

A visual grading analysis of propagation-based phase-contrast CT mammography

5th September 2017
Patrick C Brennan



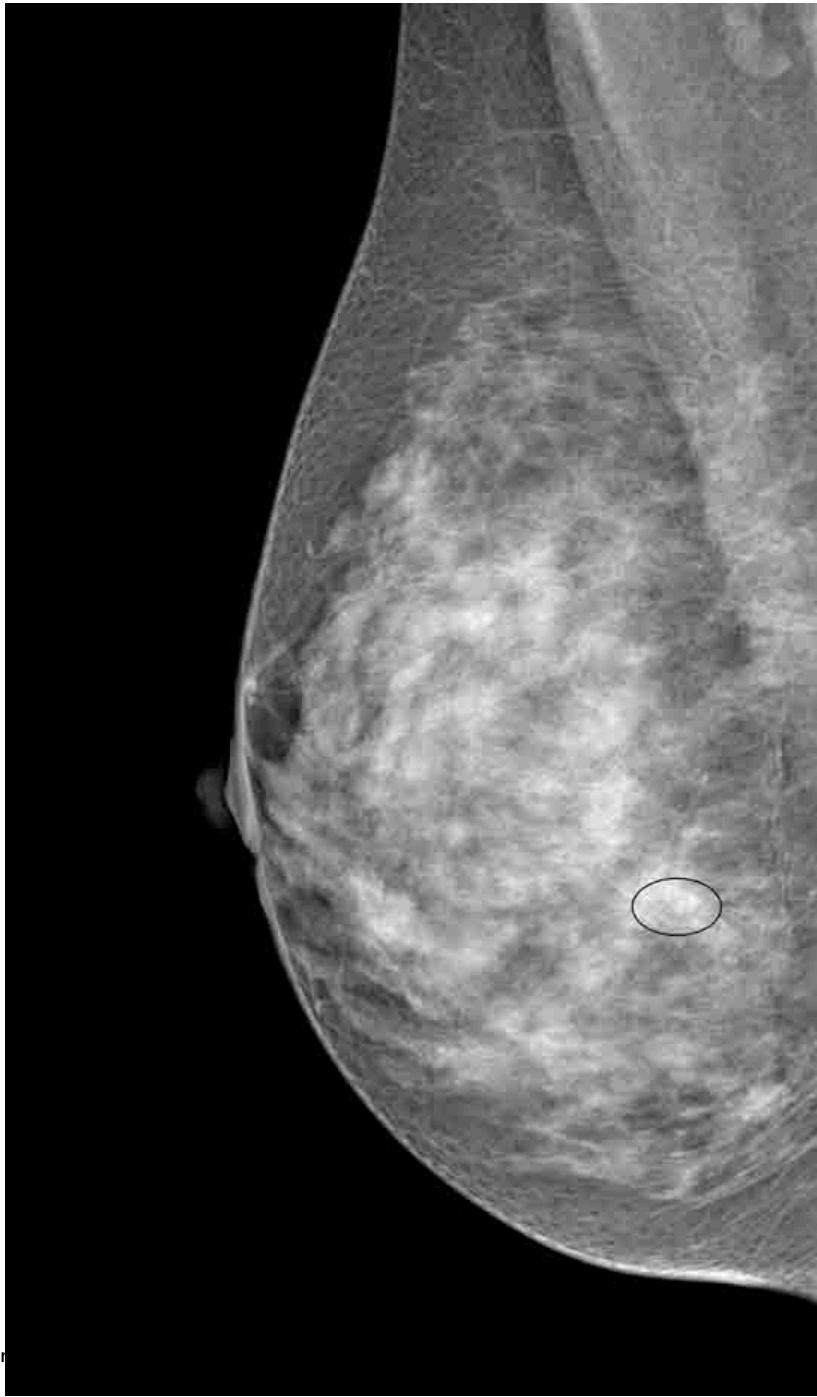
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This talk contains material contributed by

- Timur Gureyev, Patrycja Baran, Harry Quiney, Carolyn Nickson (*Melbourne University*)
- Giuliana Tromba, Serena Pacile, Fulvia Arfelli, Francesco Brun, Diego Dreossi, Sara Mohammadi (*Elettra Synchrotron, Trieste*)
- Amir Taba, Sarah Lewis (*Sydney University*)
- Yakov Nesterets, Sheridan Mayo, Frank de Hoog, Darren Thompson (*CSIRO*)
- Chris Hall, Andrew Stevenson, Anton Maksimenko, Daniel Hausermann (*Australian Synchrotron*)
- Christian Dullin (*University Hospital Goettingen*)
- Matthew Dimmock, David Paganin, Jeremy Brown, Marcus Kitchen (*Monash University*)
- Konstantin Pavlov (*University of New England*)
- Benedicta Arhatari (*La Trobe University*)
- Zdenka Prodanovic, Beena Kumar, Manish Jain, Jane Fox (*Monash Health*)
- Mikkaela McCormack (*Dorevitch Pathology*)
- Darren Lockie (*Maroondah BreastScreen*)
- Maura Tonutti, Fabrizio Zanconati (*Trieste Hospital*)
- Marian Cholewa (*University of Rzeszow*)

Breast cancer diagnostics: limitations in X-ray mammography

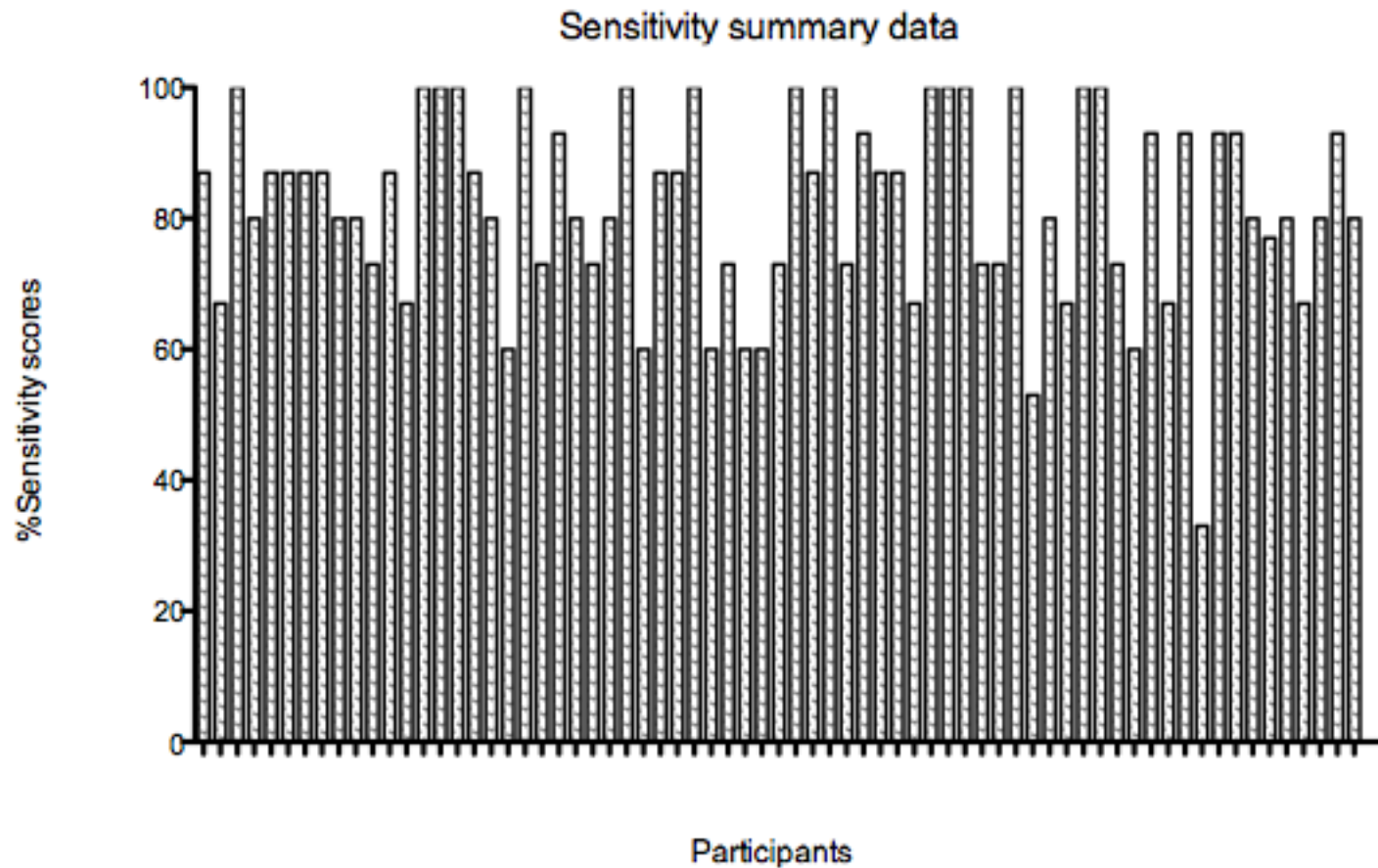
❖ Limitations of mammography



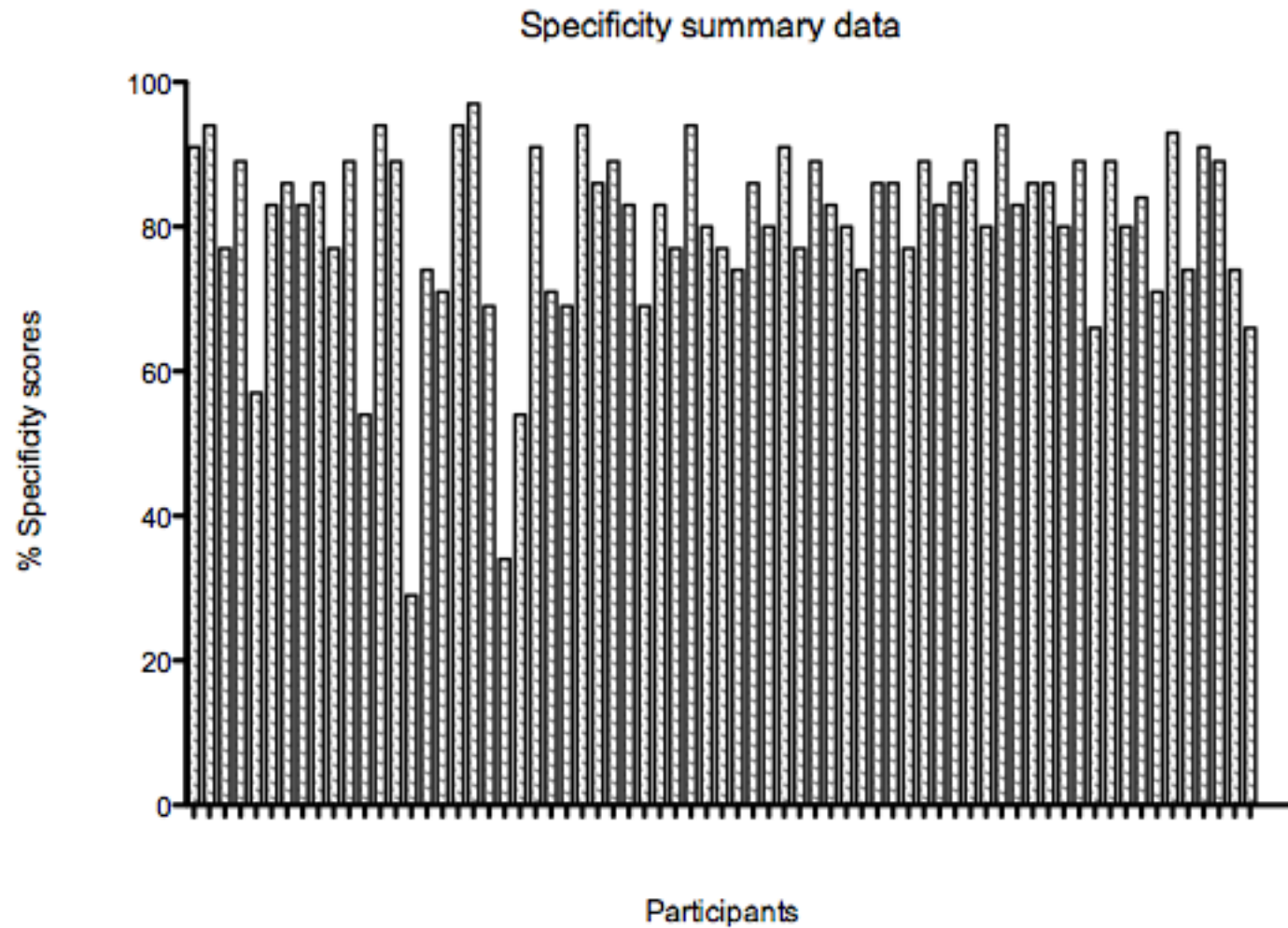




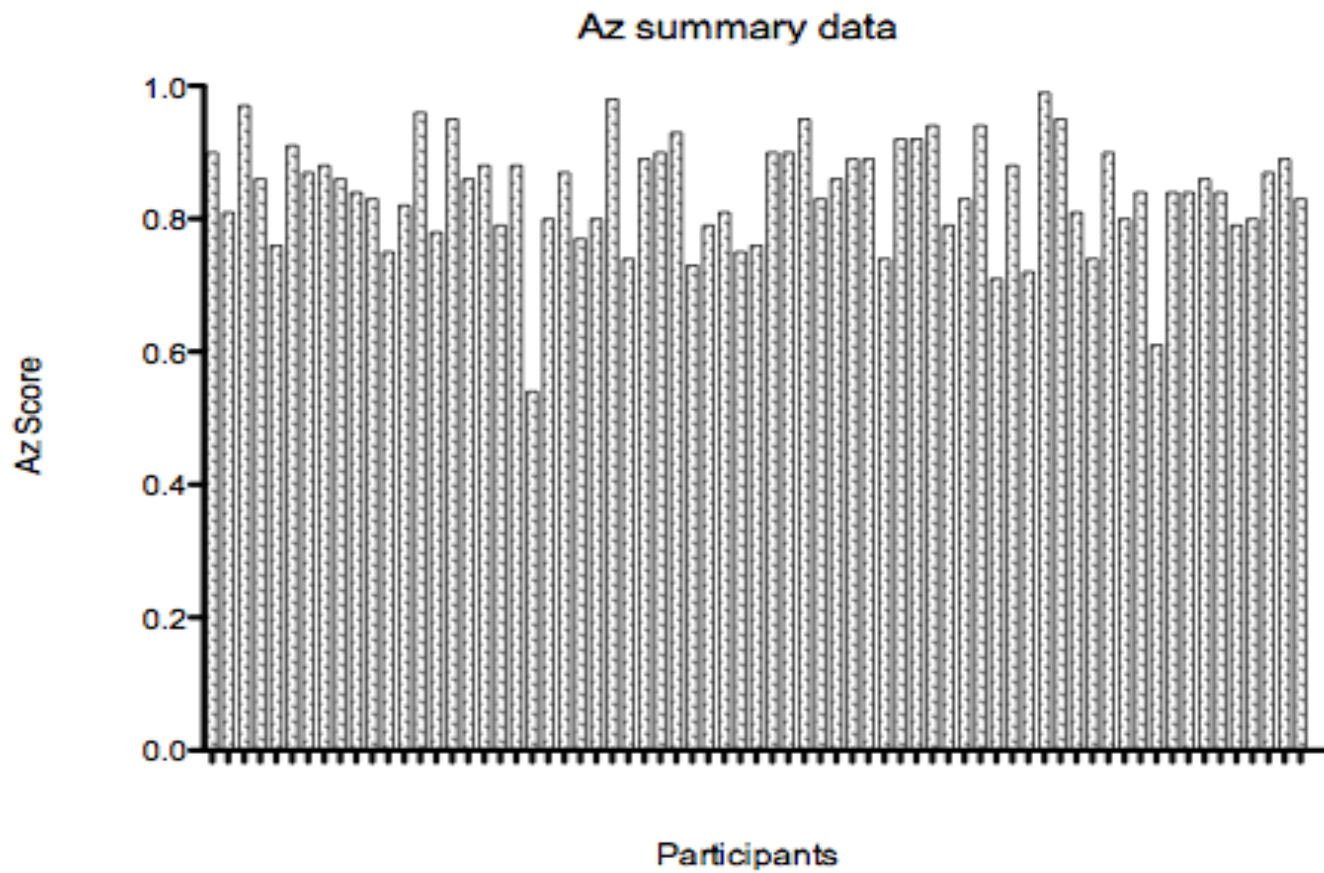
Results: Sensitivity



Results Specificity

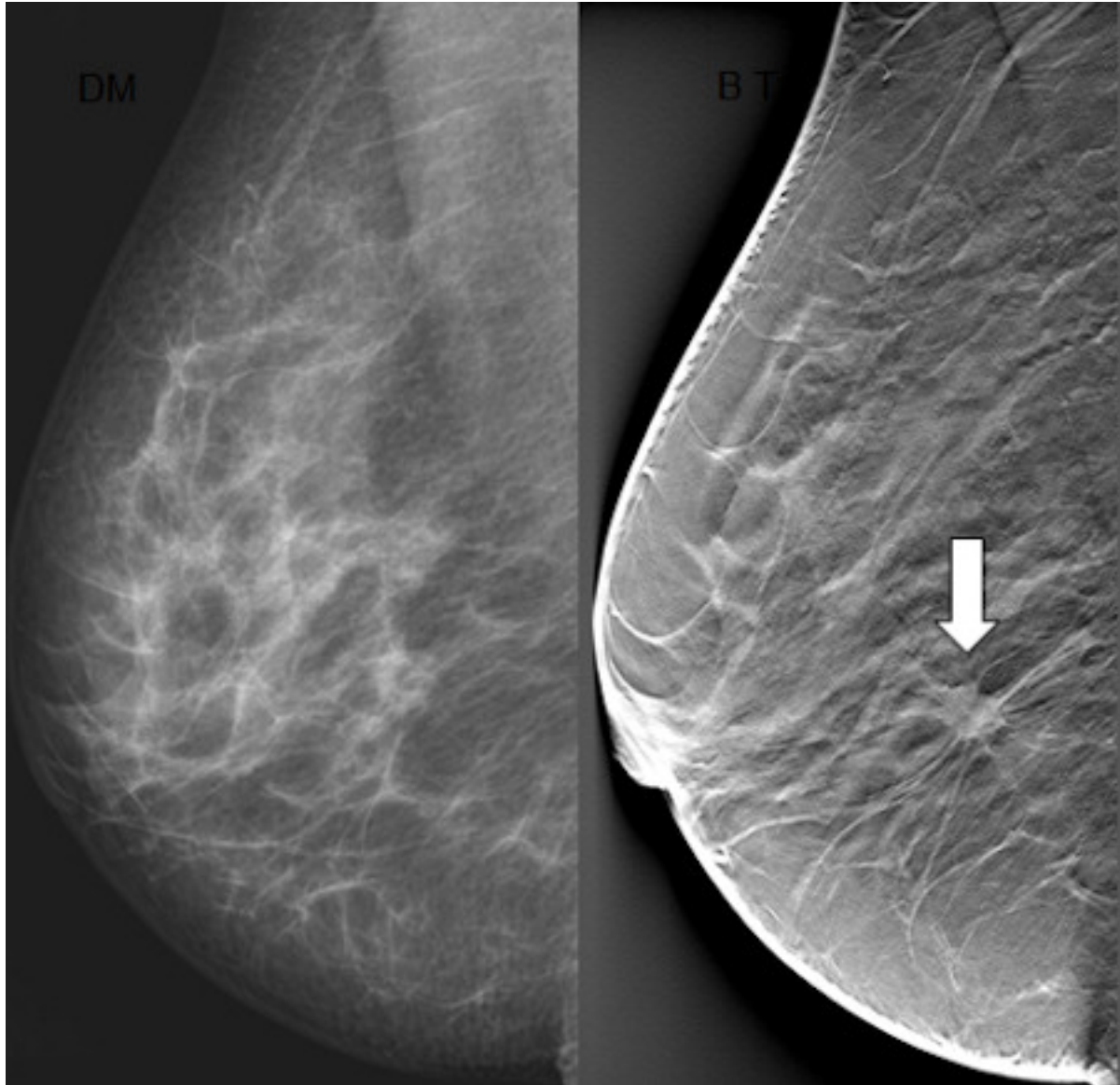


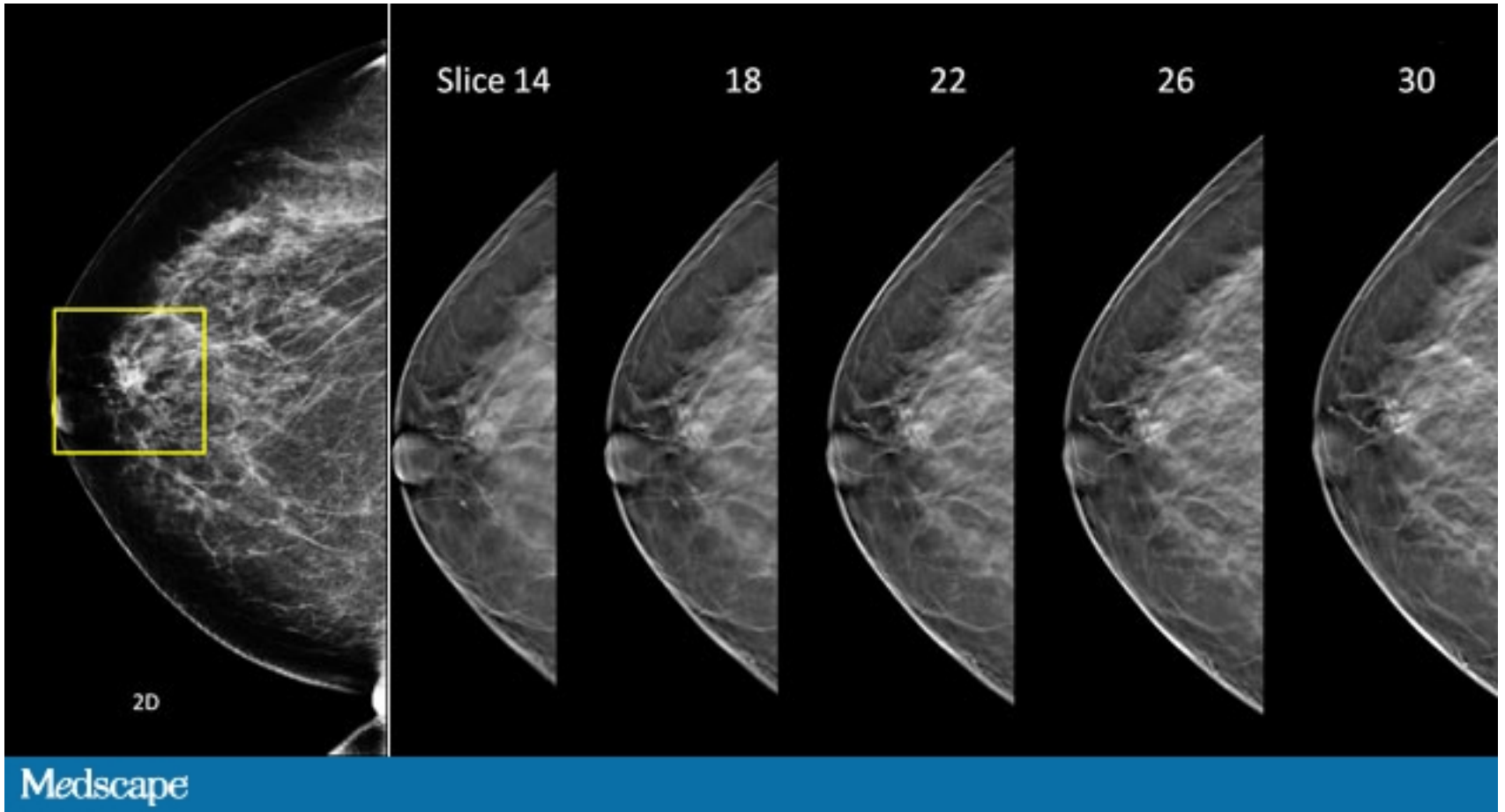
Results ROC



Breast cancer diagnostics: limitations in X-ray mammography

- ❖ Limitations of mammography
- ❖ Digital Breast Tomosynthesis





DBT Results: Part 1

	ROC			Sensitivity			Specificity		
	T value	Mean value	P-value	T value	Mean Value	P-value	T value	Median Value	P-value
2D (26 readers)	t=9.055 df=25	0.690	< 0.0001	t=4.206 df=26	0.628	0.0003	t=3.528 df=26	0.656	0.0016
2D+3D (26 readers)		0.781			0.701			0.758	

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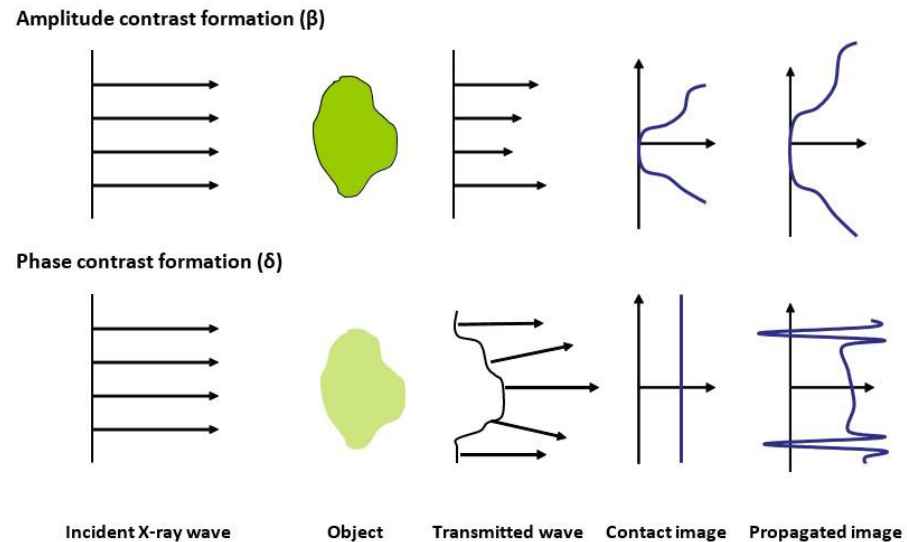
Breast cancer diagnostics: current status

- ❖ Limitations of mammography
- ❖ Digital Breast Tomosynthesis
- ❖ Propagation-based phase-contrast CT mammography
 - ❖ *the quality and the diagnostic value of the obtained 3D images are higher,*
 - ❖ *the delivered radiation dose is lower,*
 - ❖ *the need for painful breast compression is removed.*

Reference	Aim	Method			Results
		Sample	Imaging Technique	Assessment Criteria	
2016 Sarro, Malinva ¹⁸	Imaging performance of FCT	Phantom	Synchrotron, a phase retrieval algorithm	Objective indices: NPS; MTF	Images without phase retrieval showed higher spatial resolution than images with phase retrieval. Phase retrieval reduced the noise level and increased the CNR. Imaging with the phase retrieval algorithm showed overall best performance. Dose comparable with mammography.
2016 Bizziakova, Russo ¹⁹	Algorithms for volumetric breast reconstruction (France) (Same)	Four phantoms of varying texture complexity (BR3D)	Synchrotron. Reconstruction algorithms	Objective indices and subjective assessment (phantom features (BR3D) and edge enhancement features)	Phase-contrast tomosynthesis preserves enhanced edges especially for thick and inhomogeneous phantoms. FBP was superior to SAA in terms of edge visibility.
2015 Pechli, Brun ²⁰	Optimising FBI breast CT.	One phantom and one mastectomy sample.	FBI imaging at synchrotron radiation facility, using advanced CT algorithms with different pre-processing and post-processing steps.	Objective indices: eg. SNR, CNR, NQM and subjective assessment (lesion borders, spiculation, contrast & spatial resolution)	Image quality was improved using phase retrieval techniques and refined CT reconstruction methods, dose comparable to conventional 2D planar radiography.
2015 Nesteruk, Gureyev ²¹	Optimising FBI CT imaging	Phantom	FBI CT imaging at synchrotron radiation facility	Objective indices	An optimal combination of X-ray energy, sample-to-detector distance, phase retrieval and advanced CT reconstruction algorithms provided high-quality phase-contrast CT images at medically acceptable radiation doses, even with the use of a conventional flat-panel detector.
2015 Bizziakova, Russo ²²	Validating a computer based simulation platform for research purposes	Three phantoms varying in complexity	Synchrotron radiation facility vs. imaging at the platform using absorption and phase-contrast modes	Objective indices and subjective assessment	An overall good correlation was seen between simulated and experimental images. Visibility of mammographic structures was improved in phase-contrast imaging
2015 Jian, Wu ²³	Slices of human breast tumour specimens	Fourteen specimens of carcinomas and 8 adenomas	FBI at synchrotron radiation facility based on raw data reconstruction	Subjective assessments	All carcinoma and adenoma specimens were diagnosed as malignant and benign tumours, respectively. The total coincidence rate was 100%
2014 Longo, Torcetti ²⁴	Conducting the first clinical study with synchrotron radiation.	71 patients with unresolved breast abnormalities	DM at hospital vs. FBI at synchrotron radiation facility.	Subjective assessments	Phase-contrast images depicted normal structures and abnormal findings with higher image quality than DM.
2014 Gureyev, Mayg ²⁵	Evaluating key imaging parameters, to detect small tumours in breast tissue.	Two phantoms and several excised breast tissue samples	FBI vs. absorption based imaging at the same setup.	Objective indices, dose, correlation with pathology.	More than 20-fold improvement in contrast-to-noise and intrinsic quality of the reconstructed CT images and/or approximately 400-fold reduction in the X-ray dose, compared with conventional absorption based CT, without a loss in the imaging quality.
2012 Zysk, Brankov ²⁶	Introducing a new model for task-based assessment of phase-contrast images using numerical observers.	Simulation	Simulations of FBI technique.	Calcification detectability	The numerical model compared FBI and conventional mammography in detection of calcification objects and showed that strong calcification detectability in FBI technique depends on anode spot size.

Propagation-based phase-contrast CT (PB-CT) imaging with TIE-Hom phase retrieval

Propagation-based
phase contrast CT



- **X-ray phase-contrast technology in breast imaging: principles, options and clinical application.** Seyedamir Tavakoli Taba^{1*}, Timur Gureyev^{2,3,4,5}, Maram Alakhras¹, Sarah Lewis¹, Patrick C Brennan¹. Under review

What we did in the current work

Synchrotron exposures

- SYRMEP beamline at the Elettra synchrotron, Trieste, Italy:
 - bending magnet providing a monochromatic, nearly parallel, laminar X-ray beam with an area of about $160 \text{ mm} \times 3 \text{ mm}$ at a distance of 23m from the source, at 30 keV
 -
 - A Si (111) double-crystal monochromator was used in the Bragg configuration to deliver an X-ray beam in an energy range between 32 keV and 38 keV and an energy resolution of $\Delta E/E = 10^{-3}$
 - Detector: Hamamatsu CMOS flat panel sensor C9252DK-14, with a CsI scintillator on a 2D photodiode array and a pixel size of $100 \times 100 \mu\text{m}$

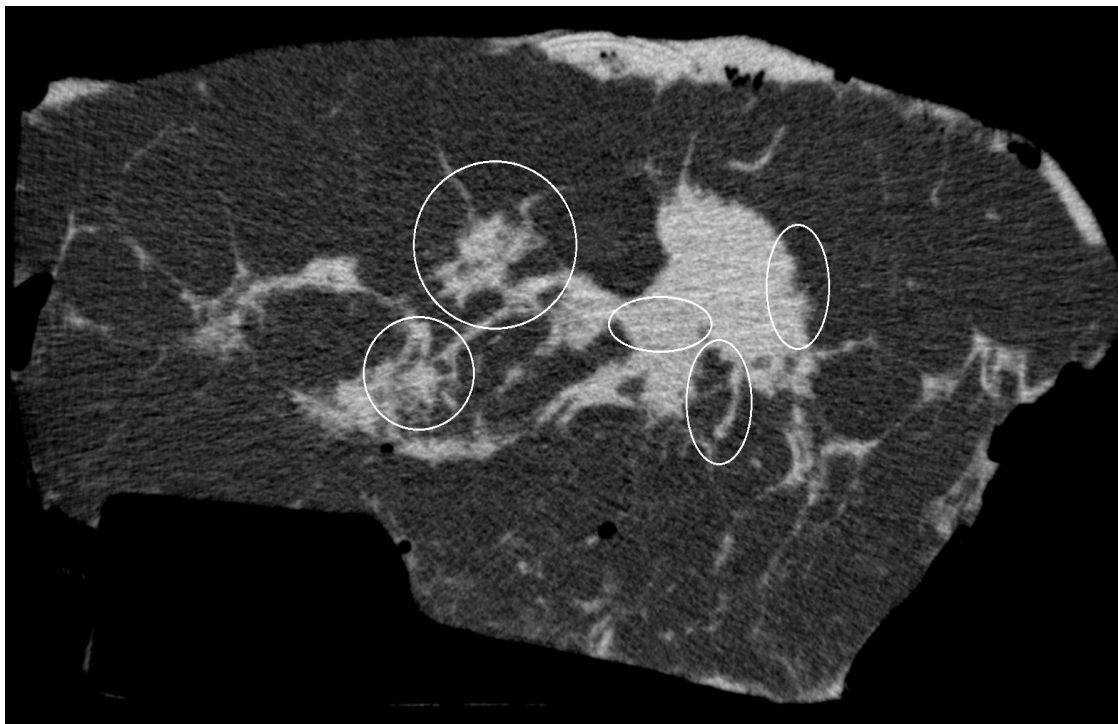
Radiological assessment of the low-dose PB-CT images

- ❖ Elettra Synchrotron
- ❖ Full-size section of a breast mastectomy specimen
- ❖ All exposures performed according to Directive 2004/23/EC of the European Parliament and of the Council of 31 March 2004. Tissues acquired in line with University of Trieste's ethical approval processes; Written consent from the patient was obtained.
- ❖ 161 synchrotron-based CT reconstructions were produced at various imaging conditions
- ❖ Two stages:
 - ❖ stage I: wide range of theoretical imaging conditions;
 - ❖ stage II: a variation of more subtle imaging conditions based on the data produced from stage I.

Radiological assessment

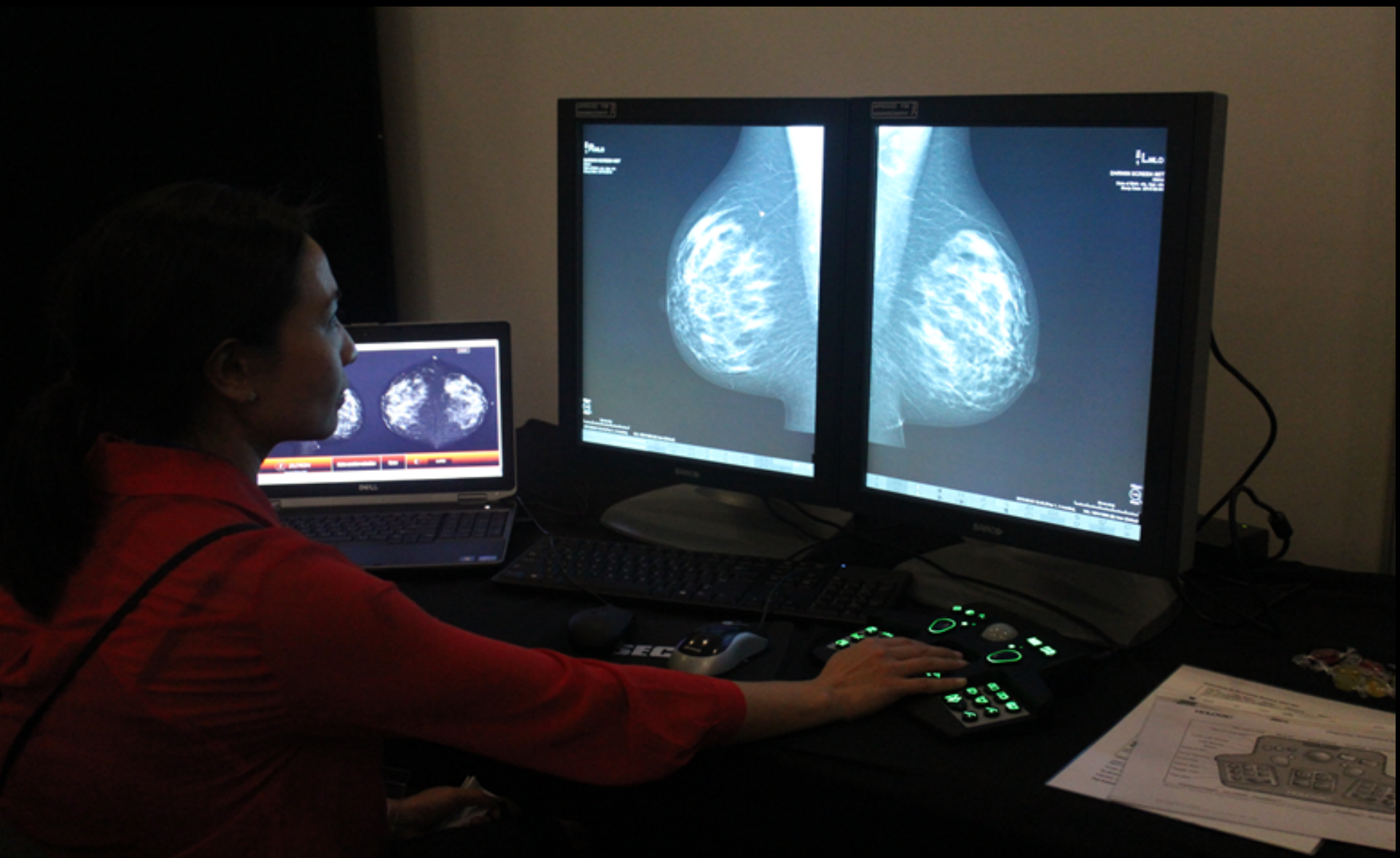
- ❖ Visual grading analysis
- ❖ Thirteen assessors in stage I and fifteen assessors in stage II
- ❖ 5 image attributes:
 - ❖ *soft tissue contrast;*
 - ❖ *edge sharpness;*
 - ❖ *soft tissue interfaces;*
 - ❖ *spiculations;*
 - ❖ *image noise*

1) soft tissue contrast, 2) edge sharpness, 3) soft tissue interfaces, 4) spiculations, 5) image noise



Radiological assessment

- ❖ Visual grading analysis
- ❖ Thirteen assessors in stage I and fifteen assessors in stage II
- ❖ 5 image attributes:
 - ❖ *soft tissue contrast;*
 - ❖ *edge sharpness;*
 - ❖ *soft tissue interfaces;*
 - ❖ *spiculations;*
 - ❖ *image noise*
- ❖ Rating scores varied between -2 to +2: image criteria were clearly better than (+2); slightly better than (+1); equal to (0); slightly worse than (-1); and clearly worse than (-2) the the same criteria in the reference image
- ❖ Reference image: *represents a conventional absorption-based mammographic image, with the best overall image quality - 0.16 m distance; 32 keV X-ray energy; SIRT1000/400 reconstruction method; no phase retrieval; no maximum intensity projection)*



Stage 1

- Three detector distances: 0.16m; 1.85m; 9.31m
- Three monochromatic X-ray energies: 32 keV; 35 keV; 38 keV
- Three CT reconstruction methods: iterative filtered back projection (iFBP); simultaneous iterative reconstruction technique (SIRT) with 400 iterations (SIRT400); SIRT1000
- Phase retrieval technique - the Homogeneous Transport of Intensity Equation (TIE-Hom): full phase retrieval, half phase retrieval and no phase retrieval.
-
-

Results from Stage 1

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
	Full	-0.85	-0.06	0.00	0.75	0.65	1.12	1.63	1.71	1.74
SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55

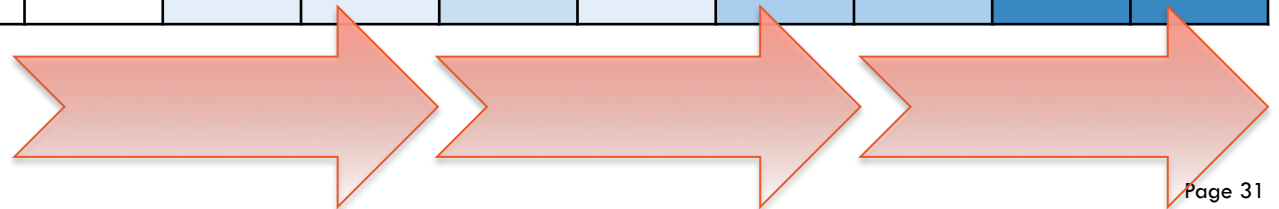
Results from Stage 1: distance

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
	Full	-0.85	-0.06	0.00	0.75	0.65	1.12	1.63	1.71	1.74
SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



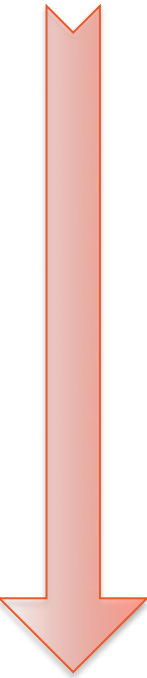
Results from Stage 1: beam energy

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
	Full	-0.85	-0.06	0.00	0.75	0.65	1.12	1.63	1.71	1.74
SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



Results from Stage 1: Reconstruction

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
	Full	-0.85	-0.06	0.00	0.75	0.65	1.12	1.63	1.71	1.74
SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



Results from Stage 1: level of phase retrieval

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
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SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



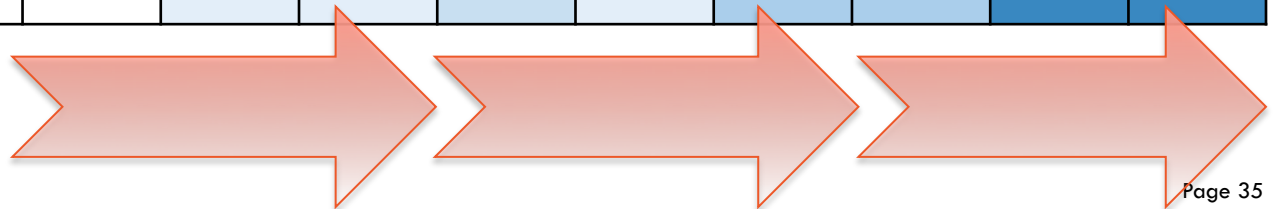
Results from Stage 1: distance (observe interactions on: energy, phase retrieval; reconstruction)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
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SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
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	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



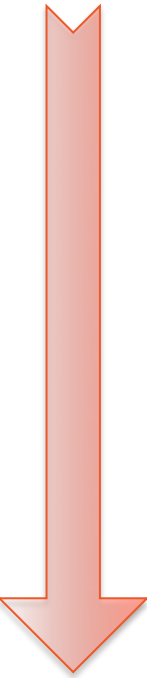
Results from Stage 1: beam energy (observe interactions on: phase retrieval)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
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SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



Results from Stage 1: Reconstruction (observe interactions on: phase retrieval)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
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SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
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SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



Results from Stage 1: level of phase retrieval (observe interactions on: reconstruction)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector								
		0.16 m			1.85 m			9.31 m		
		38 keV	35 keV	32 keV	38 keV	35 keV	32 keV	38 keV	35 keV	32 keV
iFBP	Without	-1.23	-1.02	-0.46	0.22	-0.51	0.71	-0.38	0.97	0.90
	Half	-0.77	-0.32	-0.03	0.98	0.34	0.09	1.58	1.85	1.80
	Full	-0.72	-0.42	-0.31	1.14	0.78	0.98	1.55	1.71	1.88
SIRT1000	Without	-0.88	-0.26	0.00	0.43	0.00	0.66	0.54	1.31	1.71
	Half	-0.78	-0.09	0.03	0.75	0.75	0.78	1.46	1.69	1.77
	Full	-0.85	-0.06	0.00	0.75	0.65	1.12	1.63	1.71	1.74
SIRT400	Without	-0.57	0.09	0.54	1.02	0.42	0.74	1.09	1.78	1.74
	Half	-0.42	0.37	0.31	1.02	1.02	1.02	1.34	1.72	1.80
	Full	-0.29	0.06	0.48	0.78	0.39	1.37	1.22	1.52	1.55



Stage 1: several three-way interactions

- Distance, phase retrieval and the reconstruction method
- Energy and the phase retrieval, distance
- Energy, phase retrieval and the reconstruction method

Stage 2 (more subtle, largely based on Stage 1 results)

- Two detector distances: 1.85m; 9.31 m
- Two monochromatic X-ray energies: 32 keV; 35 keV
- Five CT reconstruction methods: iterative filtered back projection; SIRT1000; equally sloped tomography, simple filtered back projection and iterative total variation minimisation reconstruction
- Phase retrieval technique - half phase retrieval and full phase retrieval
- Maximum intensity projection

Stage 2 results

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17

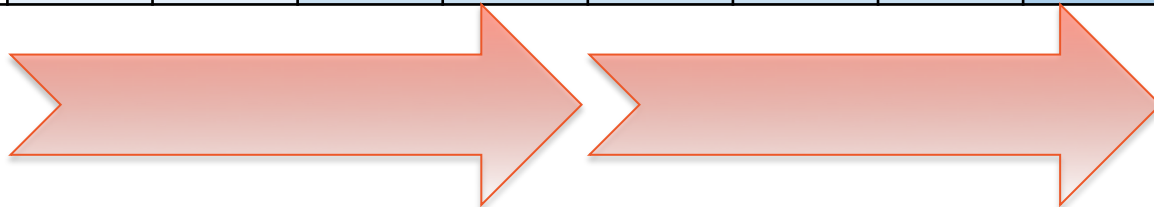
Stage 2 results: distance

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17



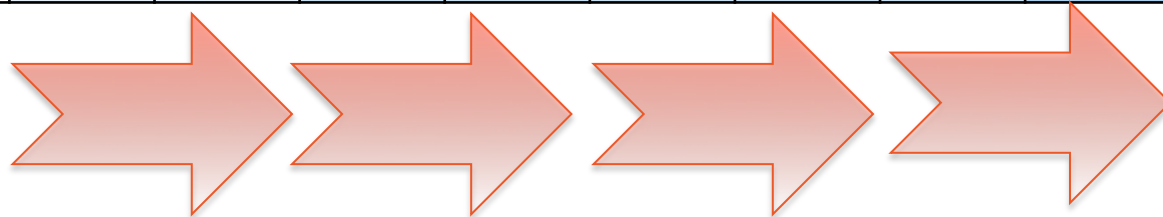
Stage 2 results: beam energy

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17



Stage 2 results: maximum intensity projection

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17



Stage 2 results: distance (observe interactions on: energy)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17



Stage 2 results: level of phase retrieval (observe interactions on: reconstruction)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17



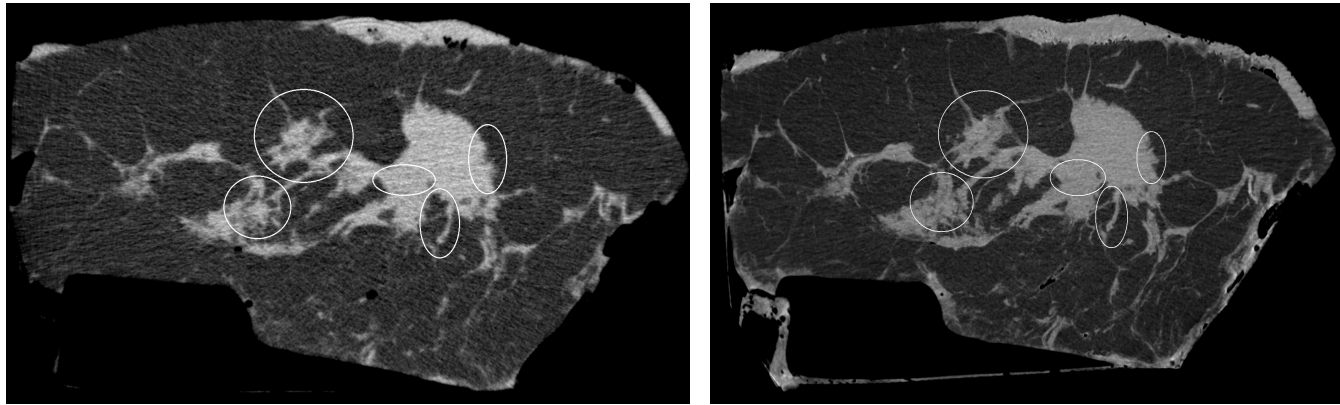
Stage 2 results: reconstruction (observe interactions on: maximum intensity algorithm)

Reconstruction Method	Level of Phase Retrieval	Distance Between Object and Detector							
		1.85 m				9.31 m			
		35 keV	35 keV	32 keV	32 keV	35 keV	35 keV	32 keV	32 keV
		NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity	NoMax Intensity	Max Intensity
EST	Half	0.33	0.14	0.47	0.79	0.52	1.00	0.88	1.00
	Full	0.34	0.42	0.71	0.87	0.99	1.17	1.29	1.37
FBP	Half	0.28	0.34	0.75	0.51	0.71	1.01	0.82	1.01
	Full	0.37	0.43	0.80	1.13	0.89	0.88	1.17	1.34
iFBP	Half	0.34	0.43	0.94	0.76	0.81	0.93	1.15	1.18
	Full	0.33	0.96	0.78	0.86	1.04	1.23	1.10	1.21
iTV	Half	0.17	0.73	0.79	0.87	0.61	1.24	0.96	1.24
	Full	0.59	0.48	0.88	0.99	0.69	0.99	0.98	1.10
SIRT1000	Half	0.54	0.38	0.86	0.71	0.94	1.09	1.11	1.07
	Full	0.34	0.08	0.87	0.80	0.73	0.86	0.87	1.17

Stage 2: several three-way interactions

- Energy, reconstruction method and phase retrieval
- Phase retrieval, maximum intensity projection and energy
- Maximum intensity, reconstruction method and phase retrieval

Phase-contrast CT with TIE-Hom phase retrieval: excised breast tissue sample



Left: The reference image, an approximation to the conventional absorption-based mammographic image (imaging condition: 0.16 m distance, 32 keV X-ray energy, approximately 4mGy dose, using SIRT1000 reconstruction method and without phase retrieval).

Right: An image with a very high quality score in radiological assessments, an optimum imaging condition of in-line phase-contrast technique (imaging condition: 9.31 m distance, 32 keV X-ray energy, approximately 4mGy dose, using iFBP reconstruction method and full phase retrieval).

- *P. Baran et al., Phys.Med.Biol. 62(6), 2315-2332 (2017)*

Inter-rater agreement and reliability

We were interested in the level of agreement between two groups of assessors, namely radiologists and medical imaging experts, and ICC was used to compare the average scores given by each group to each image.

ICC results based on two-way mixed effects of average measures

Phase of the Study	Image Attributes	Intraclass correlation	95% Confidence Interval	
			Lower Bound	Upper Bound
Stage I	ICC across all assessors	0.718	0.647	0.786
	ICC between two assessor groups	0.970	0.954	0.981
Stage II	ICC across all assessors	0.217	0.142	0.311
	ICC between two assessor groups	0.762	0.209	0.899

Main conclusions from this study

- Long propagation sample-to-detector distance;
- low X-ray energy beam;
- maximum intensity projection;
- correct level of application of TIE-Hom phase retrieval algorithm in conjunction with reconstruction methods.

Recent or current activity

- **Over the last year**
- Elettra: 161 synchrotron-based PCT (under different imaging and reconstruction conditions) vs. equivalent absorption-based images (synchrotron-based). 1 full-size section of a breast mastectomy. Two articles
- IMBL: 61 synchrotron-based CT (under different imaging and reconstruction conditions) vs. equivalent absorption-based images (synchrotron-based). 1 full-breast mastectomy sample. Radiological assessments done in Sydney and being done in Melbourne.
- Elettra: 32 sets of images, Synchrotron vs. commercial Koning Breast CT (imaged at Goettingen University Hospital). 8 different breast samples with different reconstruction conditions and doses. For each set we have 5-6 CT slices. Radiological assessments is going on in Sydney (so far we have had 3 assessors).

Recent or current activity

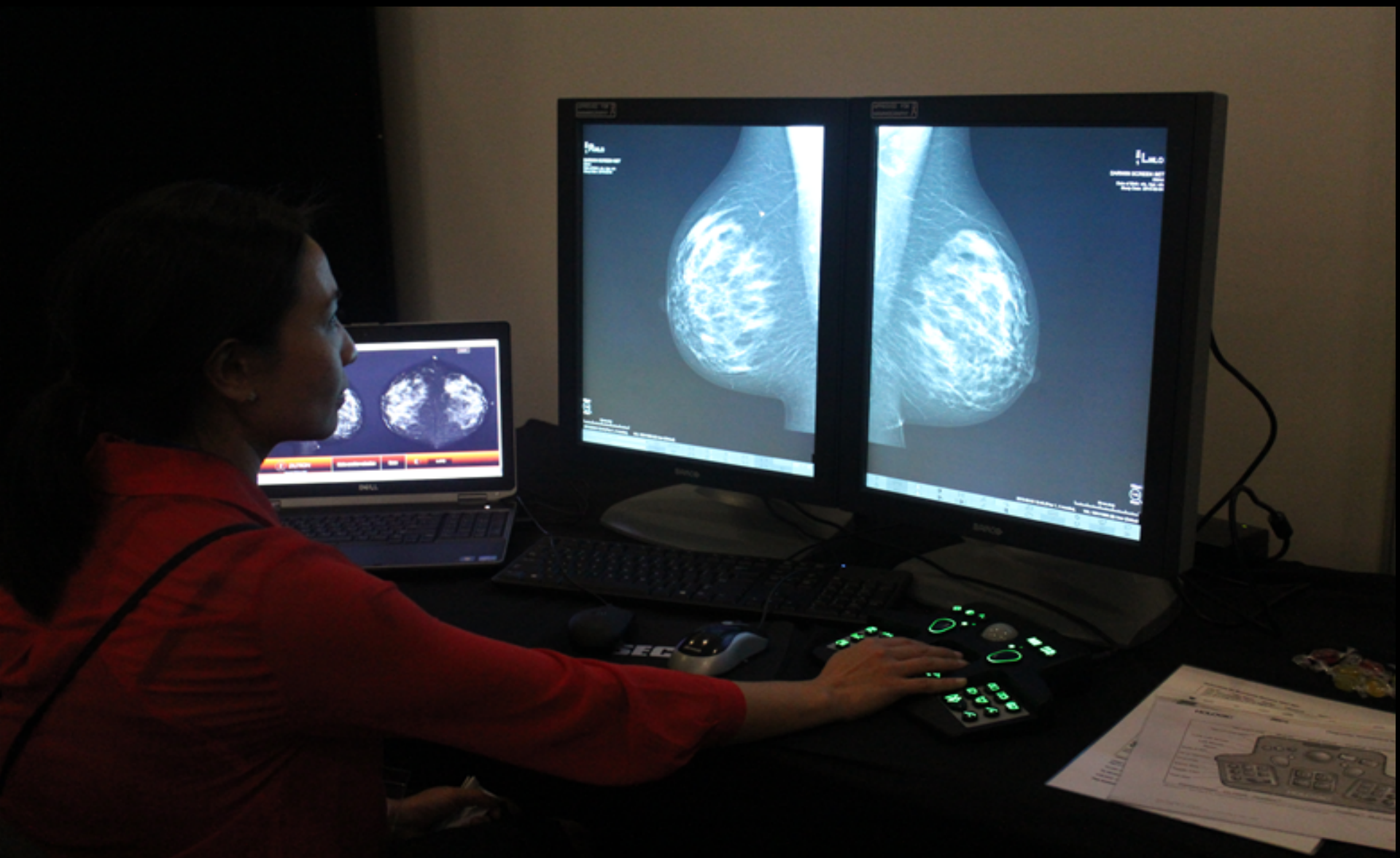
- Elettra: 30 August to 5 September 2017: Re-image large breast tissue samples with cancer lesions from Goettingen University Hospital using a different scanning regime; Fresh samples from Cattinara hospital; 1 or 2 photon counting detectors; radiation doses measured very precisely
- IMBL (Australia) August (on 4 different Thursdays: Fresh mastectomy samples from Monash Health.

Planned program of activity:

- Phase 1 will focus on exposure of excised human breast tissue samples to identify optimum imaging conditions;
- Phase 2 will centre around a clinical trial of full-field breast PCT;
- Phase 3 will see the start of operation of a clinical PCT imaging facility at the Australian Synchrotron and will establish a clinical pathway for widespread implementation of our novel technology.

Supporting platform







Your Performance



Case Level

ROC: 0.97

True Positives: 19

False Negatives: 1

True Negatives: 40

False Positives: 0

Options

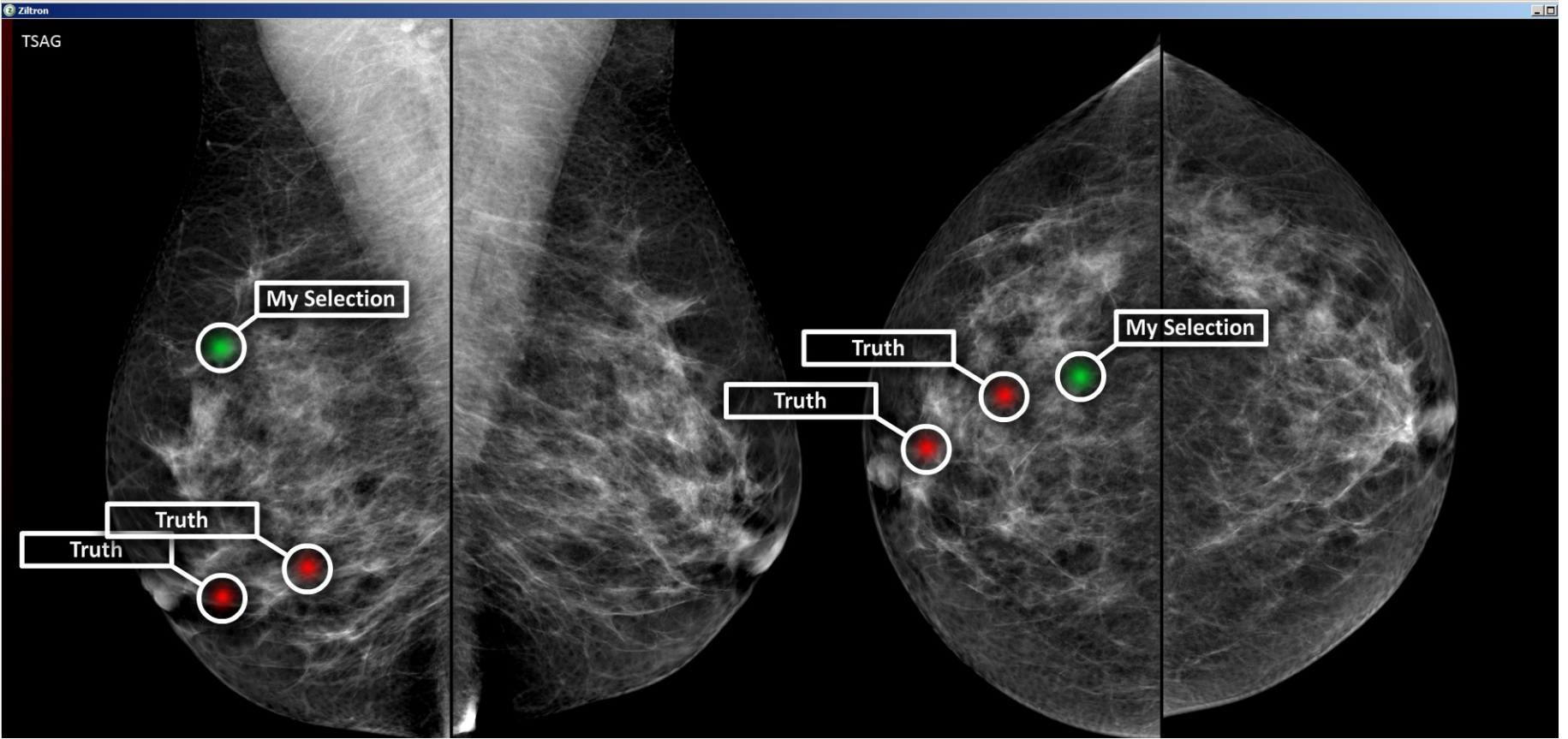
[View answers and your selections](#)

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 - National Health and Medical Research Council; University of Sydney;; Australian Institute of Radiology; Health Workforce Agency; Enterprise Ireland; Health Research Board; Science Foundation Ireland; European Union; University College Dublin;
 - Faculty of Health Sciences

