 Thereof 1.5.12.2 LUNG 2E-87 2E-87 Thereof 1.5.12.2 LUNG		121 251	55 12 P+524 55 12 P+524	542 54	2 451 1.701 1.701 2 451 1.701 1.701	1.5 826Y	155	1 -166-1116.4 1 -166-1111.4	11.17 33	1.89 -165.75 -1126.7 1.58 -164.14 -1126.9	13.13 -1.14 211.53 -1.141	1 -8.847 551.857 14.55 1 -8.841 557.511 17.55	5 1.834 8.686 3 1.84 8.696	1.616 1.512	1.514 1.41 1121.2 1.411 1.612 1252.1	1.161 I 1.165 I				1 1		917.52	15.14 145.85	
22 Annual		1 HINCL: SOMAT	2E-87 2E-87 Thereof 1.3.12.2 SOFT	2 1.1	148 258	321 101 P-404	542 54	2 136 8.281 8.281	1 8254	155	155 - 157 - 15	5.47 -2	2.00 467.44 4425.0	2.55 -0.815	1 -0.003 540.017 6.2	3 1.836 8.435	1.435 1.14	1.863 8.641 824.2	1.154 1	- i i	- i - i	- i i	- i i	- i i	1 152.55	6.55 122.75	
78 Assault	1		2E-87 2E-87 Thereaf 1.5.12.2 SOFT 2E-87 2E-87 Thereaf 1.5.12.2 SOFT		141 251	121 101 De412	542 54		1 8254	155	1 -166 -1101.0 1 -466 -1111.0		1.51 -165.77 -1126.7 1.51 -164.41 -1126.1	11.1 -1.111	1 -0.017 335.732 6.0	1.125 1.462	1.02 1.127	1.872 8.677 785.7	1.141 1	1 1	1 1	1 1	1 1		1 111.14	1.74 123.31 12.25 105.14	
11 Annual	ŝ	1 HINCL: SOMAT	2E-87 2E-87 Thereof 1.5.12.2 LUNG	2 1.1	121 251	11 12 P+524	542 54 542 54		1 8254	166	I -166 -333.35 I -166 -1002	7.51 -2	2.88 -467.46 -4425.8	2.51 -0.015	1 -0.003 357.535 10.32	1 1.834 8.58	1.51 1.715	1.555 1.107 1056	1.16 1						101.64	12.25 195.11 1.12 141.19	
II Assess	1		2E-87 2E-87 Thereof 1.5.12.2 LUNG	3 14	121 251	55 12 P+524	542 54		1 8257	155	1 -166 -1865.6		1.88 -165.61 -1126.2		1 4.147 151.611 11.1				1.154 1	. <u>.</u> .	- i i				1 107.51	1.42 145.75	
12 Annual	-		2E-17 2E-17 Theraf 1.5.12.2 LUNG 2E-17 2E-17 Theraf 1.5.12.2 LUNG	2 1.1	121 251	33 12 P+524 321 101 P+524	542 54	2 196 0.701 0.701 2 196 0.701 0.701	1 8254	166	1 -166 -100.5		1.50 -164.10 -1126.3	201.55 -0.015	1 -0.01 556.064 11.20				1.16 1						1 10.11	11.75 145.57	
If Assaul	1	1 HINCL: SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 LUNG	2 1.1	141 251	128 188 P-524	542 54	2 15 1.781 1.781	1 8254	155	-155 -1885.2	4.55 55	1.81 -165.51 -1126.7	11.01 -0.001	1 -0.016 354.136 0.70	4 1.14 1.511	1.511 1.111	1.373 1.17 324.8	1.151	i i	- i - i	i i	i i	- i i	1 171.87	5.55 145.85	
IS Assart	2		2E-17 2E-17 Thered 1.5.12.2 LUNG 2E-17 2E-17 Thered 1.5.12.2 LUNG	1.5	141 251	54 16 P-524	542 54	2 136 0.701 0.701 2 31 0.701 0.701	1 825Y 1.5 825Y	166	1 -166 -333.51 1 -166 -338.3		1.55 -164.14 -1126.5	211.5 -1.141 2.42 -1.145	1 4.00 140.00 1.61	1.011 0.634 4 1.034 0.44	1.654 1.161		1.151 1	1 1	1 1	1 1	1 1		373.33	13.12 151.23	
17 Assaul	1	1 NINCEL SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 LUNG	1.5 1.1	141 81	54 15 P-484	542 54	2 11 1.701 1.701	1.5 8254	155	1 466 4014.6	7.57 55	1.81 -165.67 -1126.7	33.83 -8.81	1 -8.818 536.435 3.63	5 1.824 8.448	1.441 1.654	1.461 8.55 378.5	1.151						1 338.83	1.41 127.81	
II Anner!	:	1 NINCE, SOMAT	2E-87 2E-87 Thursd' 1.5.12.2 LUNG	1.5 1.1	141 251	54 15 D.402 121 101 D.402	542 54 542 54	2 31 8.781 8.781	1.5 8254	155	-166 -331.63		1.55 -169.76 -1126.9	201.6 -0.02	1 -1.111 125.11 19.14		1.52 1.785		1.151 1		1 1		1 1		1916.72	11.21 124.84	
13 Annual	-		2E-87 2E-87 Thereof 1.5.12.2 SOPT 2E-87 2E-87 Thereof 1.5.12.2 SOPT	1 11	141 251	521 101 D414 521 101 D414	542 54 542 54		1 8254	166	I -166 -557.27 I -166 -1001.7		2.88 467.22 4425.8		1 -0.01 541.550 6.00				1.167 1						1 343.36	7.27 122.57	
31 Assaul	2	1 NINCEL SOMAT	2E-87 2E-87 Theres' 1.3.12.2 SOFT	1 1.1	148 258	121 111 P.414	542 54	135 8.781 8.781	1 8257	155	1 -166 -534.12	14.54 281	1.51 -164.22 -1126.5	201.53 -0.010	1 .1.11 124.614 15.15	1 1 1.544	1.544 1.854	1.638 1.185 886	1.10 1	1 1	- i - i	1 1	- i i		1 121.74	22.51 125.55	
32 A	1		2E-87 2E-87 Theread 4.5.42.2 LUNG 2E-87 2E-87 Theread 1.5.42.2 LUNG		141 251	121 111 D-524 121 111 D-524	542 54 542 54	2 451 1.701 1.701 2 451 1.701 1.701	1.1 125Y	155	1 -166 -1002.5		2.88 -467.46 -4425.8	2.55 -4.846	1 -0.003 350.506 11.4	5 1.84 8.587 1 1.833 8.684	1.587 1.525		1.164 1		1 1				308.52	1.46 145.51	
34 Assaul	ź	1 HINCL: SOMAT	2E-87 2E-87 Thereof 1.3.12.2 LUNG	1.6 1.1	141 81	128 188 P+524	542 54	451 8.781 8.781	8.5 B25Y	166	-166 -333.78	1.11 211	1.55 -164.17 -1126.5	201.6 -0.010	1 -0.003 541.622 10.05	1.011 0.700	1.711 1.555	1.517 1.755 1310.5	1.153		- i - i		- i - i		1 171.57	13.82 158.53	
35 Assarl	:	1 HINCE SOMAT	2E-87 2E-87 Thereof 1.5.12.2 LUNG 2E-87 2E-87 Thereof 1.5.12.2 LUNG	1 11	8	528 188 P+524 528 188 P+524	542 54 542 54	2 136 0.701 0.701 2 136 0.701 0.701	1 8254	155	1 -166 -1002.7 1 -166 -1006.0	6.51 -2	2.88 -167.19 -1125.8 9.89 -165.66 -1126.7	2.57 -8.846	1 -0.003 342.351 10.7	2 1.020 0.504 7 1.025 0.6	1.514 1.115	1.577 1.151 886 1.553 1.241 281	1.165		1 1		1 1		1 1050.1	5.52 116.85 5.82 122.26	
37 Assessed	ż	1 HINCE, SOMAT	2E-87 2E-87 Thereof 1.3.12.2 LUNG	2 1.1	II 81	128 188 P+524	512 51	2 135 1.701 1.701	1 8257	155	166 - 156 - 156 - 156	1.6 21	1.6 164.15 1126.5	201.61 -0.015	1 -8.811 515.175 14.72	5 1.311 1.733	1.755 1.514	1.225 2.826 581.1	1.133						1 1121.21	15.83 115.52	
38 Assaul	2	1 HINCL: SOMAT	2E-87 2E-87 Thursd' 1.3.12.2 LUNG	5 U 5 U 5 U	121 251	521 101 P+524	542 54 542 54	2 31 8,781 8,781	1.5 8267	166	-166 -1883.7		-2.1 -155.33 -1125.8	2.13 -0.017	1 -0.01 557.201 11.11	5 1.041 0.50	1.51 1.64	1.117 8.315 1482.4 1.858 8.372 1184	1.121		1 1	1 1			1006.24	1.87 142.58	
33 Annual 188 Annual	;		2E-17 2E-17 Theread 1.5.12.2 LUNG 2E-17 2E-17 Theread 1.5.12.2 LUNG	1.3 1.1	121 251	528 188 P+524 528 188 P+524	542 54		1.5 8264	166	I -166 -1006.1 I -166 -1008.2		1.53 -165.12 -1126.7		1 -0.015 552.574 5.04				1.165		1 1				112.12	6.53 145.74 15.00 140.54	

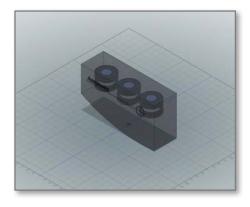
RSNA/QIBA Conformance Certification



CT Image Quality Control

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

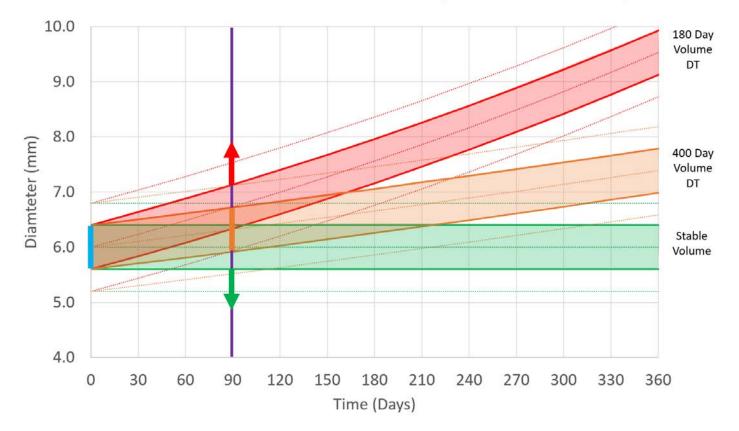
- 1. Eliminate Low Quality CT Scans
- 2. Help with Protocol & Scanner Changes
- 3. Help Optimize Your Acquisition Protocol
- 4. Set Better Follow-up Times
- 5. Perform Better Imaging Research





Precision Follow-up Time

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



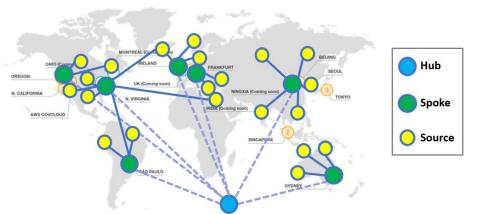
Potential Future Capabilities

- Nodule Follow-Up Times
 - Lower follow-up time from 3 months down to 1.5 months OR achieve higher sens/spec at 3 months
- Automated Detection & Volume Change
 - With Enough Image Quality We Could One Day Auto Detect >= 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. 10⁴ → 10⁶)
- 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



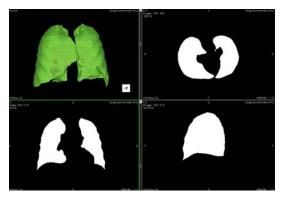
Critical Requirements:

- 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

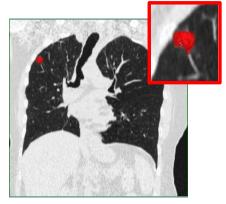
ELIC Pilot Project

- 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

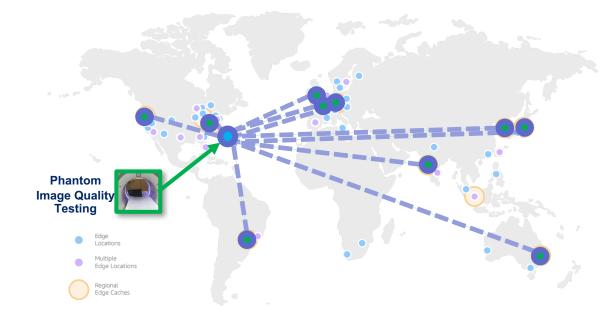


ELIC Live Demonstration Using The Amazon Web Services (AWS) Cloud



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





 $= 668 \text{ mm}^3$

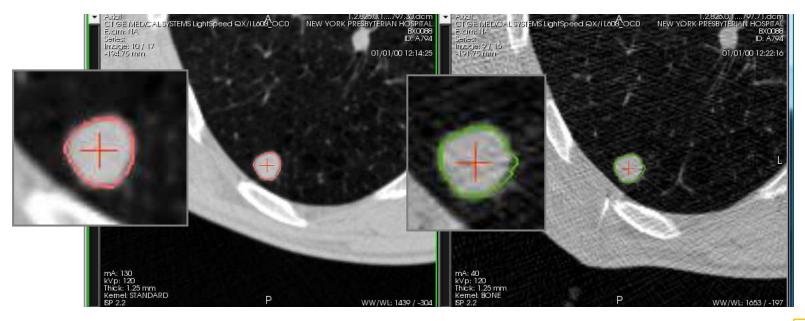
 $T2 = 661 \text{ mm}^3$

 $\Delta V = No Change$

Image Measurement Precision

Need to be able to:

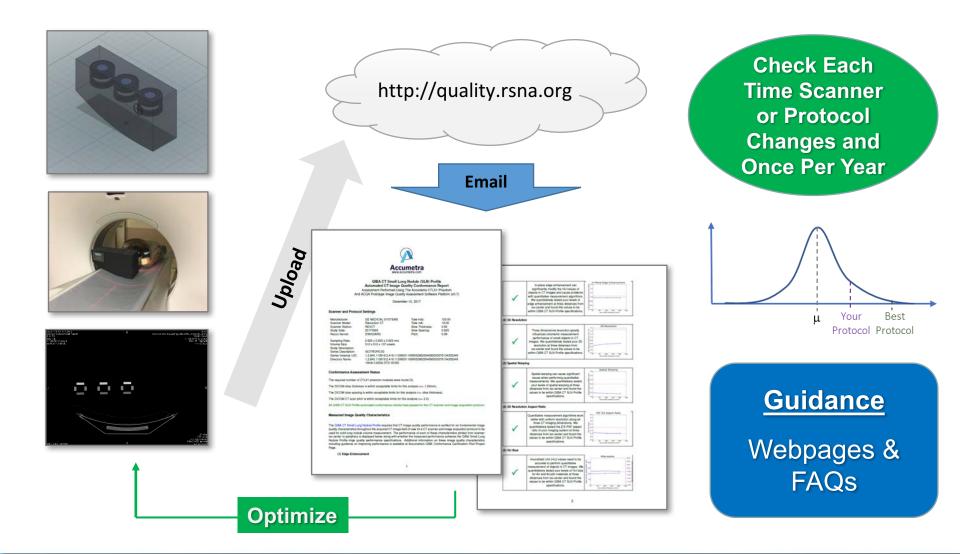
• Measure the change in volume of a solid lung nodule with a specific level of error (95% CI).



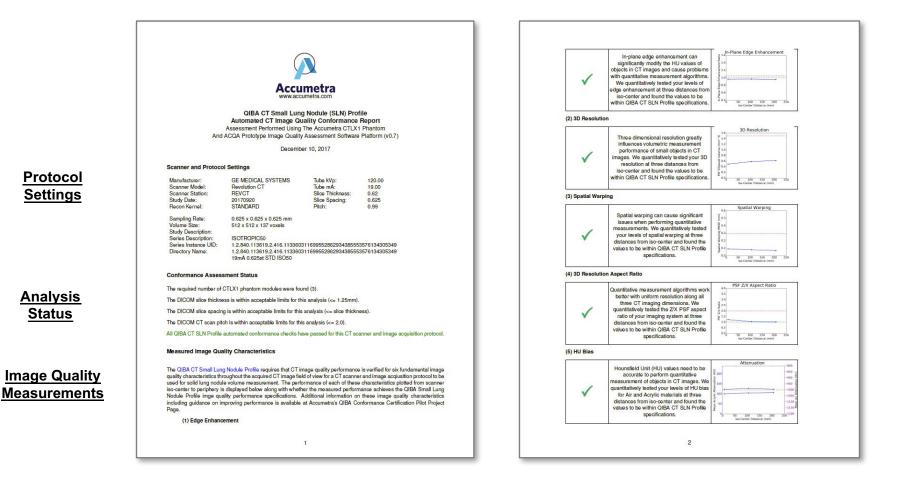
T1 = $668 + 183 \text{ mm}^3$ T2 = $661 + 181 \text{ mm}^3$ + 37% + 1.2 mm

Volume Change Error = -7, Volume Change Error = -7 +- 257 mm³

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



Automated CT Scanner/Protocol Image Quality Report



Protocol

Settings

Analysis

Status

Report With Issues

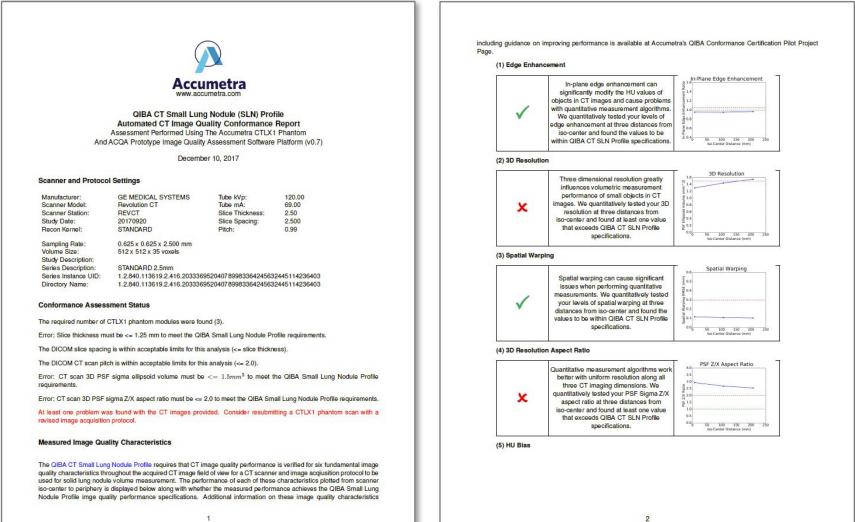
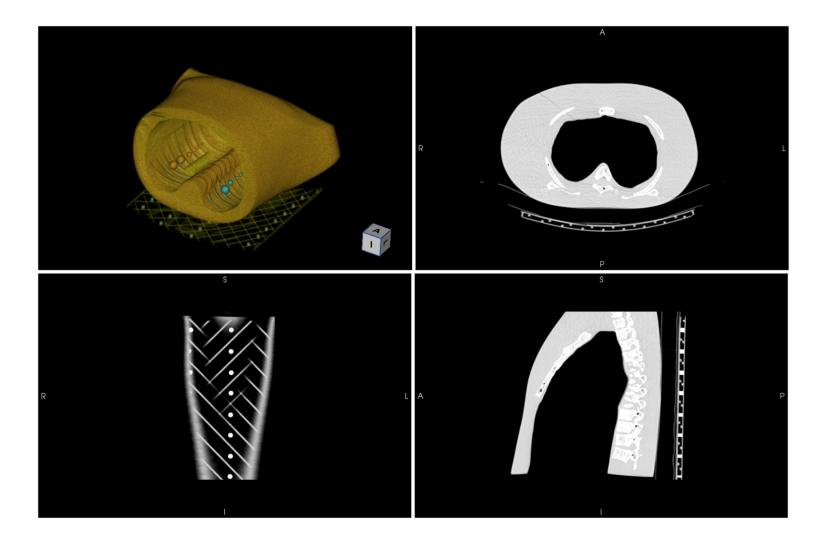
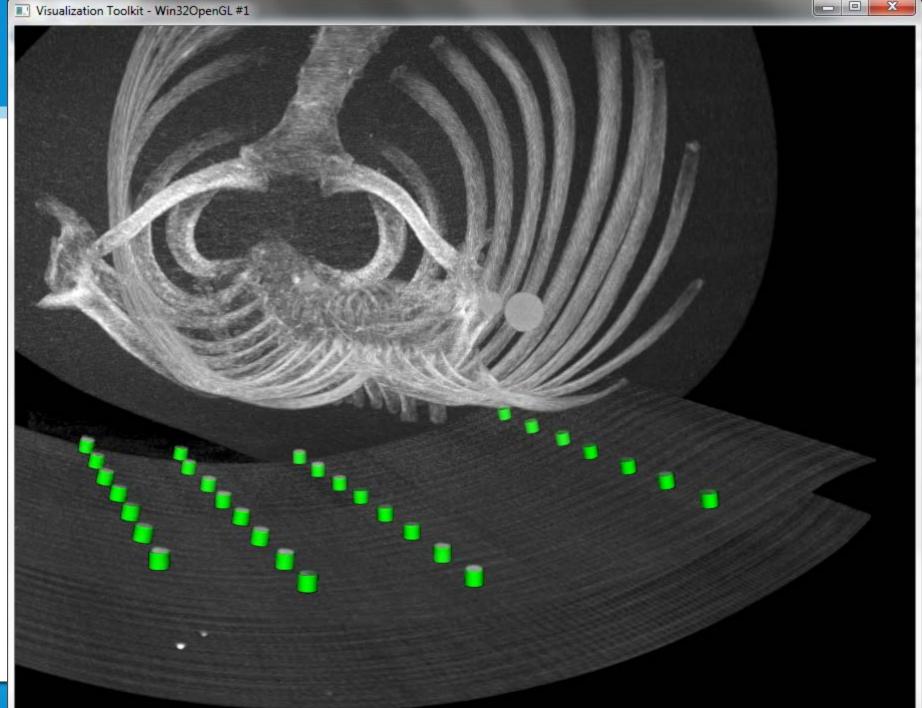
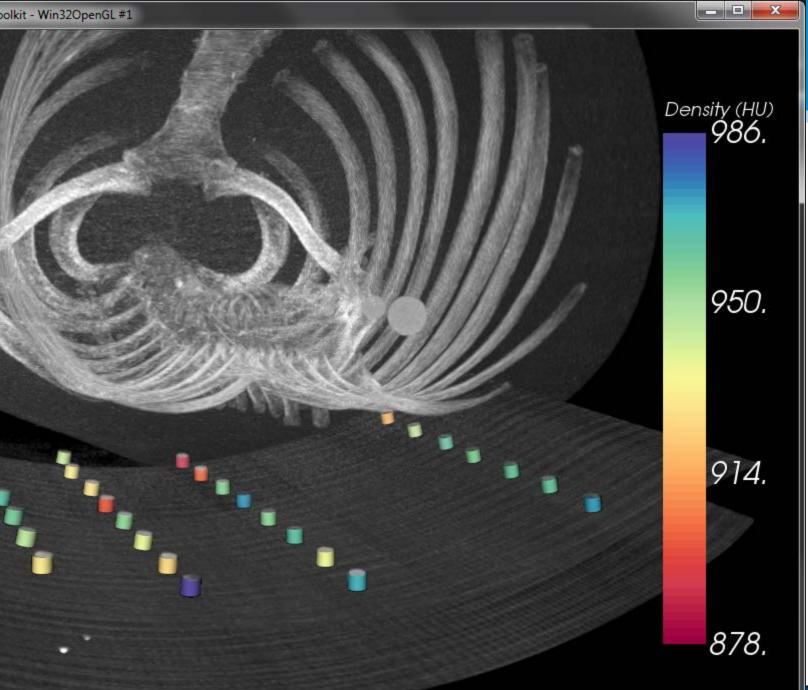


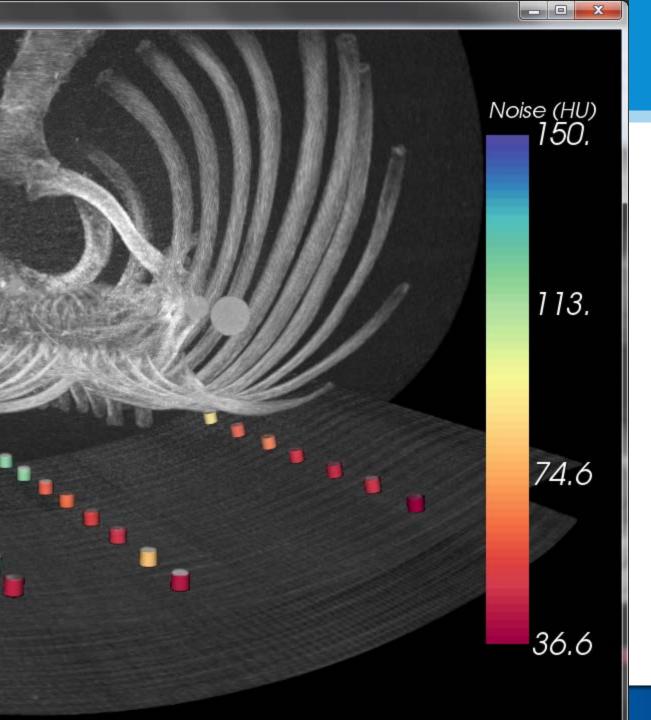
Table Phantom Scanning













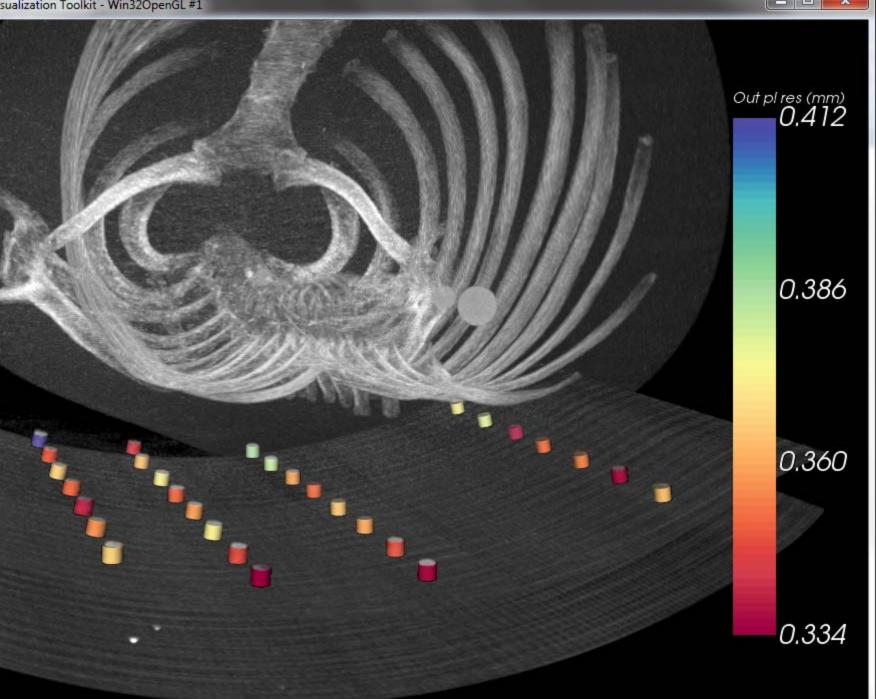


0.580

0.541



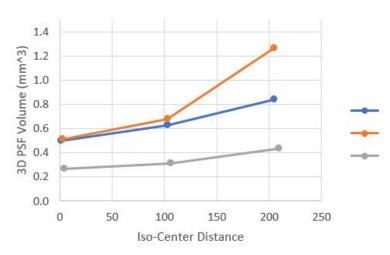




Where Will Improved Image Quality Take Us?

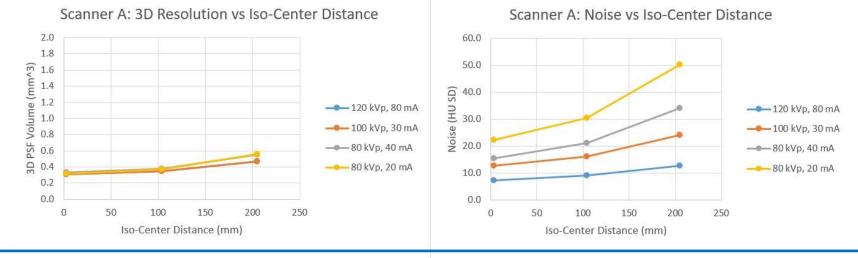


Resolution vs Iso-Center Distance

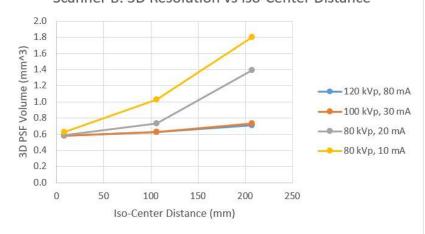


Noise vs Iso-Center Distance 40.0 35.0 30.0 Noise (HU SD) 25.0 20.0 15.0 10.0 5.0 0.0 0 50 100 150 200 250 Iso-Center Distance

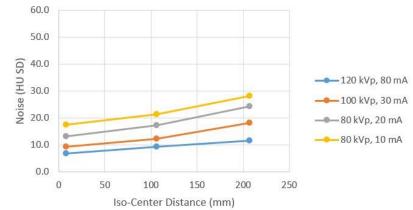
Radiation Dose and Resolution



Scanner B: 3D Resolution vs Iso-Center Distance



Scanner B: Noise vs Iso-Center Distance



Requested vs Observed Slice Thickness

