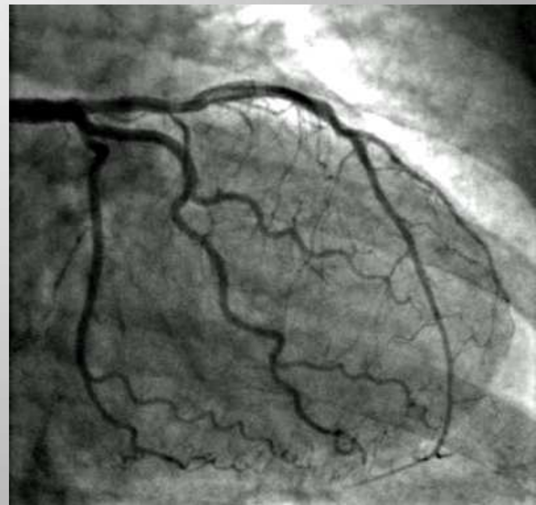
A comparison of radiation doses from modern multi-slice Computed Tomography angiography and conventional diagnostic Angiography:

Rob Loader

Oliver Gosling



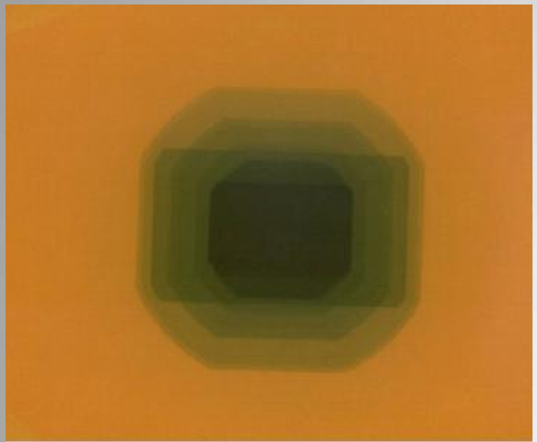
Introduction

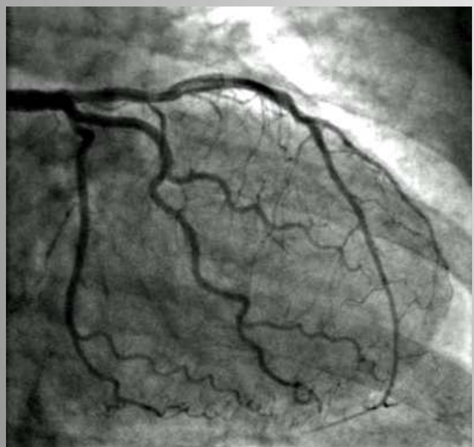
- Approached by Dr Oliver Gosling (Research Physician, RD&E) to help perform comparison of radiation doses from CTCA with conventional cardiac angiographic techniques within cardiac catheterisation labs. Work was strongly supported by Dr Carl Roobottom (Consultant Radiologist) and Dr Gareth Morgan Hughes (Consultant Cardiologist).
- Aim was to calculate system & technique specific dose conversion factors to apply to a larger patient population to enable an effective dose to be estimated to compare the two complex imaging modalities.

Its all be done before.... ??

- Conversion factors do exist from previous studies but rely on dated, non specific techniques and limited conversion factors range by ~100%
- Introduction of prospective gating in CTCA was thought to have significantly reduced radiation doses in CT compared to catheter based angiography.

Conventional angiography (Fluoroscopy & Fluorography)

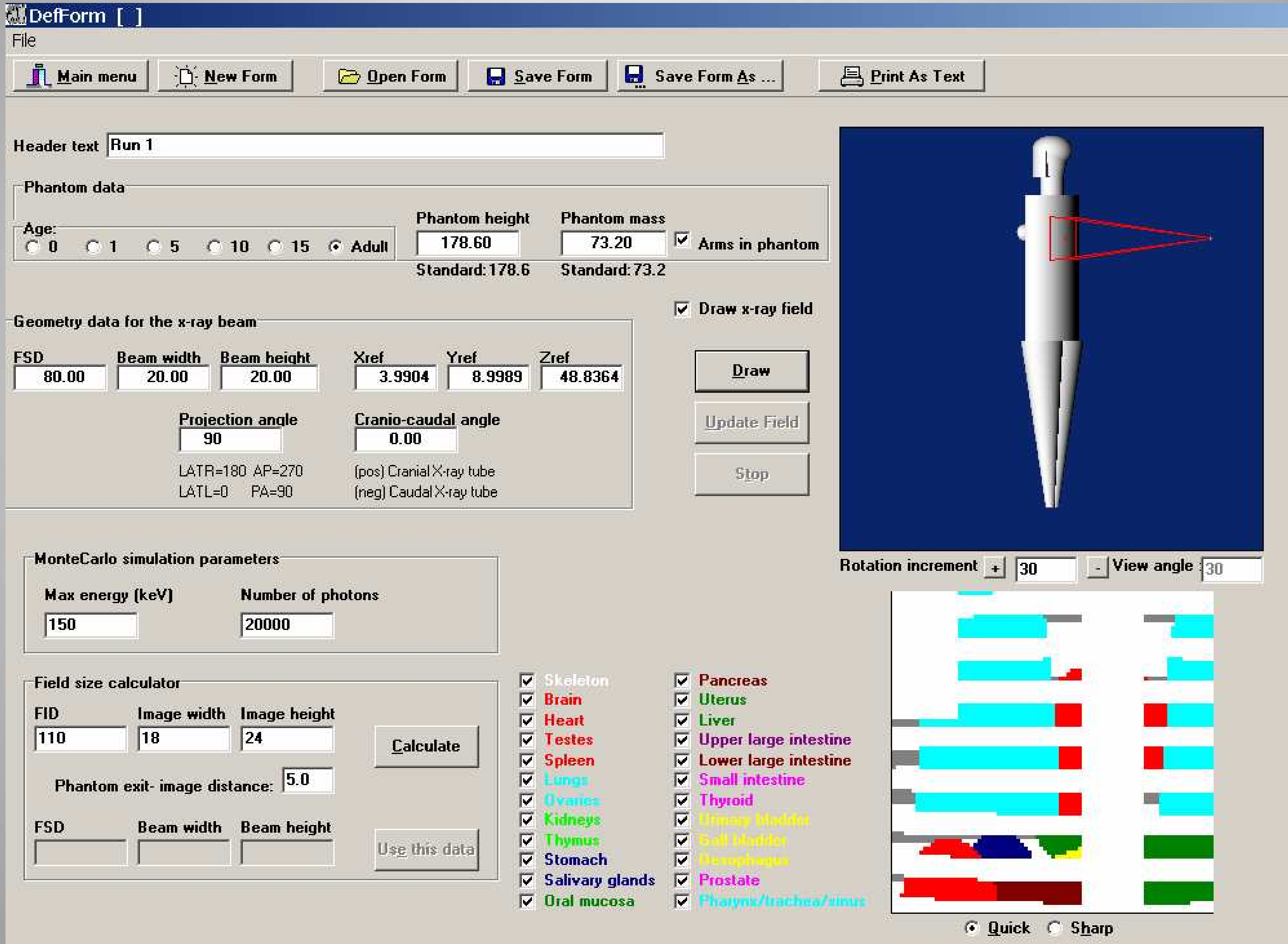




Calculation of radiation dose for Conventional Cardiac angiography

- Use of computer based Monte Carlo simulator (PCXMC), integration of many projections for high dose runs.
- Input values specific to Derrifords' imaging systems (matched for filtration etc)
- Involved audit, key dose parameters and patient BMI recorded by cath lab staff.

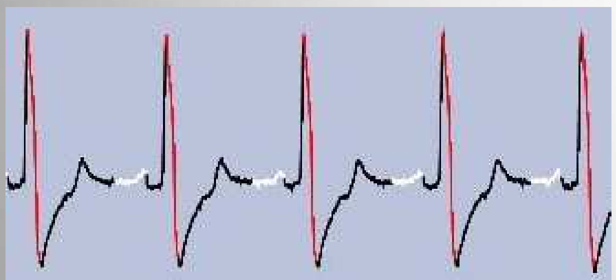
PCXMC

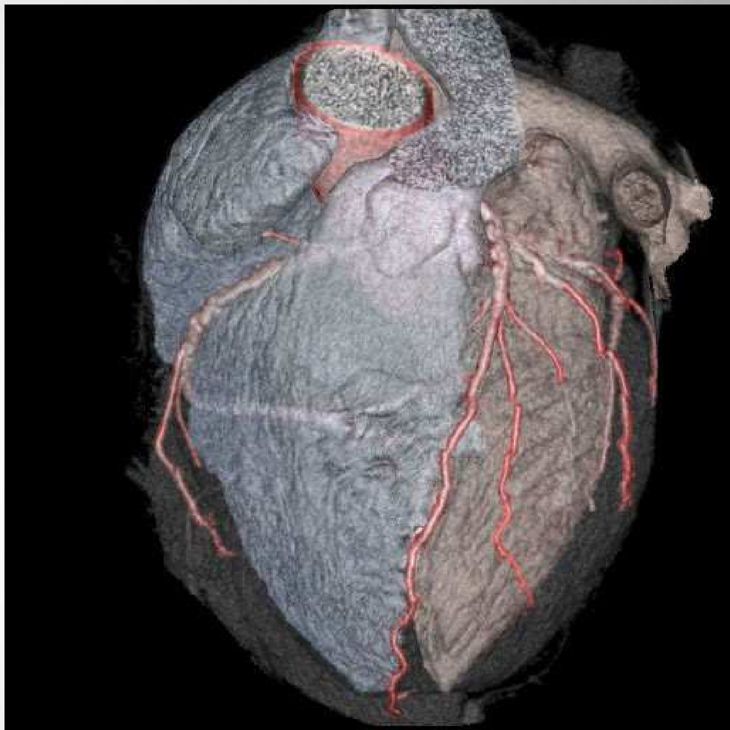

DefForm [ ]
File
Main menu
New Form
Open Form
Save Form
Save Form As ...
Print As Text
Header text
Run 1
Phantom data
Age:
0
1
5
10
15
Adult
Phantom height
178.60
Standard: 178.6
Phantom mass
73.20
Standard: 73.2
Arms in phantom
Draw x-ray field
Geometry data for the x-ray beam
FSD
80.00
Beam width
20.00
Beam height
20.00
Xref
3.9904
Yref
8.9989
Zref
48.8364
Projection angle
90
Cranio-caudal angle
0.00
LATR=180 AP=270
LATL=0 PA=90
(pos) Cranial X-ray tube
(neg) Caudal X-ray tube
Draw
Update Field
Stop
Rotation increment
30
View angle
30
MonteCarlo simulation parameters
Max energy (keV)
150
Number of photons
20000
Field size calculator
FID
110
Image width
18
Image height
24
Calculate
Phantom exit- image distance:
5.0
FSD
Beam width
Beam height
Use this data
Skeleton
Brain
Heart
Testes
Spleen
Lungs
Ovaries
Kidneys
Thymus
Stomach
Salivary glands
Oral mucosa
Pancreas
Uterus
Liver
Upper large intestine
Lower large intestine
Small intestine
Thyroid
Urinary bladder
Gall bladder
Oesophagus
Prostate
Pharynx/trachea/sinus
Quick
Sharp

Conversion factor for IA

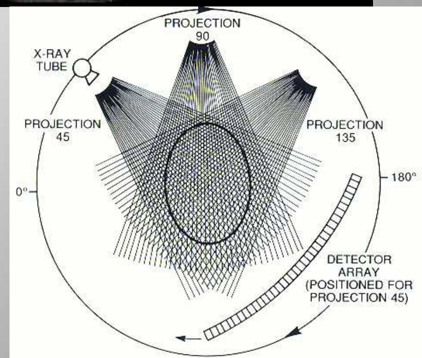
BMI	Total DAP Fluoro (mGycm^2)	Exposure (mGycm^2)	Screening time (mm:ss)	Corrected KERMA	% difference KERMA	#Runs	Total DAP (mGycm^2)	Average DAP difference (runs)	Average mAs difference (runs)	E Runs (mSv)	E fluoro (mSv)	E Total (mSv)	Conversion factor (mSv/(Gycm^2))
20.16	6920	19866	04:03	470	-4.4	10	26786	17.2	20	3.29	2.00	5.29	**0.20**
27.34	2451	16296	01:30	290	-4	10	18747	22.2	14.8	3.11	0.84	3.95	**0.21**
19.95	764	4208	01:04	88	-21	8	4972	46.5	23.2	1.08	0.36	1.44	**0.29**
25.46	3038	12432	02:22	270	-7.7	10	15470	10.6	15.2	2.58	1.15	3.73	**0.24**
27.48	9037	17069	06:57:00	434	0.8	14	26106	21.5	18	3.45	3.16	6.61	**0.25**
29.07	4271	20558	02:02	380	-5.3	9	24829	21.6	14.3	3.95	1.40	5.36	**0.22**
27.16	2408	23368	01:06	467	-11.2	9	25776	14.7	15.6	4.42	0.76	5.18	**0.20**
33.65	2742	15234	01:17	267	0.4	9	17976	12.1	12.4	2.86	0.90	3.76	**0.21**
25.36	3760	23886	02:04	483	-13.6	9	27646	22.6	18	4.72	1.23	5.95	**0.22**
22.49	2381	5104	01:53	110	5.5	8	7485	98.6	47.9	1.27	0.98	2.24	**0.30**
23.99	4491	18650	02:15	349	-2.5	10	23141	16	24.6	4.12	1.65	5.77	**0.25**
26.78	1933	9493	01:53	189	-12.2	9	11426	32	18.8	1.99	0.75	2.75	**0.24**
30.78	9301	25487	02:50	517	11.4	10	34788	15.4	13.7	4.85	2.91	7.76	**0.22**
29.62	3353	11799	02:32	227	-4.3	10	15152	33.1	16.2	2.47	1.24	3.72	**0.25**
25.16	3362	16308	02:21	298	2.3	9	19670	22.6	10.9	3.02	1.29	4.91	**0.25**
31.24	4072	16558	02:29	320	-6	10	20630	18.9	18.5	3.34	1.41	4.75	**0.23**
26.6	4017.8	16019.8		322.4	-4.5	9.6	20037.5	26.6	18.9	3.16	1.38	4.57	**0.24**

CTCA (64 slice gated computed tomography)





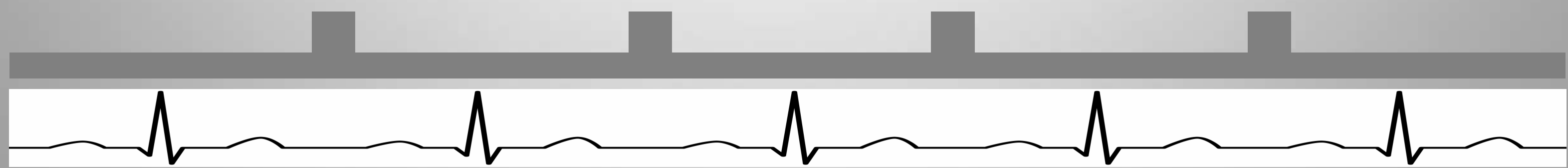
4 Beat Cardiac CTA
0.35 sec scan speed
175ms temporal resolution
4.06 sec scan
Heart Rate 60bpm



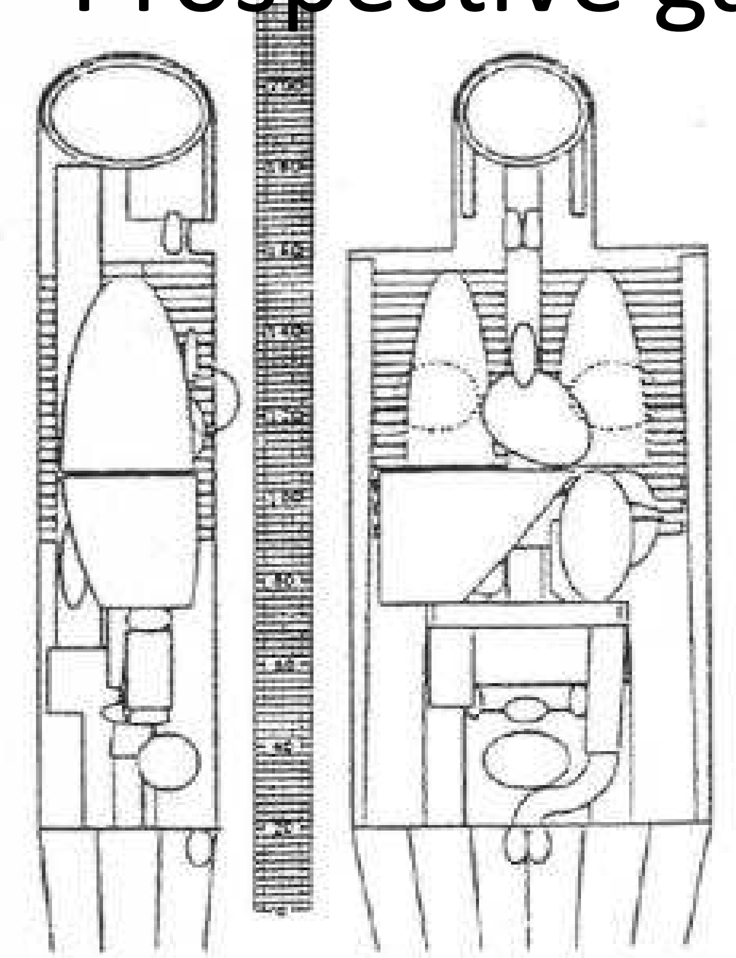
CTCA Protocol (Derriford Hospital)

- Heart rate of < 65bpm for P-Gating
- Beta blockers given to achieve if required
- CTCA 90 ml of visipaque 320 administered via a cannula in the antecubital fossa at a rate of 6mls/second followed by 50mls of N-saline.
- 64X0.625mm SW (40mm, 35mm interval)
- X-ray window at 75% R-R interval (no additional padding).
- Tube current/KV set according to BMI

BMI	15-20	20-25	25-35	35-40
mA	550	600	650	750
kV	80	100	120	140

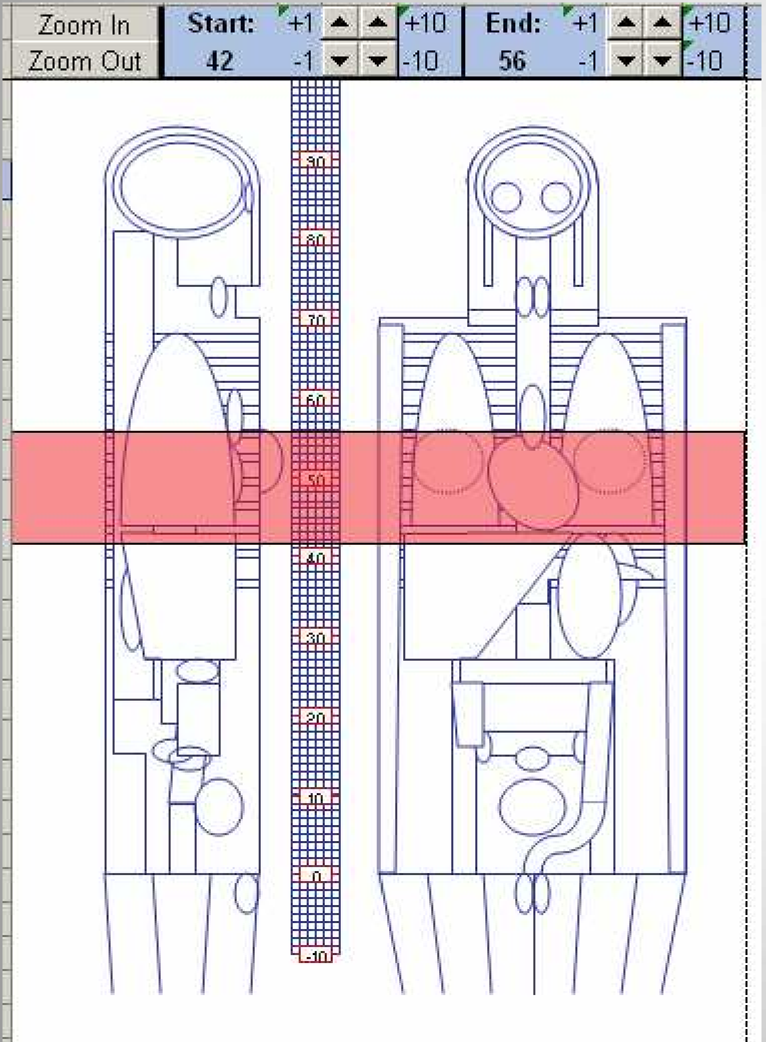


Prospective gated CT Dosimetry



- Use of IMPACT Dosimetry calculator (Monte Carlo based program)
- Averaging of peripheral measurements and assumes a full rotation per scan.
- Use of updated organ weighting factors (ICRP 103).
- Comparison of Effective dose with old organ weighting factors (ICRP 60)
- Effective dose calculated for all clinically used cardiac protocols (prospective gating only)
- Identified need for partial rotation Monte carlo simulator

Example



ImPACT CT Patient Dosimetry Calculator

Version 0.99y-pre-release 20/08/2009

Scanner Model:		
Manufacturer:	GE	
Scanner:	GE LightSpeed VCT	
kV:	120	
Scan Region:	Body	
Data Set	MCSET20	Update Data Set
Current Data	MCSET20	
Scan range		
Start Position	42 cm	Get From Phantom Diagram
End Position	56 cm	

Acquisition Parameters:			
Tube current		650	mA
Rotation time		0.227	s
Spiral pitch		0.85	
mAs / Rotation		147.55	mAs
Effective mAs		173.588	mAs
Collimation		40	mm
Rel. CTDI	Look up	0.86	at selected collimation
CTDI (air)	Look up	30.0	mGy/100mAs
CTDI (soft tissue)		32.1	mGy/100mAs
$_nCTDI_w$	Look up	8.2	mGy/100mAs

Organ weighting scheme	ICRP 103

$CTDI_w$	12.1	mGy
$CTDI_{vol}$	14.2	mGy
DLP	199	mGy.cm

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.08	0.018	0.0014
Bone Marrow	0.12	3.2	0.39
Colon	0.12	0.12	0.12
Lung	0.12	16	1.9
Stomach	0.12	2.7	0.32
Bladder	0.04	0.007	0.00028
Breast	0.12	18	2.2
Liver	0.04	4.6	0.18
Oesophagus (Thymus)	0.04	11	0.43
Thyroid	0.04	0.27	0.011
Skin	0.01	2.4	0.024
Bone Surface	0.01	6.6	0.066
Brain	0.01	0.013	0.00013
Salivary Glands (Brain)	0.01	0.013	0.00013
Remainder	0.12	4	0.48
Not Applicable	0	0	0
Total Effective Dose (mSv)			**6.2**

Remainder Organs	H_T (mGy)
Adrenals	5.4
Small Intestine	0.13
Kidney	0.93
Pancreas	3.6
Spleen	3
Thymus	11
Uterus / Prostate (Bladder)	0.017
Muscle	2.3
Gall Bladder	1.1
Heart	22
ET region (Thyroid)	0.27
Lymph nodes (Muscle)	2.3
Oral mucosa (Brain)	0.013

Other organs of interest	H_T (mGy)
Eye lenses	0.034
Testes	0.00039
Ovaries	0.035
Uterus	0.027
Prostate	0.007

Scan Description / Comments	663967 Cardiac Medium, 120KV Scanner CTDIv=12.6 Scanner DLP =177

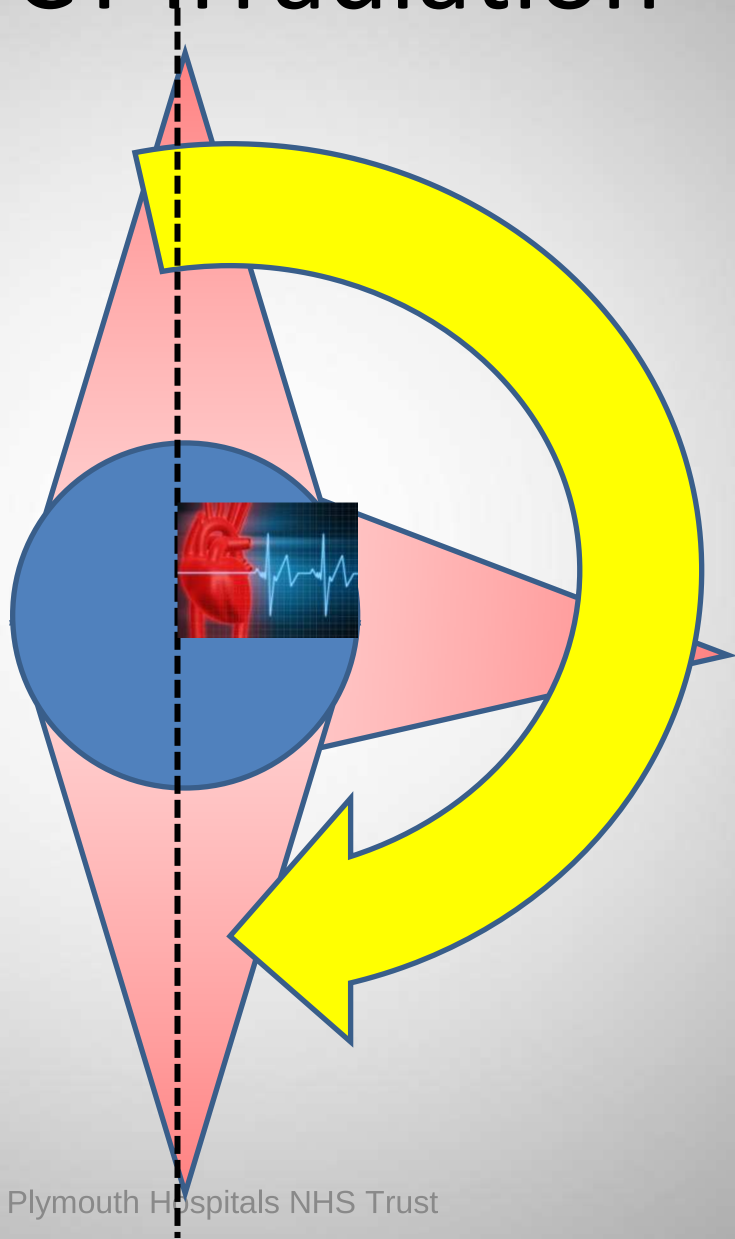
GE VCT Partial rotation scanning

- Cardiac modes, X-rays on for 180°
- T=0.35s (cardiac modes)
- Dicom image header states exposure time of 227ms
- Originally thought this did not make sense, as 227ms/350ms = 0.65 ~234 ° (not 180°)
- Jacky Bye (GE) kindly reminded me that CT uses a fan beam!

GE VCT Irradiation

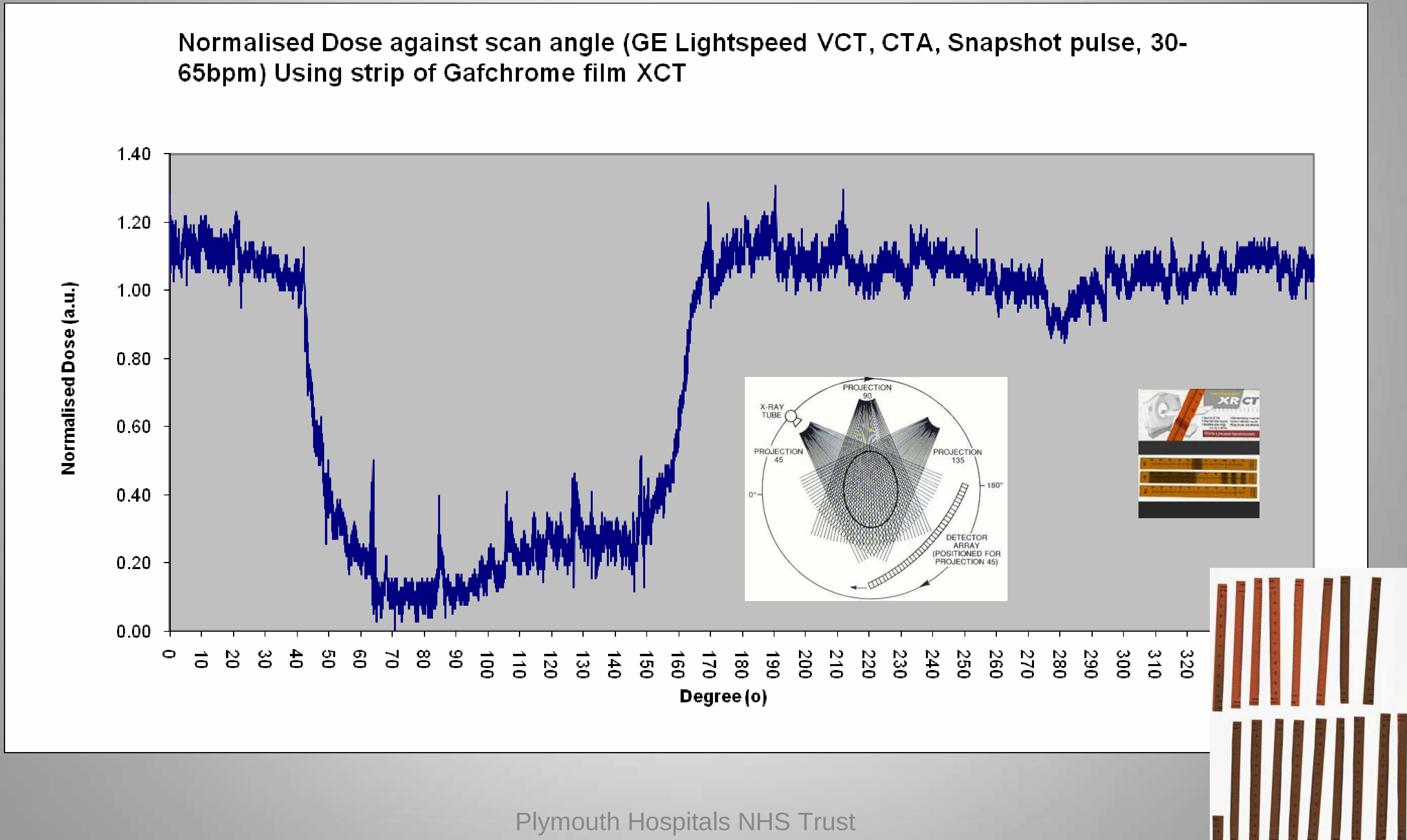
•Actual irradiation = 180°+Fan angle

•Verified using Gafchrome film XCT

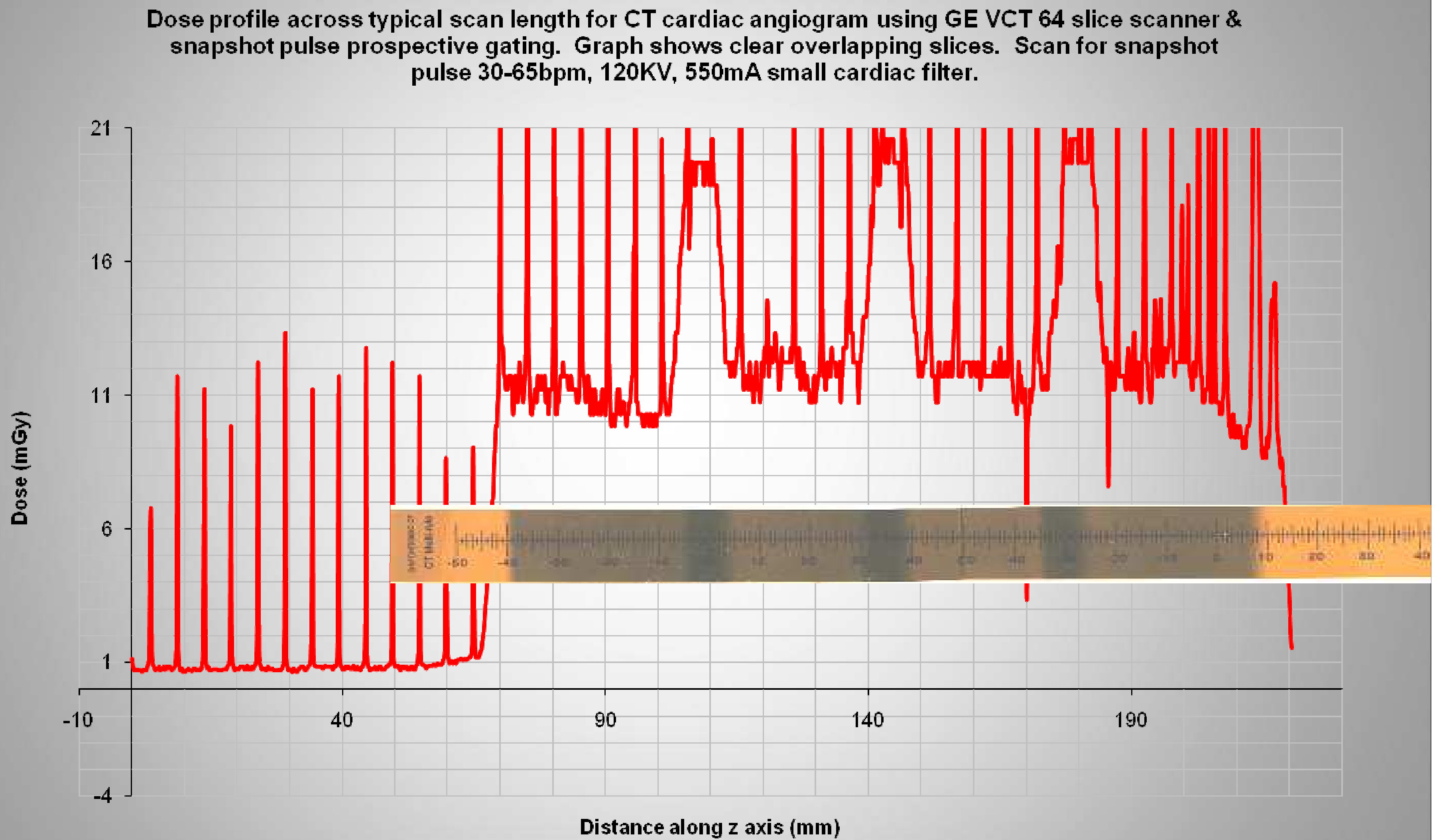


Start point relative to patient completely governed by ECG

Radiation exposure during CTCA rotation (227ms exposure)... A dosimetry Headache!



Overlapping "axial pitch" and dosimetry



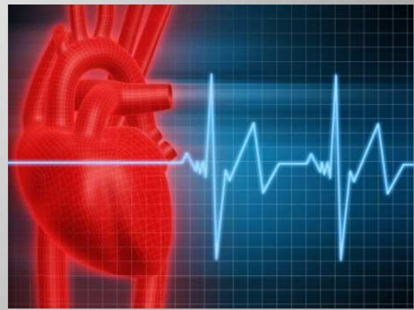
Step-and-shoot data acquisition and reconstruction for cardiac x-ray computed tomography

Jiang Hsieh,[a] John Londt, Melissa Vass, Jay Li, Xiangyang Tang, and Darin Okerlund
GE Healthcare Technologies, Waukesha, Wisconsin 53188

A different approach to CTDIw

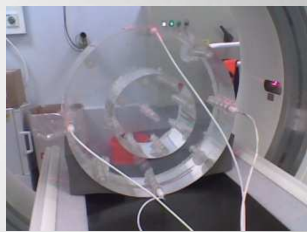
Cardiac Medium		550mA, 227ms, 64*0.625mm			
120KV					
C	**N**	**S**	**E**	**W**	
2.651	1.039	2.296	7.415	7.53	
2.603	1.003	6.374	7.669	8.01	
2.466	8.236	6.067	2.606	2.904	
2.661	7.297	5.965	2.519	2.777	
2.601	0.806	0.552	3.668	3.759	
2.468	0.792	6.104	7.711	8.01	
2.657	7.958	6.12	7.035	2.514	
2.597	7.939	6.37	0.631	4	
2.473	2.334	2.059	7.456	8.01	
2.455	4.419	0.569	0.698	7.755	
2.678	8.29	6.153	7.533	7.982	
2.589	8.294	6.372	7.634	1.766	
	7.754	6.378	4.099	7.978	
	0.708	1.063	7.711	1.685	
	0.723	0.582	7.606	0.733	
2.575	4.506	4.202	5.466	5.028	mean
0.086	3.483	2.595	2.762	2.886	s.d

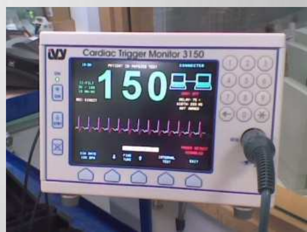
Arbitrary start location of X-ray meant we had to re-think the measurement of CTDIw (look at variance of successive measurements!)



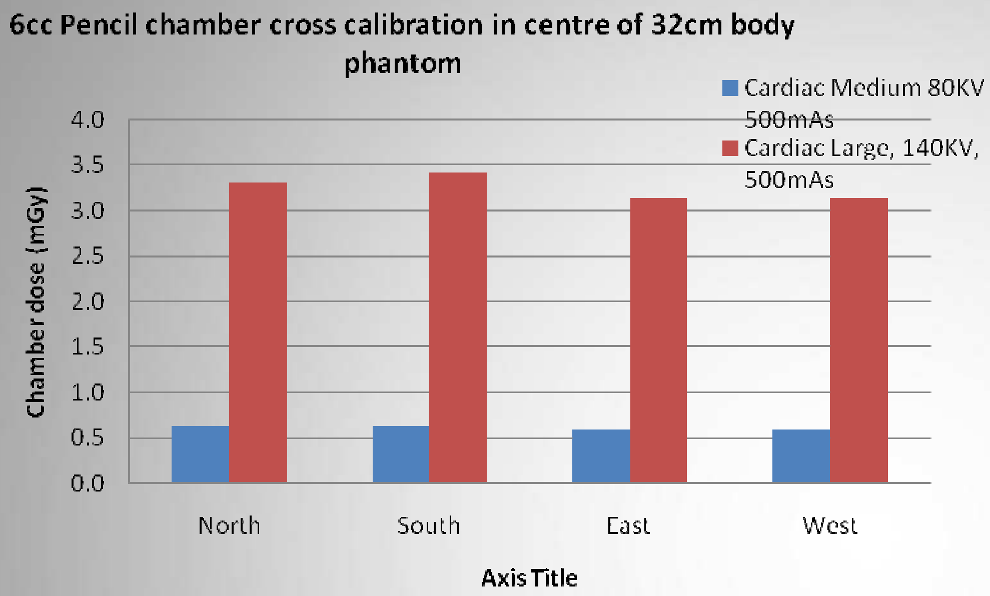
Calculation of nCTDIw & DLP

	Filter	bpm (set)	kV	C	N	S	E	W	Mean Periph	CTDIw (mGy/mAs)	nCTDIw	Scanner CTDIv (for the actual mAs)	Our measure	Our measure (DLP)	Scanner DLP	% difference DAP
1st	Cardiac medium	60	120	2.570	4.410	4.560	5.270	5.050	4.823	0.082	8.155					
Method	Cardiac Small	60	120	2.289	4.294	4.138	5.097	4.857	4.597	0.077	7.665	10.67	9.57	38.28	37.36	**-2.41**
	Cardiac Large	60	120	2.376	5.928	4.625	6.041	5.050	5.411	0.088	8.811					
	Cardiac medium	60	100	1.478	3.819	2.865	3.344	2.947	3.244	0.053	5.318	7.59	6.64	26.56	26.57	**0.05**
		60														
2nd	Cardiac medium	60	120	2.379	7.155	2.505	6.589	1.633	4.471	0.083	8.313	s.d				
Method	Cardiac medium	60	120	2.379	5.550	6.104	6.637	0.598	4.722	0.087	8.683					
	Cardiac medium	60	120	2.379	1.502	6.366	2.999	6.644	4.378	0.082	8.177	0.26				
	Cardiac Large	60	140	3.425	9.698	5.307	9.216	1.635	6.464	0.120	12.009					
	Cardiac Large	60	140	3.425	3.511	8.834	3.093	9.283	6.180	0.116	11.592					
	Cardiac Large	60	140	3.425	4.776	8.758	9.160	2.167	6.215	0.116	11.644					
	Cardiac Large	60	140	3.425	9.997	3.087	3.191	9.308	6.396	0.119	11.909	0.20				
	Cardiac Small	60	80	0.578	1.989	1.717	0.105	2.014	1.456	0.026	2.564					
	Cardiac Medium	60	100	1.455	4.347	3.619	0.299	4.434	3.175	0.057	5.731					
	Cardiac Medium	60	80	0.637	2.479	2.015	0.136	2.477	1.777	0.031	3.077					
	Cardiac Large	60	120	2.245	7.074	1.125	6.269	3.836	4.576	0.084	8.369					
	Cardiac Large	60	120	2.245	7.093	1.052	4.057	6.346	4.637	0.085	8.459					
	Cardiac Large	60	120	2.245	7.094	0.993	4.251	6.313	4.663	0.085	8.497					
	Cardiac Large	60	120	2.245	6.150	5.390	6.475	0.610	4.656	0.085	8.487					
	Cardiac Large	60	120	2.245	5.737	5.693	0.591	6.596	4.654	0.085	8.484	0.05		s.d for pixel value (ROI)		
	Cardiac Large	50	120	2.339	6.909	3.010	6.424	1.525	4.467	0.083	8.278			70.3		
	Cardiac Large	80	120	2.244	6.511	4.847	6.462	0.718	4.635	0.085	8.455			67.6		
	Cardiac Large	150	120	2.192	6.942	2.608	6.415	1.746	4.428	0.081	8.113			67.9		

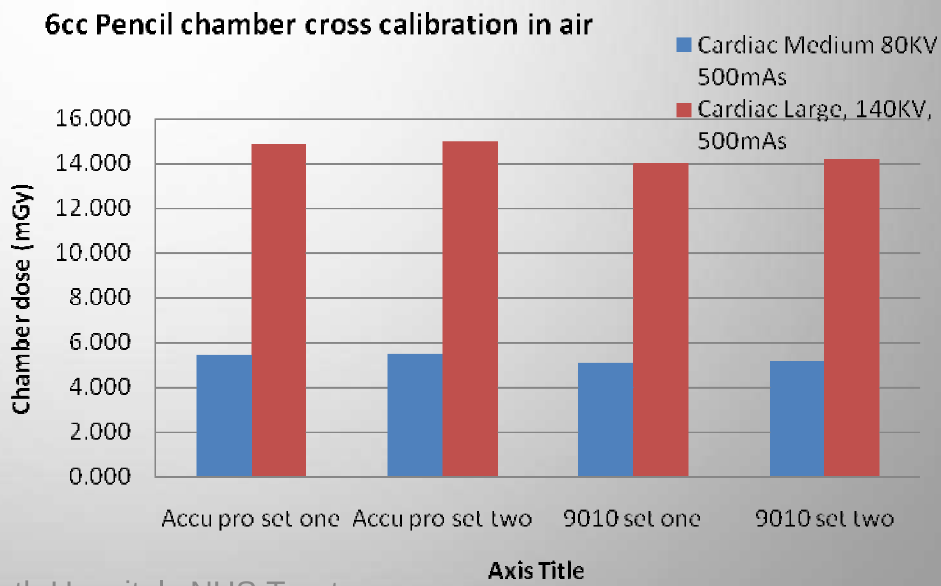


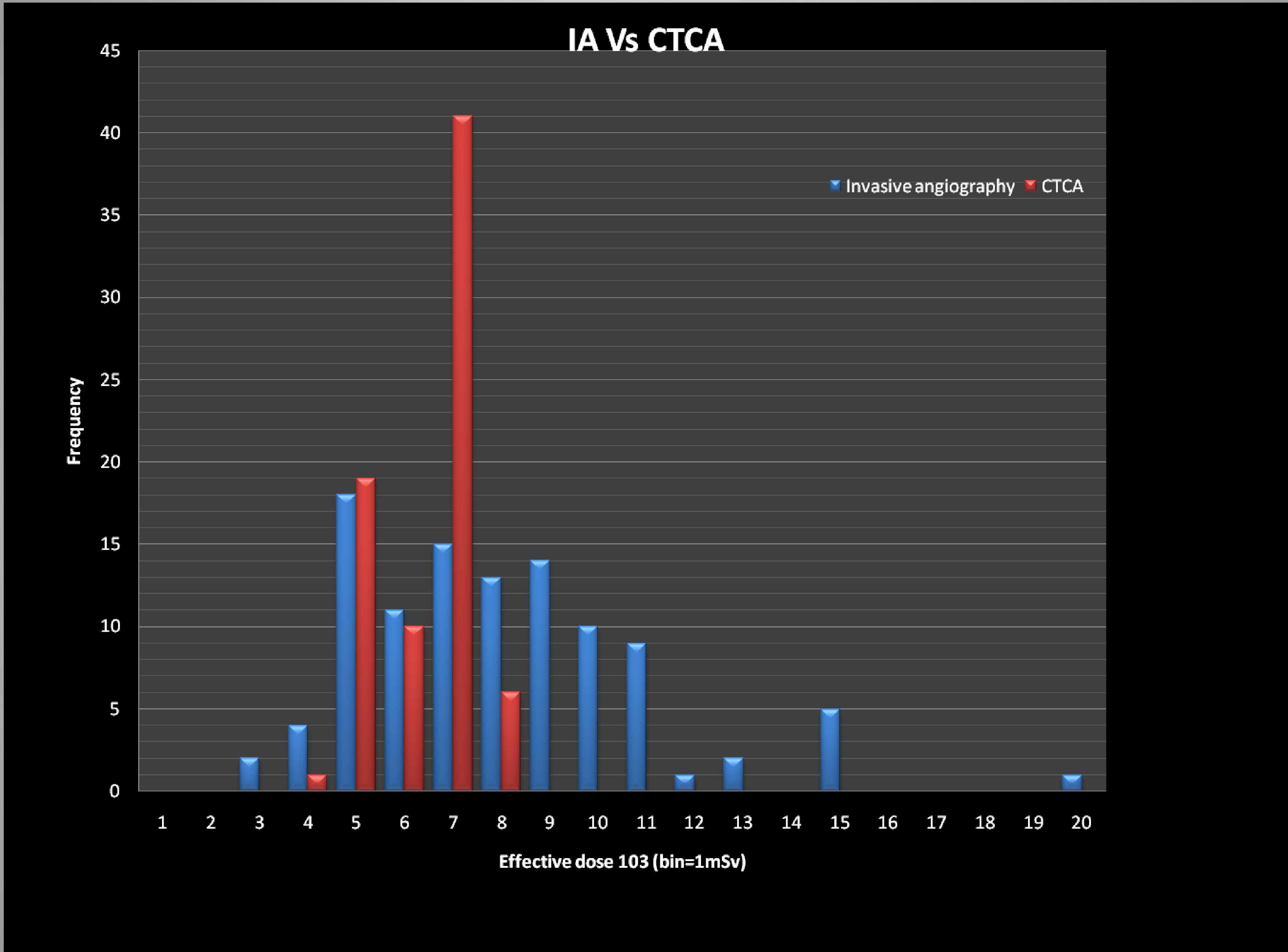


Chamber cross calibration performed



Cardiac Medium 80 KV 500mAs			mean	s.d
5.421	5.461	5.419	5.434	0.024
5.446	5.465	5.461	5.457	0.010
5.1	5.102	5.106	5.103	0.003
5.147	5.149	5.158	5.151	0.006

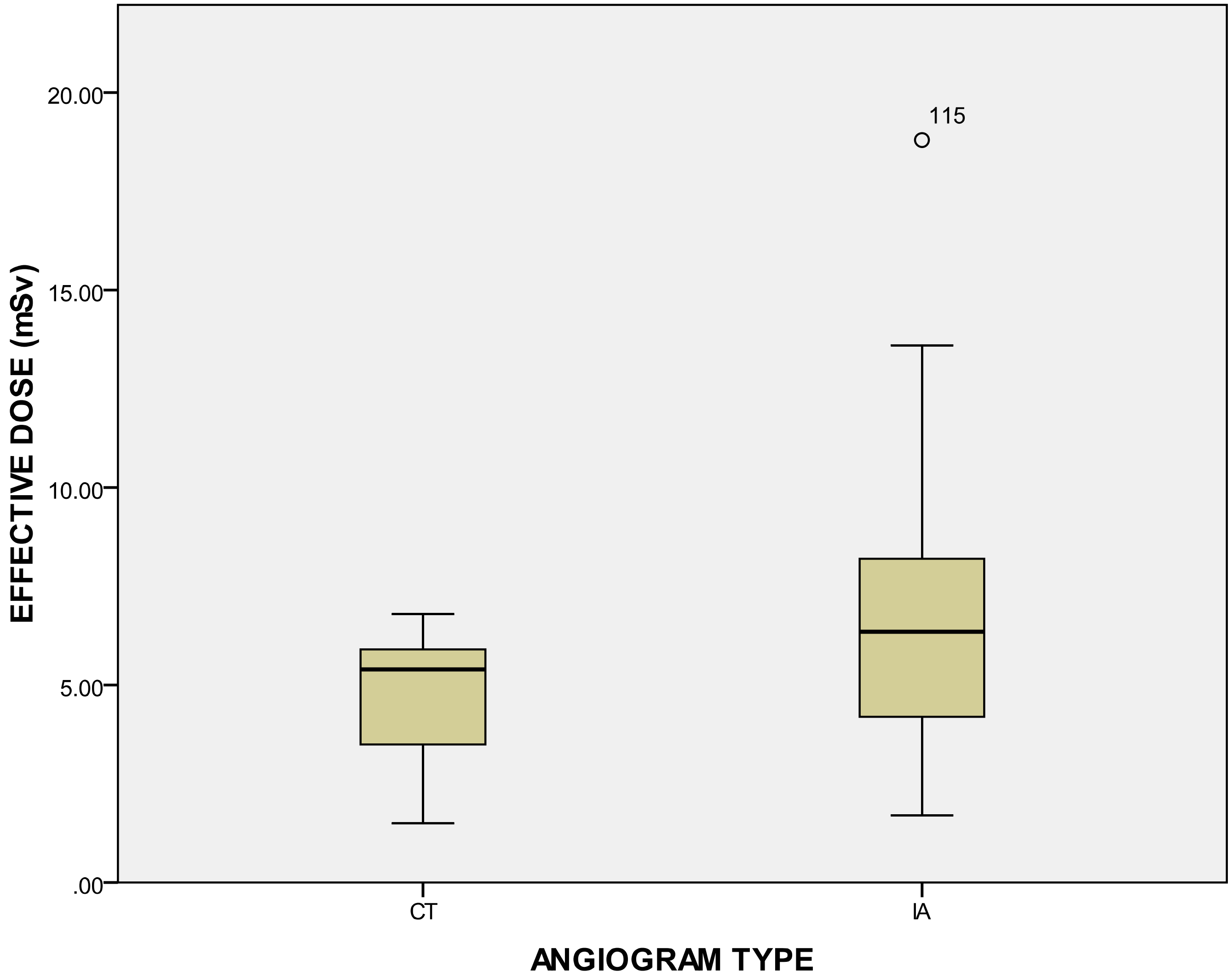



IA Vs CTCA
Invasive angiography
CTCA
Frequency
Effective dose 103 (bin=1mSv)
0
5
10
15
20
25
30
35
40
45
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Patient population & Results

	CTCA (PROS G)	IA (Catheter Labs)
N	84	94
Medin DLP/DAP	159±47.7 (mGycm)	27.2±12.3 (Gy*cm^2)
Median (E mSv)	**5.4**	**6.3**
IQR	(3.5-5.9)	(4.2-8.2)
BMI	27±3.8	27±3.6

Results



20.00
15.00
10.00
5.00
.00
EFFECTIVE DOSE (mSv)
115
CT
IA
ANGIOGRAM TYPE

Preliminary results

Summary

Study	Cardiac cath lab angiography conversion factor (DAP to Effective dose)	Cardiac cath lab mean dose (mGy)	N (cath lab patients)	CTCA technique (R/P)	CTCA conversion factor (DLP to Effective dose)	Tissue weighting factors	CTCA mean Effective dose dose (mGy)	N (CTCA)
"Derriford"	0.24 (Derriford)	6.5	105	P	0.03 but we calculated all patients	ICRP 60 +ICRP 103	5	80
"Bristol"	NA	5.6	91	R	IMPACT/NRPB	ICRP 60	14.7	91
"Head to head"	0.22 (NRPB)	8.5	42	P	0.017 (European commission)	ICRP 60	2.1	42
"Jama"	NA	NA	NA	R+P	0.017 (European commission)	ICRP 60	12	1965

Bristol "Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography"
J. Am. Coll. Cardiol. 2006;47;1840-1845, Duncan R Coles, Mary A. Smail, Ian S Negus, Peter Wilde….

Head to Head "First head to head comparison of effective radiation dose from low dose CT with prospective ECG-triggered versus invasive coronary angiography"
Heart 05/07/2009. Bernhard A Herzog et al

Jama "Estimated radiation dose associated with cardiac CT angiography
JAMA 2009;301(5):500-507. Jorg Hausleiter et al

Organ (Breast) dose with PG CTCA

- The X-ray tube in conventional (catheter) angiography is positioned under the examination table to reduce the absorbed dose to the breast and to limit the scattered radiation dose to staff.
- In PG CTCA we have shown the x-ray exposure time is a fraction of the rotation time and triggered by ECG (essentially random). This means that the total absorbed dose to the breasts will vary significantly.

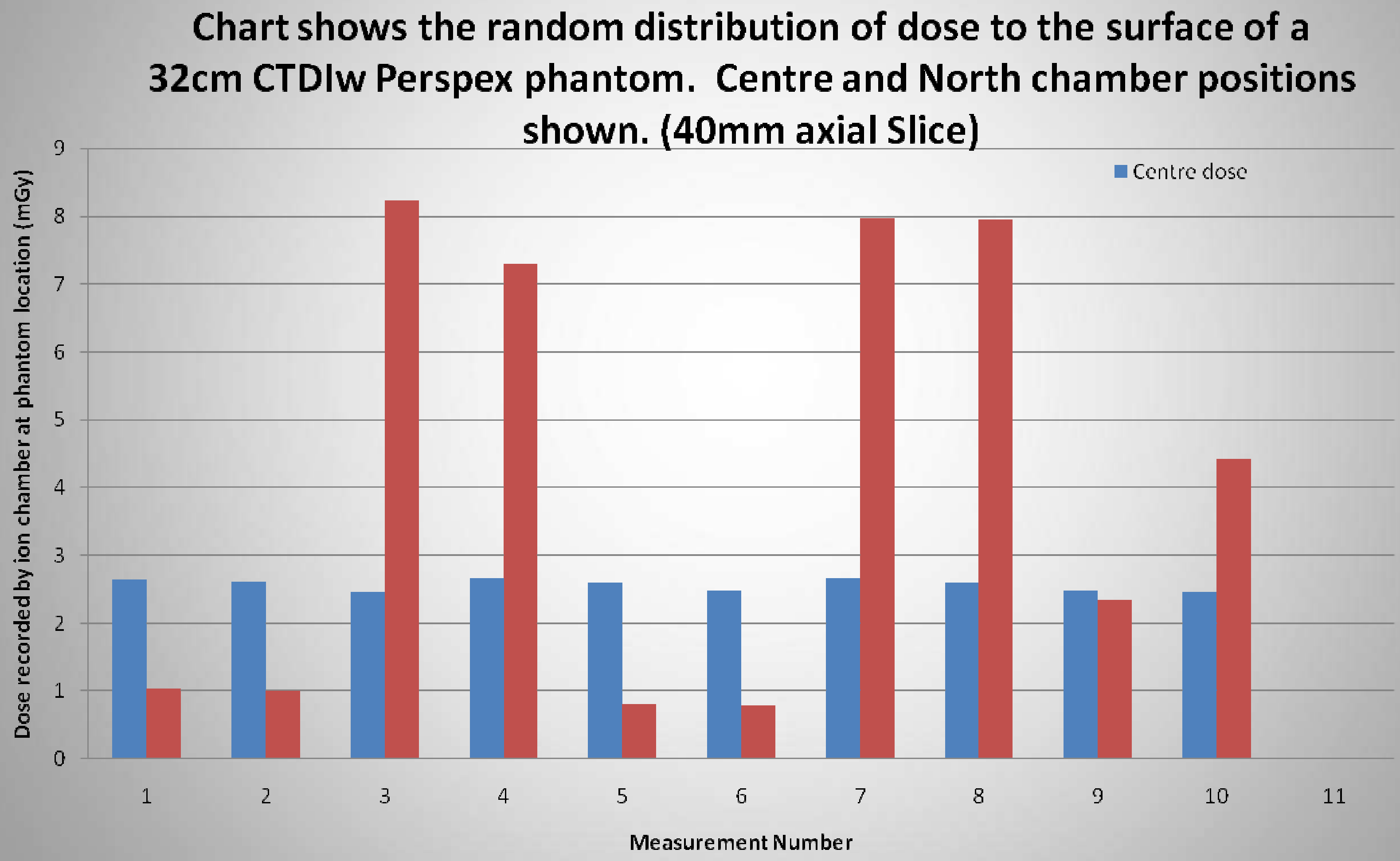
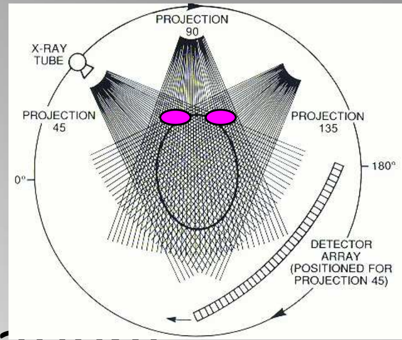


Chart shows the random distribution of dose to the surface of a 32cm CTDIw Perspex phantom. Centre and North chamber positions shown. (40mm axial Slice)
Centre dose
Dose recorded by ion chamber at phantom location (mGy)
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
11
Measurement Number

Breast dose



- Doses shown are for a medium size (70Kg) patient (cardiac medium filter, 120KV, 550mA) using a 32cm CTDIw phantom to represent the patient. Doses are for a single axial rotation. For the average size heart, 4 axial rotations are required to cover the heart (~140mm)
- Larger patients will require higher KV, mA combinations and larger patients/ breasts will be positioned closer to the X-ray tube.
- For large female patients, requiring higher tube current it is estimated that the absorbed dose to the breast could exceed 100mGy/scan under certain conditions.

Conclusions & Further work

- Radiation doses for prospectively gated CTCA have dropped significantly and dose audit from this study places effective doses from CTCA similar (if not lower) to that from those performed within the catheter labs.
- For the average size patient, Effective dose can no longer be a reason to perform coronary angiography over CTCA (prospective gated).
- More work is needed in order to ensure breast dose in CTCA is as low as possible and this may require the introduction of Bismuth breast shielding.

Limitations

- Effective dose contribution to CTCA from scout view and unenhanced scan not accounted for
- Patient populations not identical
- Different anthropomorphic phantoms (PCMXC vs ImPACT dosimetry calculator)
- Patient size not accounted for in ImPACT calculator.
- ImPACT calculator assumes uniform dose distribution in body.

Questions?