Dose Reduction Options in Cardiac CT

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Background

- 1 in 5 deaths in Europe related to cardiac disease – about every second victim dies without being hospitalised[1]
- Invasive Coronary Angiography (CA) – gold standard for diagnosing coronary artery disease (CAD)
- 2.5 million CA's/year performed in Europe > 40% not followed by interventional/surgical therapy, thus conducted only to rule out CAD[2]
- Evidence that majority of acute coronary events occur at the site of angiographically non-significant lesions[3]

Background

- Several investigations made on accuracy of CTA[4]

  – all compare detection rates of lumen >50% with CTA and CA

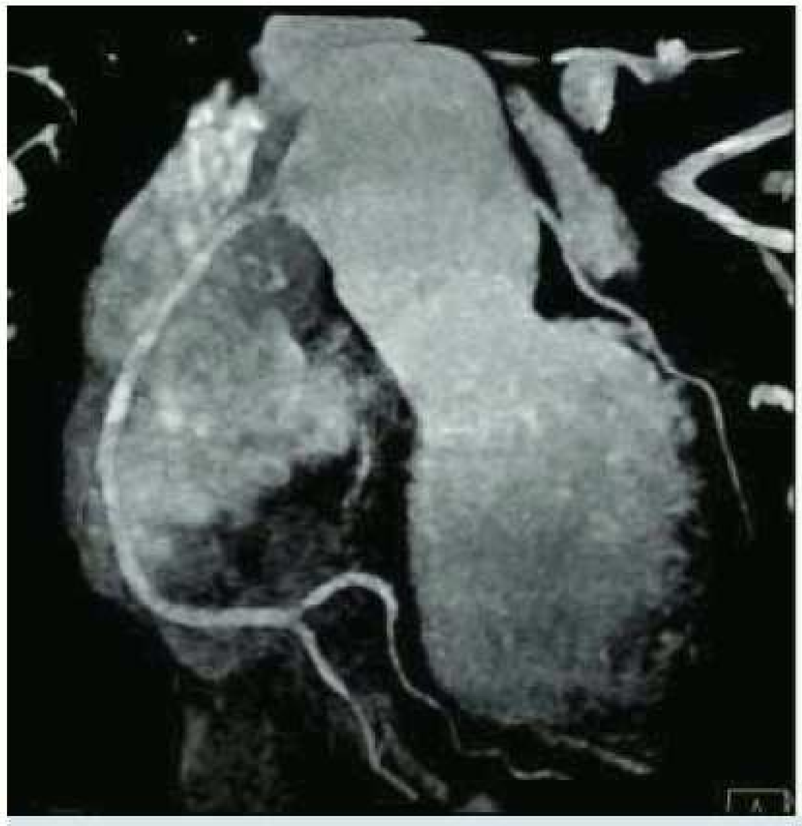
  Sensitivity ranges from 82% - 100%

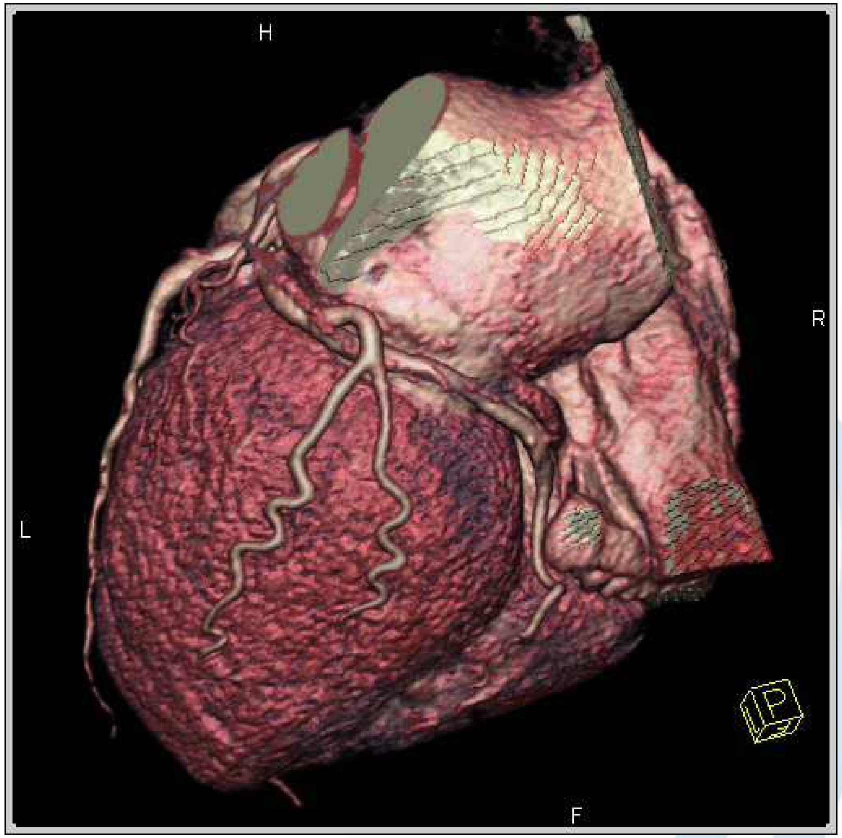
  Specificity ranges from 78% - 98% but real strength is in NPV

  Negative Predictive Values of 95% - 97% (for all patient risk cat.)

- Since advent of 64 slice scanners CTA now widely used to rule out CAD, particularly in patients with atypical chest pain, low to intermediate risk and a questionable stress test[5]

CTA examples





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Other uses of cardiac CT

- Apart from CTA, cardiac CT is also used for:-

  Triple rule-out (coronary arteries, thoracic dissection, pulmonary embolism)

  Coronary artery bypass graft assessment (30% repeat symptoms within 1 year,,,)

  Perfusion, viability and function (in acute myocardial infarction)

  Calcium scoring (invaluable in stratifying risk of CAD among asymptomatic patients, especially those deemed < 60% according to traditional risk factors[4])

Predicted future growth rate for CTA is substantial

Nice Guideline Draft (May 2009)

"Chest pain or discomfort of recent onset" (due 2010)

For patients with <30% pre-test likelihood:

After clinical assessment and resting ECG offer Calcium score, if:

0 $\Rightarrow$ investigate other causes of chest pain

1 – 400 $\Rightarrow$ offer 64 slice CTA

> 400 $\Rightarrow$ offer invasive CA

Status Quo in CTA

- Conflicting evidence from the literature on CTA protocols & effective doses, wide variation in:
  - CT model – no. of slices and variation in using scanner specific available options
  - Patient cohort – BMI, heart rate, drugs, clinical Q, history
  - Use of dose reduction techniques
  - Pace of accepting technological adaptations
  - Scan length

Review of effective doses reported for CTA

	Effective Dose (mSv)	
64 Slice Scanner	Retrospective ECG gating	Prospective ECG triggering
GE[6,7,8,9]	19.7 (19)	3.7
Philips[10]	18.9 (10)	3.7
Siemens[11,12]	(9)	2.8

50 centre international study by Hausleiter J et al (2009) JAMA 301(5):500-507; 1965 patients

General Dose Reduction Strategy

1. Use manufacturer default protocols as the starting point, identify the application specialist and investigate protocol alternatives
2. Examine CT scanner specific options (available kVs, pitch etc.) and scope for optimisation
3. Assess implications for patient dose using phantoms, Impact spreadsheet, TLDs etc.
4. Identify clearly the clinical question posed and perform a literature review
5. Communicate possible changes to clinical staff in terms of improvements in image quality not just dose reduction!
6. Some form of clinical image quality assessment is required (especially in the absence of clinical evidence from literature)

Specific CTA considerations

- Patient size, sex & age
- Heart Rate (HR)
- Heart Rate Variability

Need to decide appropriate scan technique and factors – axial or helical and mA, kV, pitch & rotation time.

- Investigate appropriate dose reduction options e.g. ECG dose modulation and/or in-plane shielding
- Ensure HR not in sync with scanner harmonics
- Identify appropriate cardiac phase for reconstruction e.g. 75% or larger 40-75% R-R interval

Philips Brilliance 64

- Uses COBRA – cone beam reconstruction algorithm (based on 3D filtered back projection, weighted to cardiac phase)
- Temporal Resolution 210 ms* (single sector)
- Multi-sector reconstruction (automatically uses max available for each voxel, reducing temporal resolution to as little as 56 ms)
- ECG gated mA modulation (80% max reduction from peak)
- Pitch range 0.2 – 0.3
- Effective Dose 14 mSv or 8 mSv with ECG D-MOD*

*CEP report 08027

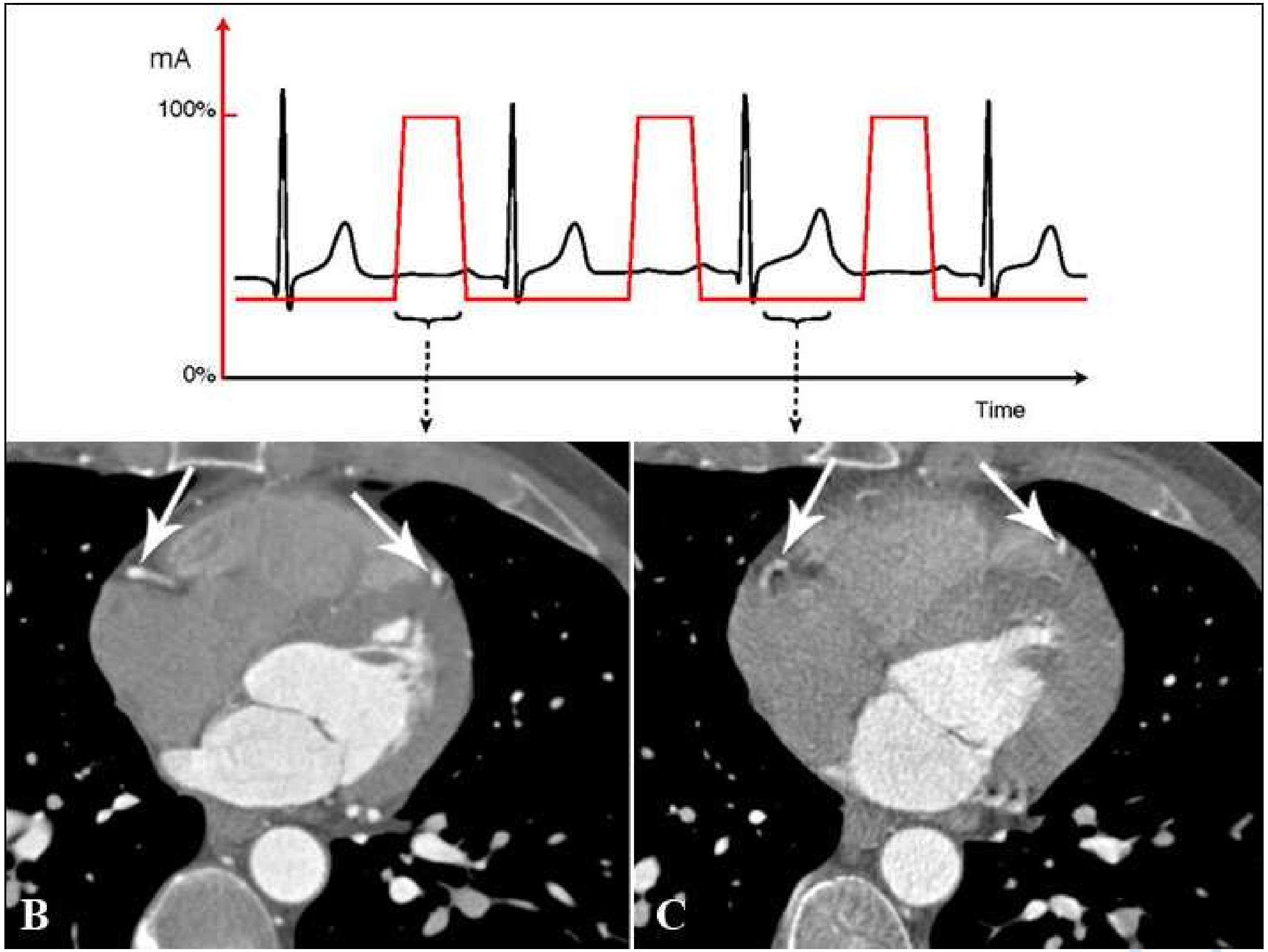
Identify patient cohort and triage

Working with Applications and clinical staff the following four protocols were agreed locally:

- Standard protocol 120kV, pitch 0.2, rot time 0.4 s, 800 mAs/rot, 64 x 0.625 mm collimation, fov 22cm, X-res standard filter, 0.9 mm image slice thickness, 0.45 mm increment. ECG D-MOD ON.
- Large protocol 1000 mAs/rot, 1.4mm thickness, 0.7mm inc.
- Small protocol 80kV
- Axial protocol 210 mAs/slice

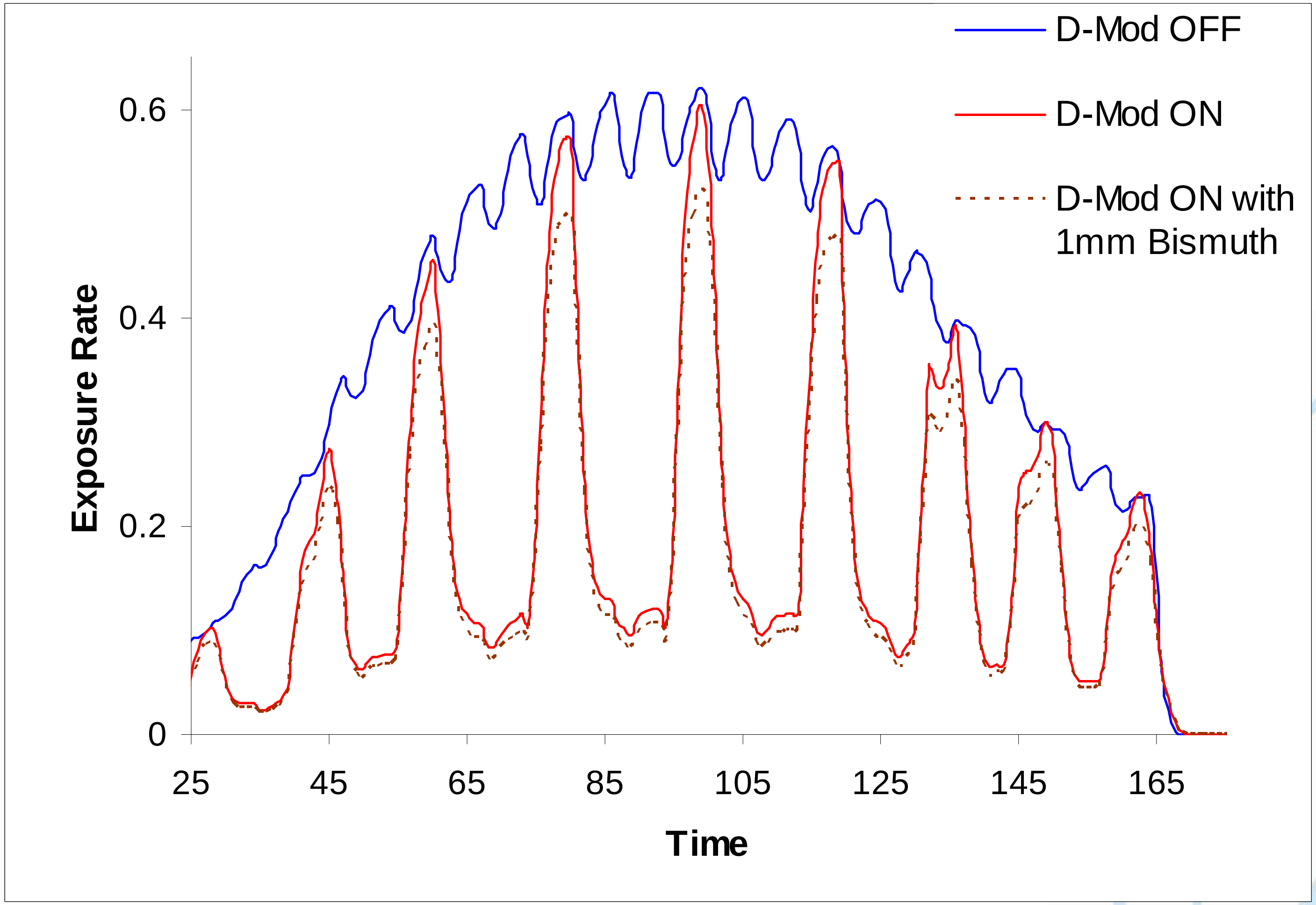
Standard, large & small protocols use retrospective gating. Axial protocol conducted with ECG prospective triggering.

Retrospective ECG gating with D-MOD



www.medscape.com

Pencil chamber measurement showing ECG D-Mod output



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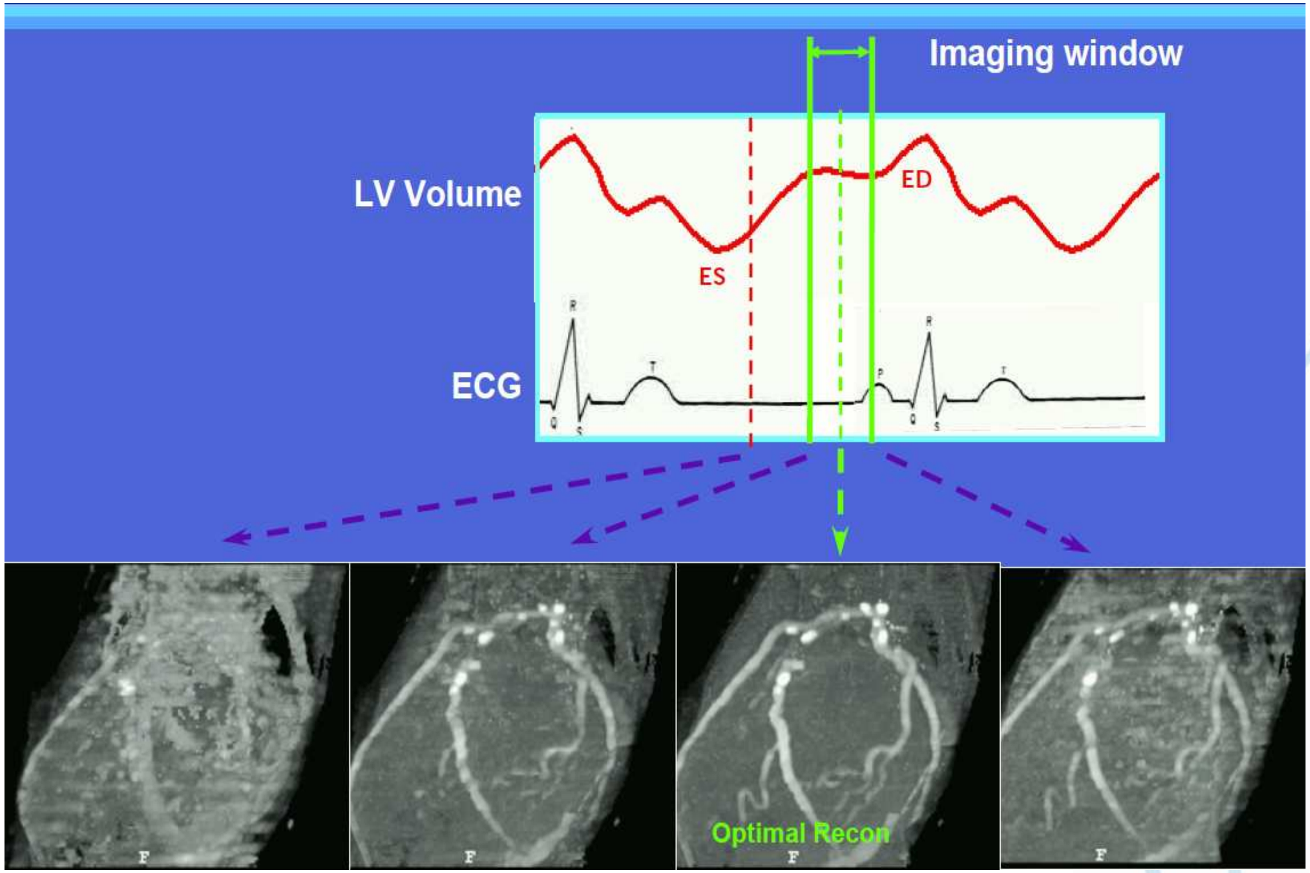
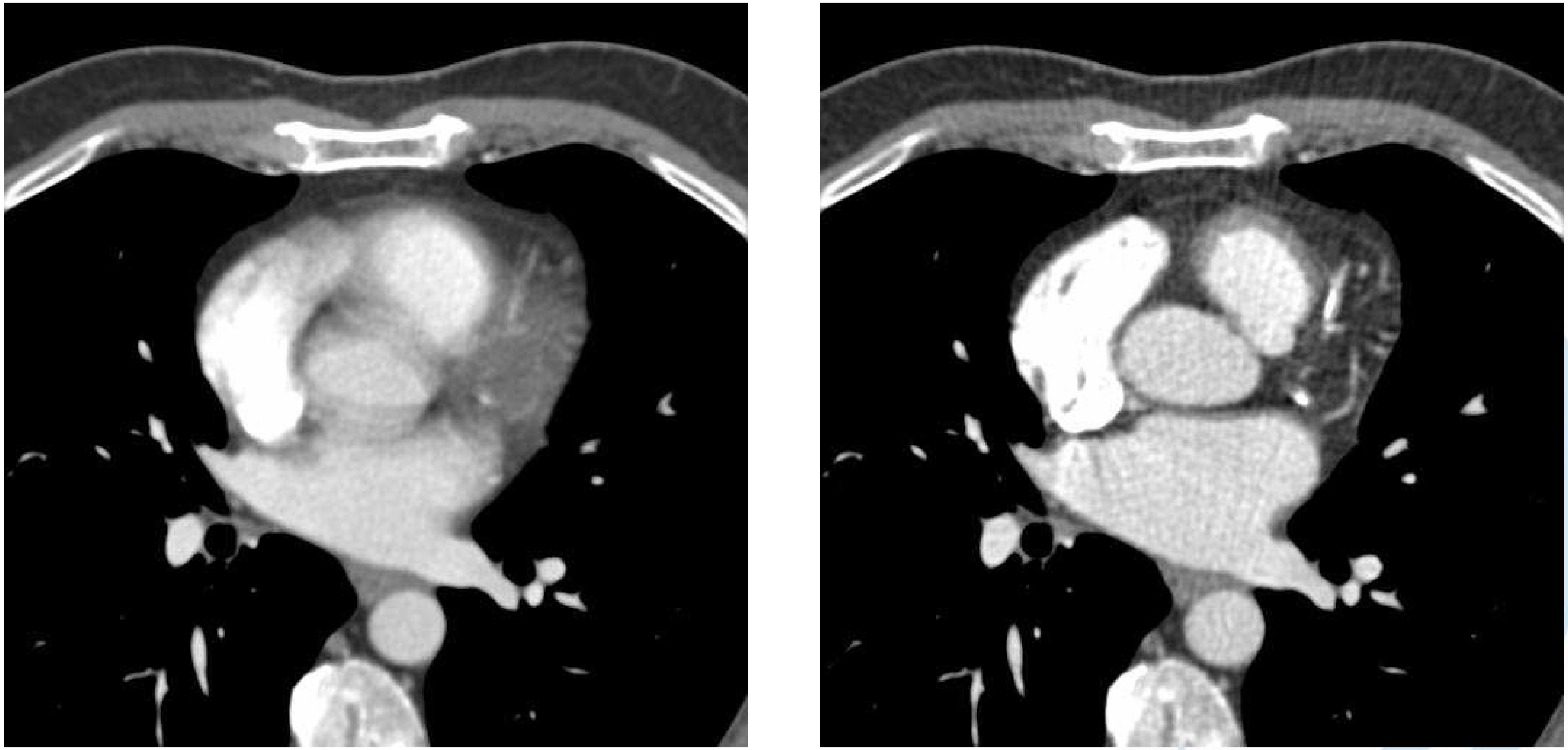
Cardiac phase selection?

40-75% R-R interval first used, changed to 75% when confidence grew:



Harefield BSCR 2006

Blurring on left image resulting from recon at wrong cardiac phase



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Protocol development

- Largely the result of clinical findings from literature[13-17], practical experience of Applications Specialist and confidence/experience of reporting Consultants
- Little room for meddling by medical physics…..

Cue

Development of a frequency dependent noise model and

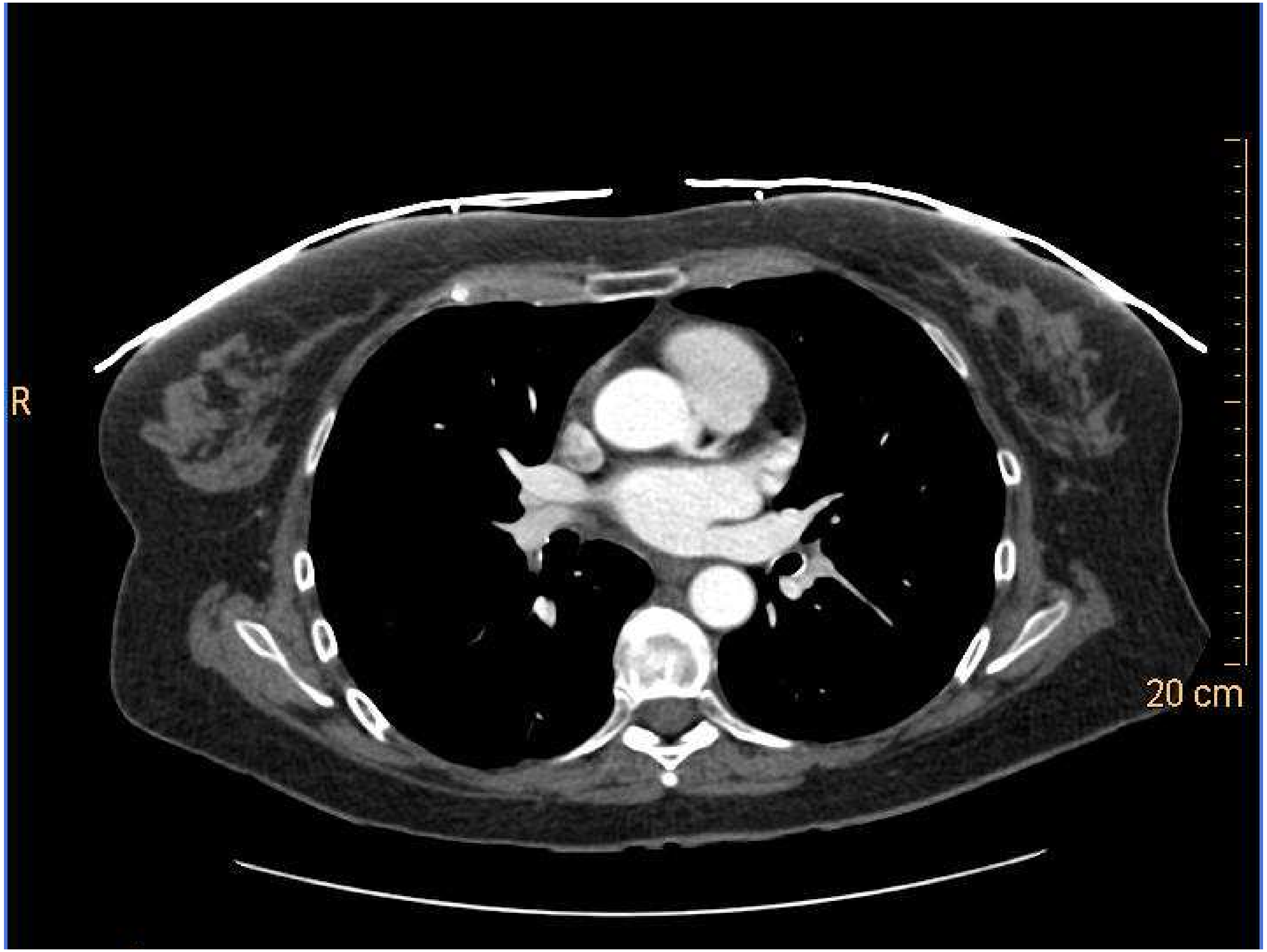
Investigation of in-plane bismuth shielding

Breast shield composition

- Bismite (Bi_2O_3)
  0.092mmPb equiv./ 0.43 transmission @ 120 kV
- 1 mm thick coated in latex
- Positioned on the anterior chest, to cover the breasts
- Primary attenuation major factor for dose reduction, backscatter < 2%[18]

Attenurad CT, F&L Medical Products, Pa. USA

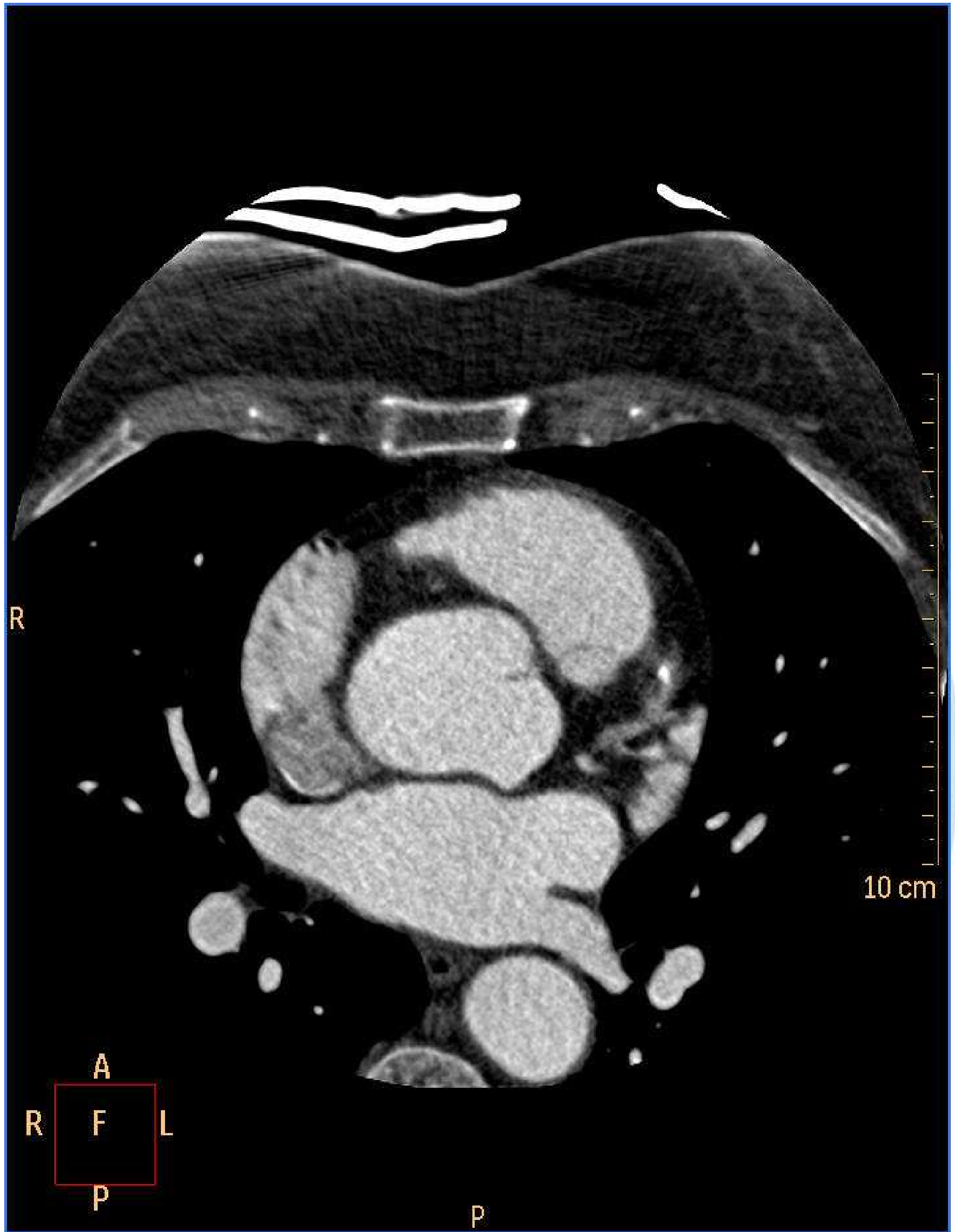
A wide field of view image from CTA – notice the breast shields anteriorly



CTA with 2 breast shields

Note

- Streak artefacts are confined to soft tissue
- Calcification in the LAD



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In-plane bismuth shielding ☺ / ☹

Evidence in the literature appears quite negative

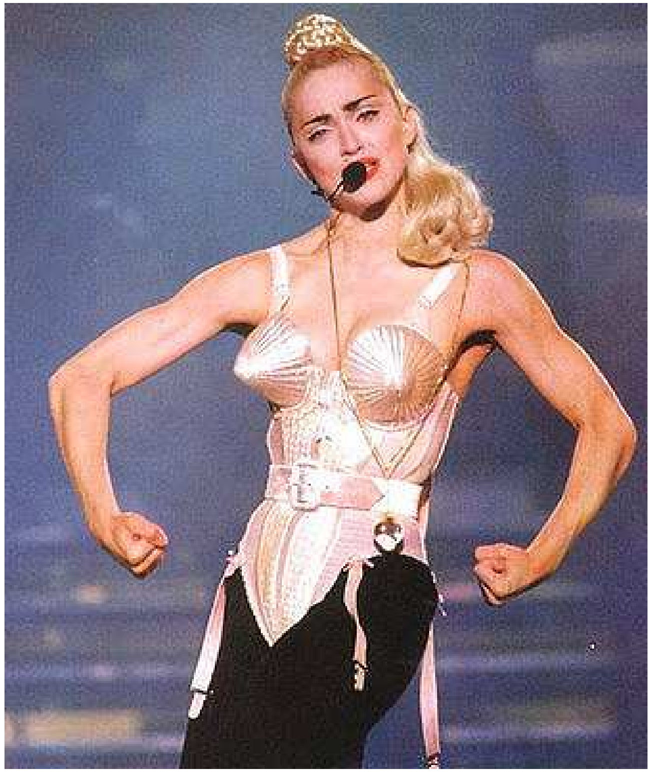
- Mannudeep et al (2009): suggests reducing mA, kV, using AEC as alternative for routine chest CT[20]
- Leswick et al (2008): Z-axis AEC more effective (for thyroid)[18]
- Geleijns et al (2006): suggests 'theoretically' reducing mA by 30% for same dose reduction in chest but relative increase in image quality (relatively lower noise)[19]

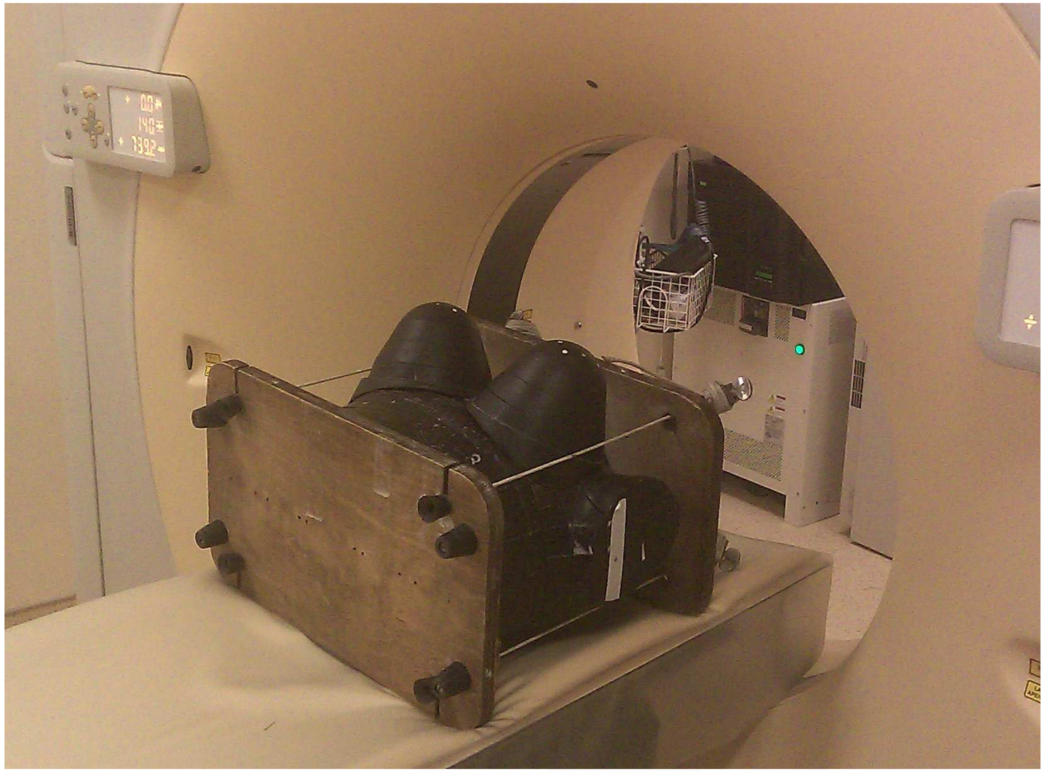
However some studies support its use and report no increase in image noise[21-23].

- No studies to-date on use of bismuth shields in CTA

Method

- A female Rando® phantom with/without bismuth shields was used
- 140 TLDs positioned throughout various breast layers
- TLD readings converted from $Hp_{0.07}$ to air kerma (0.58) to MGD of 50/50 breast (0.86)
- Entrance surface dose also measured (with Barracuda R100)





Method contd.

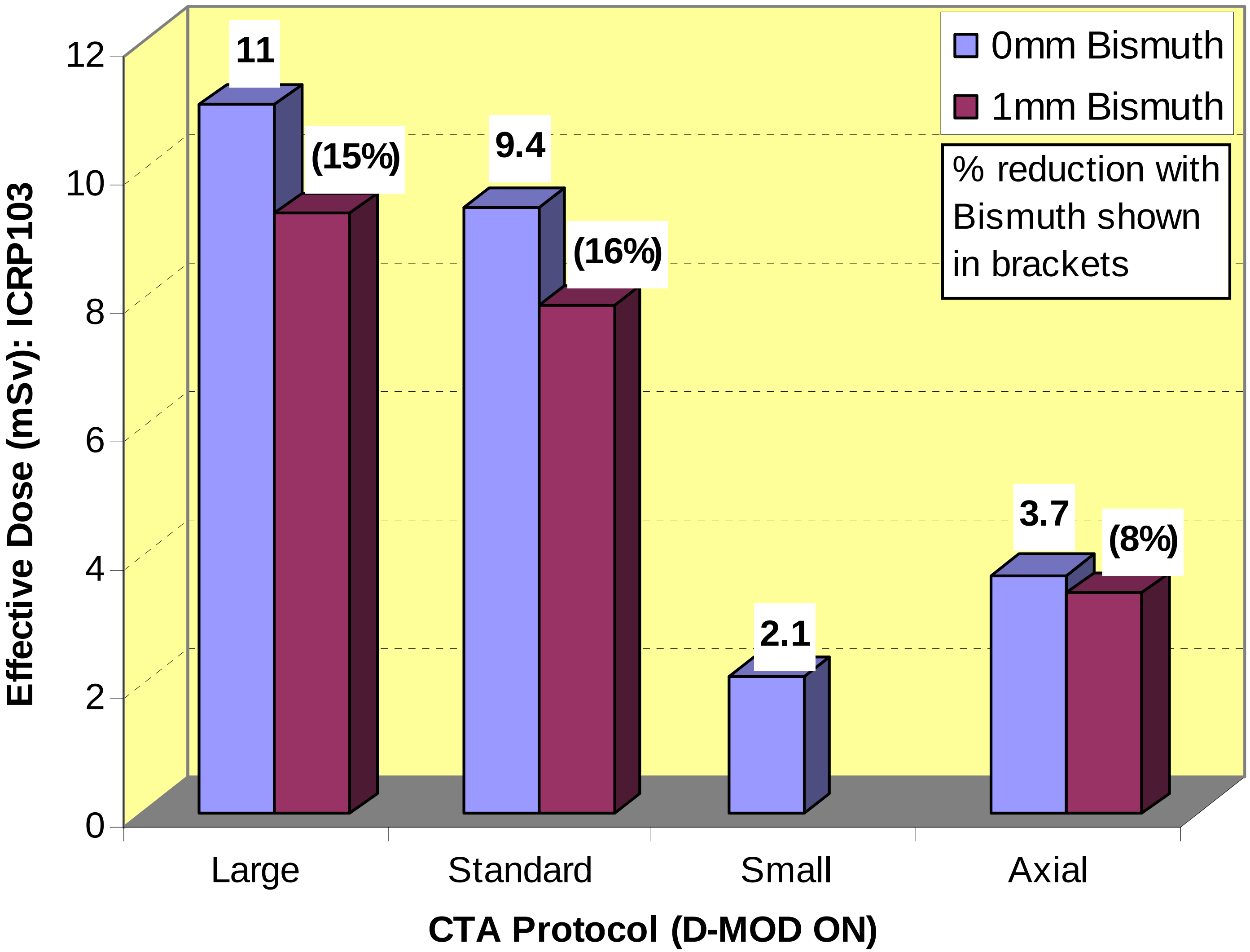
- $CTDI_w$ was also estimated for the four CTA protocols using the 32cm CTDI Body Phantom
- Impact spreadsheet used to calculate doses
- Results compared for TLDs, Impact method and DLP eff. dose conversion coef. for chest (EUR 16262)
- Measurements were repeated with and without ECG dose modulation and 0 or 1 mm thick bismuth
- Physically fit colleague provided stable ECG readings (55-60bpm) without need for beta blockers

Dose results for chosen CTA protocols: TLD readings and output with CTDI phantoms

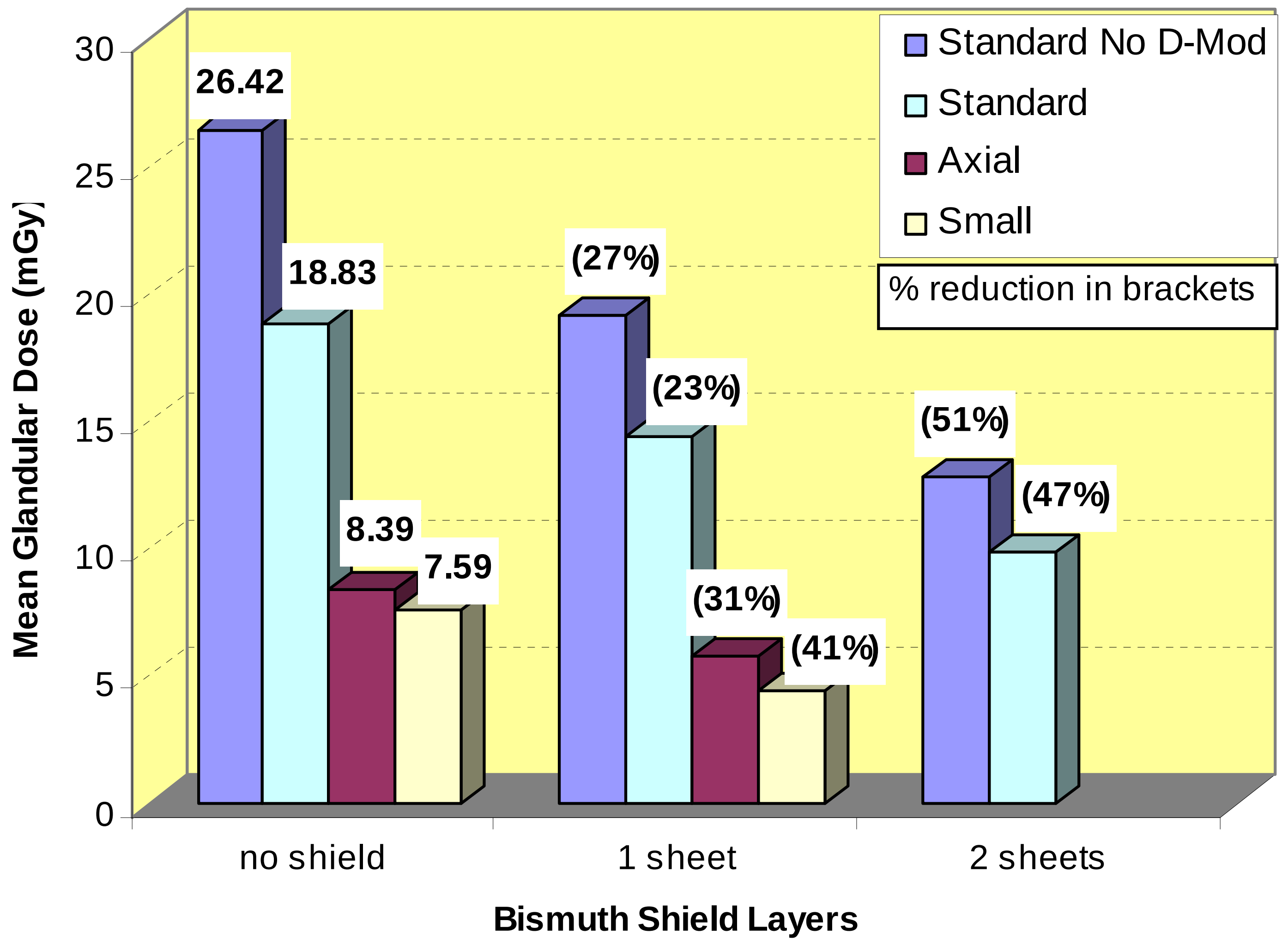
	Bismuth	DMOD	nCTDIw (mGy/100mAs)	Breast (mGy)	TLD MGD (mGy)	DLP (mGycm)	ED103 (mSv)	ED60 (mSv)	ED60 coef (mSv)	Patient Survey
Large Protocol	0 mm	ON	-	38		390	11	8.1	6.6	
		OFF	6.2	73		748	21	16	12.7	15.8
	1 mm	ON	-	32		324	9.3	6.8	5.5	
		OFF	5.7	66		682	20	14	11.6	
Standard Protocol	0 mm	ON	-	32	18.8	327	9.4	6.8	5.6	6.8
		OFF	6.5	60	26.4	627	18	13	10.7	9.7
	1 mm	ON	-	27	14.5	277	7.9	5.8	4.7	
		OFF	5.7	51	19	550	16	11	9.4	
Small Protocol	0 mm	ON	-	7.3	7.6	81	2.1	1.6	1.4	
	0 mm	OFF	1.6	14	4.5	158	4.2	3.1	2.7	
Axial Protocol	0 mm	NA	5.1	12	8.4	128	3.7	2.7	2.2	3.7
	1 mm	NA	4.8	11	5.8	120	3.4	2.5	2.0	

Breast = organ dose from impact; ED60 coef. = DLP x 0.017 (EUR 16262); ${}_{n}CTDI_{air}$ = 15.8; 40 patients

Effective Dose variation with Bismuth shielding for 4 CTA protocols studied



MGD results with Bismuth shielding for 4 CTA protocols studied



Risk of cancer induction

- The theoretical risk of cancer induction using standard protocol with and without 1 breast shield was calculated with respect to:
  - various ages of 1st CTA examination and
  - frequency of follow up CTA's (1, 3 or 5 procedures)*
- The rates of cancer induction were obtained from MGD estimates using an average of the UK breast screening risk model[24] and that of extrapolated NRPB (2003) data.

* Common in the US

Risk estimates for CTA (standard protocol)

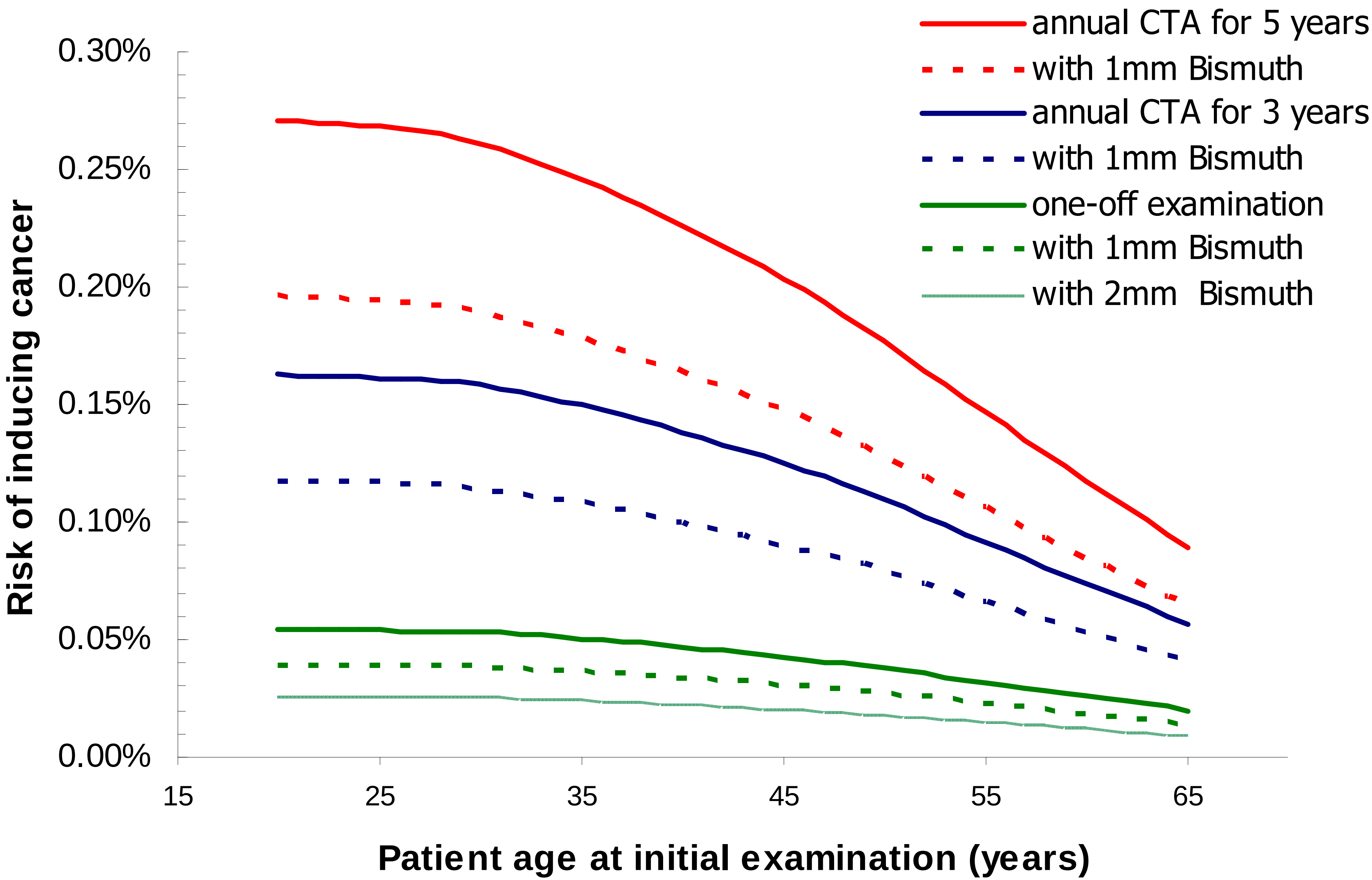


Image quality assessment

- 60 studies (30 with & 30 without shielding) were altered to remove visibility of breast shields and patient details
- 2 readers each with 7 years cardiac CT experience, and blinded to the study protocol, assessed image quality using a 3-point liekart score:
    1. no artefact present
    2. artefact present, but not sufficient to affect diagnosis
    3. artefact was present which would affect diagnosis
- No images had segments reported non-diagnostic with 1 mm Bismuth (correlation between observers 0.92)

Summary & conclusion

- Bismuth breast shields afford substantial MGD reduction for all protocols (ave. 30% for 1mm)
- Reduction in dose, and thus cancer induction risk to the breast, is such that clinicians should consider shields for all female CTA patients
- Bismuth shielding can be used alongside other dose reduction techniques such as ECG dose modulation, prospective ECG gating, and low kV
- No image quality degradation sufficient to affect diagnosis, was found using 1 mm bismuth, in a trial of 60 random patients

Summary & conclusion contd..

- Use of 2 Bismuth sheets not recommended routinely: problematic due to streaking when placed close to chest wall (ok for obese women or large breasts)
- Majority (> 80%) patients triage into standard protocol – further scope for optimisation
- Currently investigating padding to promote more use of prospective axial protocol (affords 55% dose reduction relative to standard)
- mA reduction currently being examined through spatial frequency dependent noise model, watch this space….

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References

1. Ohnesorge B.M et al (2002) *Multi-slice CT in Cardiac Imaging*, Springer, Berlin
2. Windecker S. et al (1999) *Interventional cardiology in Europe.* Eur Heart J 20:484-495
3. Deanfield JE et al (2001) *Coronary Artery disease: from managing risk factors to treating complications*. Clin Cardiol 24 [suppl 1 Int]
4. Escolar E et al (2006) Review: *New Imaging techniques for diagnosing coronary artery disease.* CMAJ 174(4):487-495
5. Bury R (2009) *Indications for Cardiac CT*. RAD Magazine 34(406):31-32
6. Hirai N et al (2008) *Prospective v retrospective ECG gated 64 detector coronary CT angiography….* Radiology 248:424-430
7. Hussmann L et al (2008) *Feasibility of low-dose coronary CT angiography*…. Eur. Heart J 29:191-197
8. Maruyama T et sl (2008) Radiation dose reduction and coronary assessability of ECG gated CTA….. J Am Coll Cardiol 52:1450-1455
9. Shuman WP et al (2008) *Prospective v retrospective ECG gating for 64 detector CT of the coronary arteries….* Radiology 248:431-437
10. Klass et al (2009) *Prospectively gated axial CT coronary angiography…..* Eur Radiol 19:829-836
11. Stolzmann P et al (2008) *Dual source CT in step and shoot mode…..*Radiology 249:71-80

References contd.

11. Scheffel H et al (2008) *Low dose CT coronary angiography in step and shoot mode…..*Heart 94:1132-1137
12. Bischoff B et al (1999) *Impact of reduced tube voltage on CTA and radiation dose.* JACC 2(8):940-946
13. Feuchtner et al (2009) *Radiation dose reduction by using 100kV tube voltage in cardiac 64 slice CT: A comparative study.* Eur J Radiol (in press)
14. Dewey M et al (2008) *Is there a gender difference in noninvasive coronary imaging?* BMC Card Dis 8(2)
15. Hur et al (2007) *Uniform Image quality achieved by tube current modulation using SD of attenuation in CTA*. AJR 189:188-196
16. Hussmann L et al (2009) *Body physique and heart rate variability determine the occurrence of stair-step artefacts in 64 slice CTA with prospective ECG triggering.* Eur Radiol 19:1698-1703
17. Kim S et al (2009) *Dosimetric characterisation of bismuth shields in CT*…. Rad. Pro. Dosim. 133(2):105-110
18. Leswick DA et al (2008) *Thyroid shield versus z-axis automatic tube current modulation for dose reduction of neck CT*. Radiology 249(2):572-580
19. Geleijns J et al (2006) *Quantitative assessment of selective in-plane shielding of tissues in CT through evaluation of absorbed dose and image quality*. Eur Radiol 26:2334-2340

References contd..

20. Mannudeep KK et al (2009) *In-plane shielding for CT: Effect of off-centering, AEC and shield-to-surface distance*. Korean J Radiol 10(2):156-163
21. Hohl C et al (2006) *Radiation dose reduction to breast and thyroid during MDCT….*Acta Radiologica 6:562-567
22. Mukundan S et al (2007) *MOSFET Dosimetry for radiation dose assessment of bismuth shielding of the eye in children.* AJR 188:1648-1650
23. Hopper KD et al (1997) *The Breast: In-plane X-ray protection during diagnostic thoracic CT*….Radiology 205:853-858
24. Review of Radiation Risk in Breast Screening. Report by a joint working party of the NHSBSP National Coordinating Group for Physics Quality Assurance and the National Radiological Protection Board. NHSBSP Publication No 54, February 2003
25. Baverstock K. (2003) *The 2003 NRPB report on UK nuclear-test veterans.* The Lancet 361(9371):1759-1760