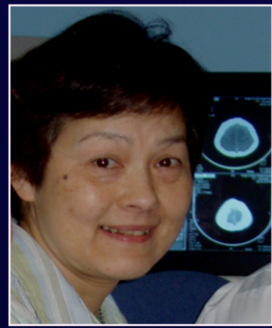


Justification & Optimisation of Chest CT in Children

Dr. Catherine M Owens

Carol Young

On behalf of GOSH/ ESR/ESPR

June 2011

Background Radiation Exposure

Natural background exposure

- Radon & thorium accounts for largest natural source of radiation exposure far ahead of cosmic and internal radiation
- UK 2.7mSv/y, Germany 4mSv/y
- Chernobyl & Fukushima

Biological Impact of Radiation Exposure

- No clear evidence of cancer risk in dose range used in diagnostic radiology
- Risk increased proportionally with repeated exams
- Cancer will develop in 5% population with exposure of 1Gy – risk higher in children
- Reduced to 2-3% at 60-70 years (western Europe)
- Majority of diagnostic examination will never reach threshold for deterministic effect (e.g. skin burn)
- Long period of fluoroscopy-based angiography and interventional treatment may reach 3Gy threshold

Medical Effective Dose in Europe

- Low

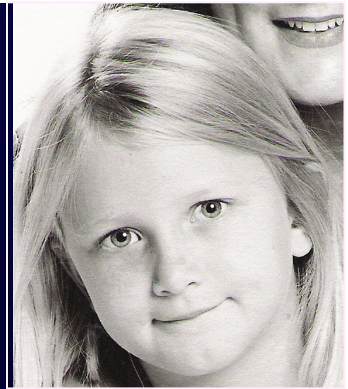
  0.4 - 0.75mSv/y - UK, Netherlands, Sweden

- Intermediate

  1.1mSv/y - Norway, Switzerland

- High

  1.8 - 2mSv/y - Luxemburg, Belgium, Germany



FDA Public Health Notification

The risks from ionising radiation greater in paediatric population than in adults

- Tissues more radiosensitive
- Prospects of longer life so more likely to develop asociated problems

USA TODAY Jan 22, 2001

CT scans in children linked to cancer

By Steve Sternberg, USA TODAY

Each year, about 1.6 million children in the USA get CT scans to the head and abdomen — and about 1,500 of those will die later in life of radiation-induced cancer, according to research out today.

What's more, CT or computed tomography scans given to kids are typically calibrated for adults, so children absorb two to six times the radiation needed to produce clear images , a second study shows. These doses are "way bigger than the sorts of doses that people at Three Mile Island were getting," David Brenner of Columbia University says. "Most people got a tenth or a hundredth of the dose of a CT."

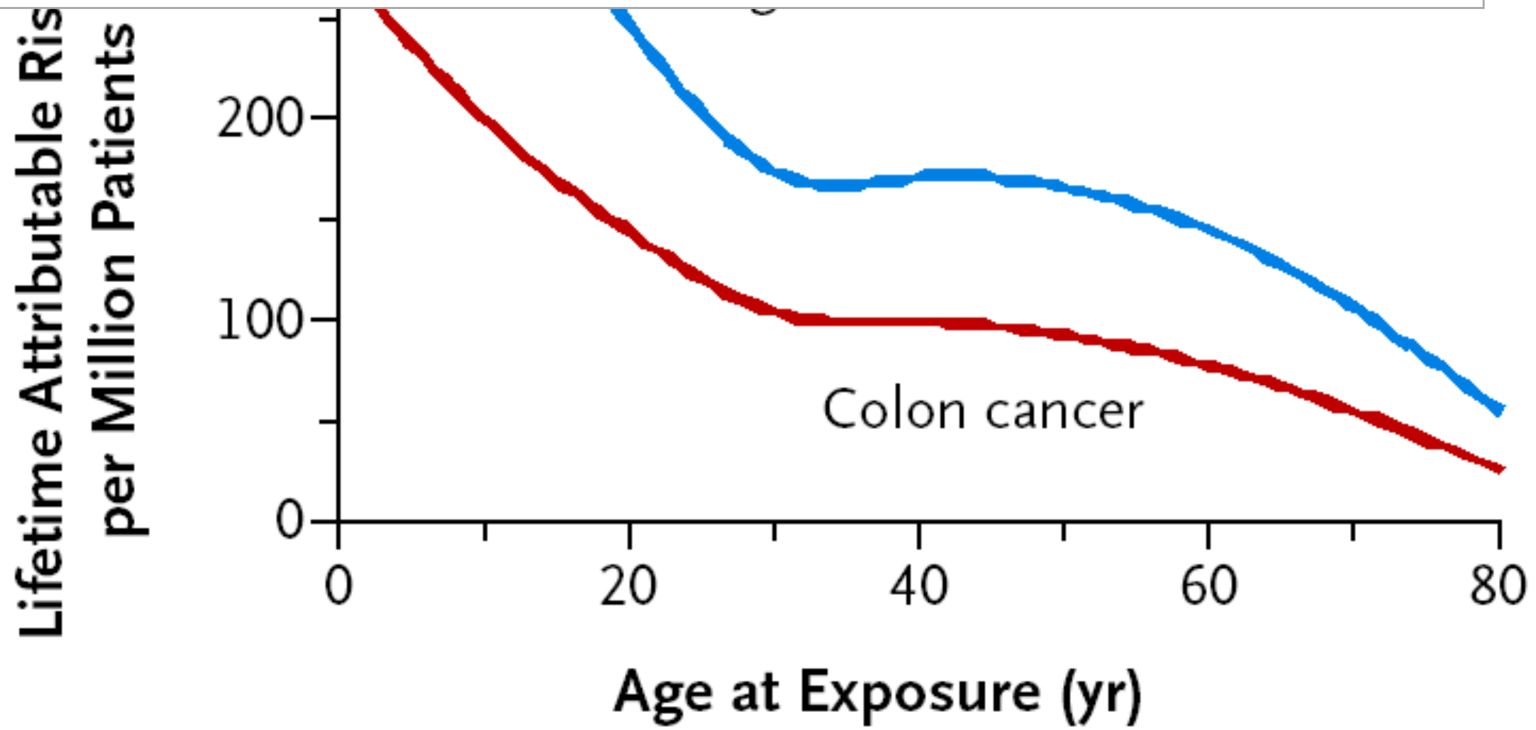
The NEW ENGLAND JOURNAL of MEDICINE

REVIEW ARTICLE

CURRENT CONCEPTS

Computed Tomography — An Increasing Source of Radiation Exposure

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc.



Effective Dose in frequent X-ray investigations (5 year old)

Examination	Effective dose (mSv)
Chest ap/pa	0,01
Abdomen ap	0,1
Barium meal	0,7
MCU	1,0
CT Abdomen	10,0

Legislations

- EU-directive 97/43/Euratom NB Revision Simeonov 2011
  - Justification & Optimisation
  - Patient Dose Monitoring
  - Diagnostic Reference Level

- Ionising Radiation (Medical Exposure) Regulations 2000 - IRMER

- ESR – White Paper on Radiation Protection 2011 (in press)

ESR Directive

- Promote *education & training* of all medical staff involved with justification & optimisation of imaging examinations
- Establish imaging referral guidelines to ensure appropriate *justification* for imaging
- Create SOP and DRLs for specific exams as important tool in *optimisation*
- *Disseminate information* with regards to radiation protection to all European countries

Medical Exposure - Professional

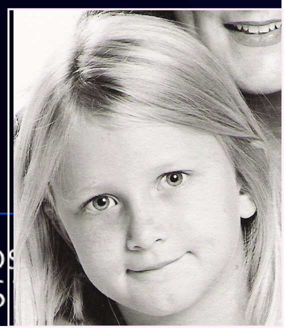
- Radiologist achieving lowest patient dose receive lowest professional dose (applicable to fluoroscopic intervention)
- General rule :
  - Short fluoroscopy time/ Pulsed fluoroscopy
  - Low number of high quality exposures
  - Optimal parameter selection
- Knowledge of specific equipment :
  - Best position for workers inside the room
  - Optimally modify technical parameters and effects on exposure
- Use of protective devices to minimise dose to critical organs :
  - Body trunk
  - Thyroid gland
  - Eye lens
  - Hands (dependent on time of direct exposure)

Diagnostic Reference Levels

(National & Local Levels)

Diagnostic Reference Levels (DRL)

- Established for country with relative homogenous level of healthcare
- Benchmark (75th percentile of patient population)
- Not to be exceeded in patients of average body size rather than absolute threshold for individual exposure
- Exceptions – obese or complex procedures
- Collectively, mean exposure within DRL limits
- Separate DRL levels for children



Stochastic Effects, DRL for CT (EMAN data)

	UK	Germany	Belarus	Switzerland	EUR
Author	NRPB 67	BfS	Kharuzhyk	FOPH	MSCT
Year	2005	2010	2010	2010	2004
	CTDIvol/DLP	CTDIvol/DLP	CTDIvol/DLP	CTDIvol/DLP	CTDIvol/DLP
Brain	65-55 / 930	65 / 950	60 / 730	65 / 1000	60 / 337
Chest	13-14 / 580	12 / 400	20 / 500	15 / 450	10 / 267
Abdomen	14 / 470	20 / 900	25 / 600	15 / 650	25 / 724
Pelvis	14 / -	20 / 450	25 / 490	15 / 650	--

Justification

benefit must outweigh risk ie all necessary information acquired at lowest possible dose

Justification in Medicine

- Critical step in medical radiation protection
- Create awareness of impact on radiation exposure based on understanding of potential biological impact of the x-ray exam
- Use of alternative diagnostic tools e.g. US or MRI
- Justification must be evidence-based from scientific studies
- Use of established guidelines:
  - RCR UK – 'Making the best use of Clinical Radiology Services'
  - ACR USA - 'ACR Appropriateness Criteria'
- ESR establishing database with WHO and IRQN

Radiation Risks in CT Clinical Practice

- CT constitute 5% of radiological examinations worldwide but contributes 34% of the collective dose (UN scientific commission 2000)
- Stochastic Effects may result in cancer to the individual and genetic effects in their offspring
- Probability depends on the absorbed dose
- Lifetime mortality risk attributable to CT exposure in 1 year old* is - 0.18% for abdominal scan

  - 0.07% for head scan

* Brenner 2001

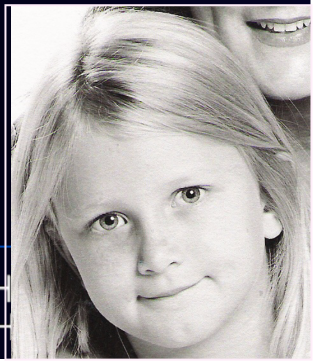
ALARA

Optimisation

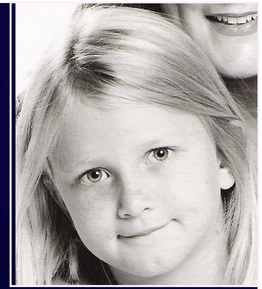
benefit must outweigh risk ie all necessary information acquired at lowest possible dose

Optimisation – Why?

- Adult scanning parameters often used in paediatric imaging
- Unlike plain films, CT images never look over-exposed
- Easy to over-irradiate younger children
- Children receive higher effective dose due to distribution of absorbed energy over smaller area and organs
- Lack of adequate guidelines/protocols from manufacturer
- Dealing with wide age and weight range in patient groups
- 'EXPORT' quality images unnecessary
- Images should be 'fit for diagnostic purposes'



Our quest CT at Great Ormond Street



- Optimise & establish CT imaging guidelines/protocols
- Define & maintain acceptable image quality threshold using minimum radiation exposure
- Set national / international standards
- Share data and protocols/guidelines
- Collaborate with CQC and HPA and YOU!

Optimisation – How? ALARA

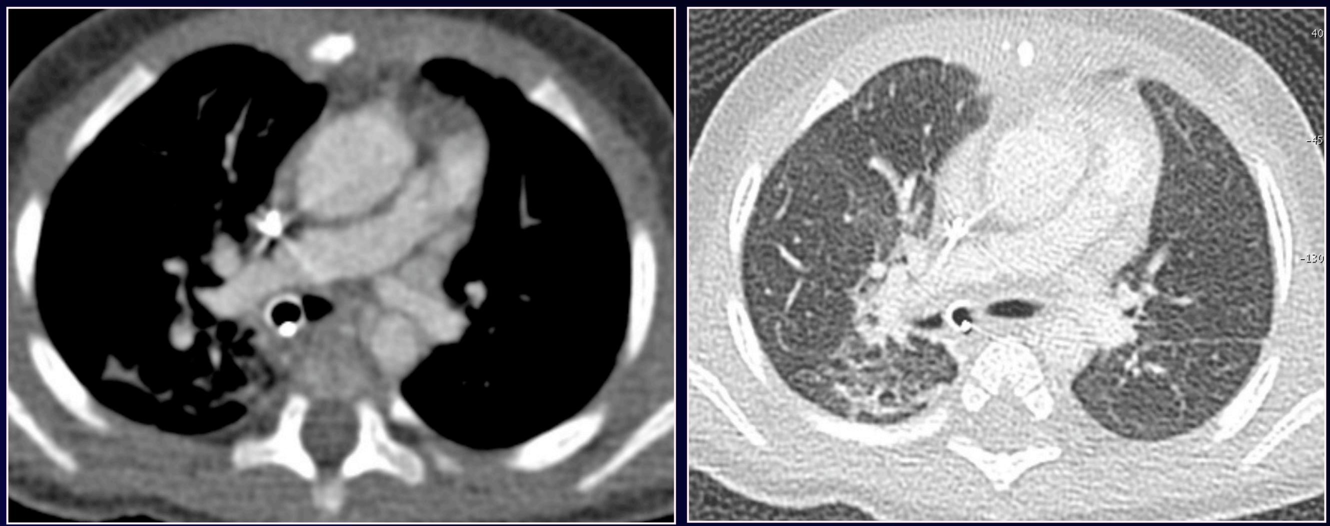
- Follow the ALARA principle
- Establish own paediatric weight-based or diameter-based scanning protocols
- Limit coverage to area under investigation only
- Reduce kVp (80 - 100)
- Apply dose modulation
- Ensure patient in the isocenter – optimal dose & image quality
- Prospective ECG-gated cardiac imaging provides similar radiation burden as non-gated studies but improved image sharpness

Optimisation – kV reduction

100kV vs 80kV

100kV, 90mAs$_{ref}$
CTDIvol 2.1mGy
Eff dose = 1.8mSv

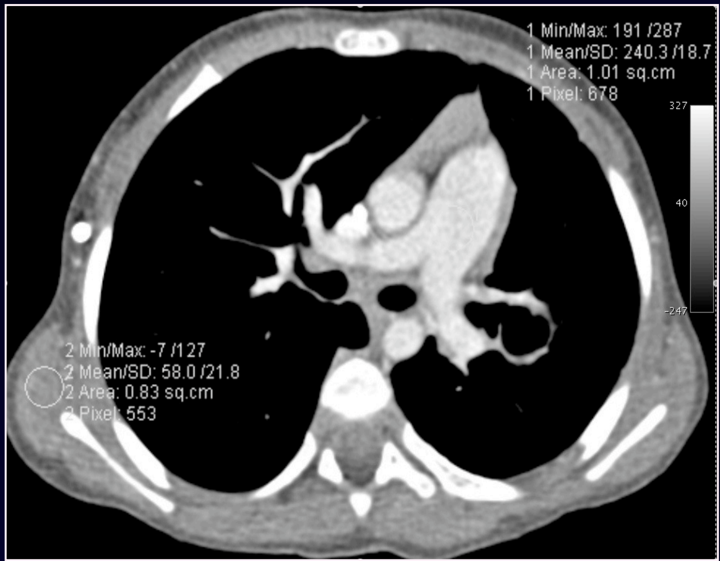
57% dose reduction



80kV, 60mAs$_{ref}$
CTDIvol 0.68mGy
Eff dose = 0.76mSv

6 month old

Optimisation - mAs Reduction

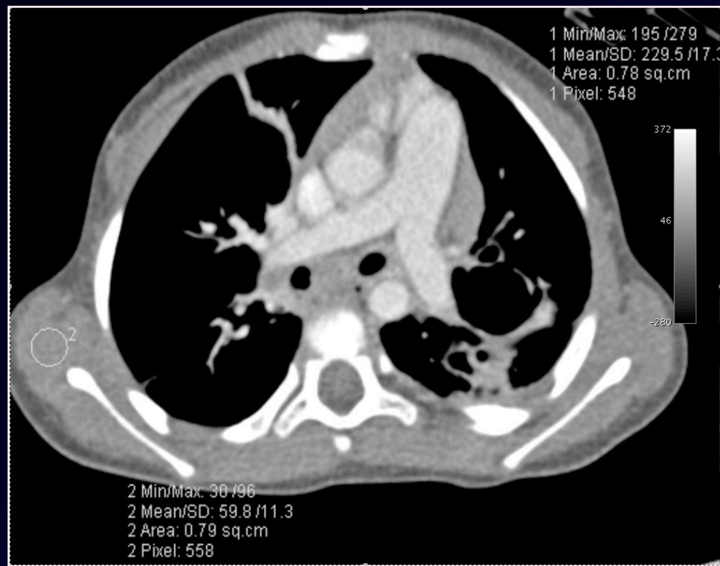


$50mAs_{ref}$ vs $35mAs_{ref}$
2.5yrs female

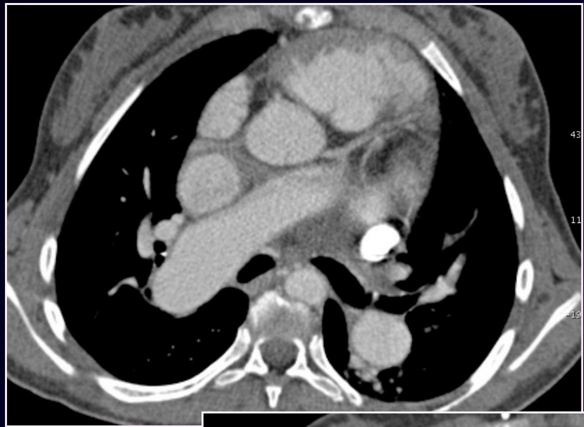
100 kV
35 ref. mAs
35 eff. mAs
1.56 mSv
Image noise
SD 21.8 (soft tissue)
SD 18.7 (contrast)

47%
dose reduction

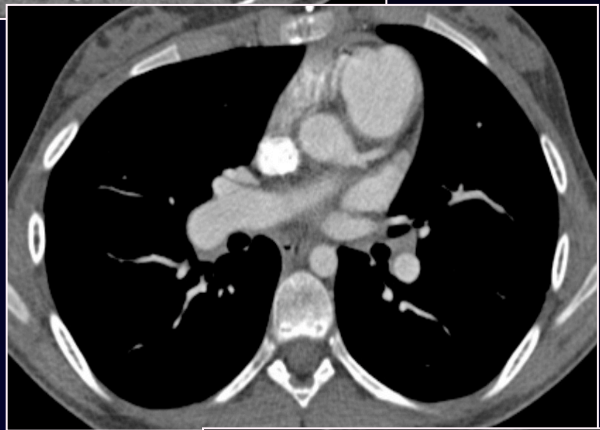
100 kV
50 ref. mAs
53 eff.mAs
2.3 mSv
Image noise:
SD 11.3 (soft tissue)
SD 17.3 (contrast)



Optimisation - mAs Reduction

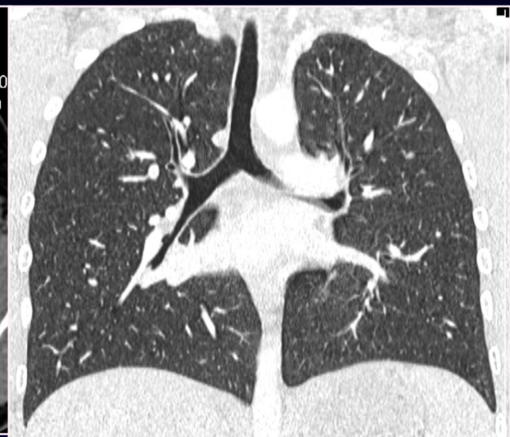


14 year old
$150mAs_{ref}$
CTDIvol = 8.2mGy
Eff dose = 6.9mSv



13 year old
$70mAs_{ref}$
CTDIvol = 4.1mGy
Eff dose = 4.4mSv

49%
dose reduction



11 year old
$60mAs_{ref}$
CTDIvol = 5.44mGy
Eff dose = 3.5mSv

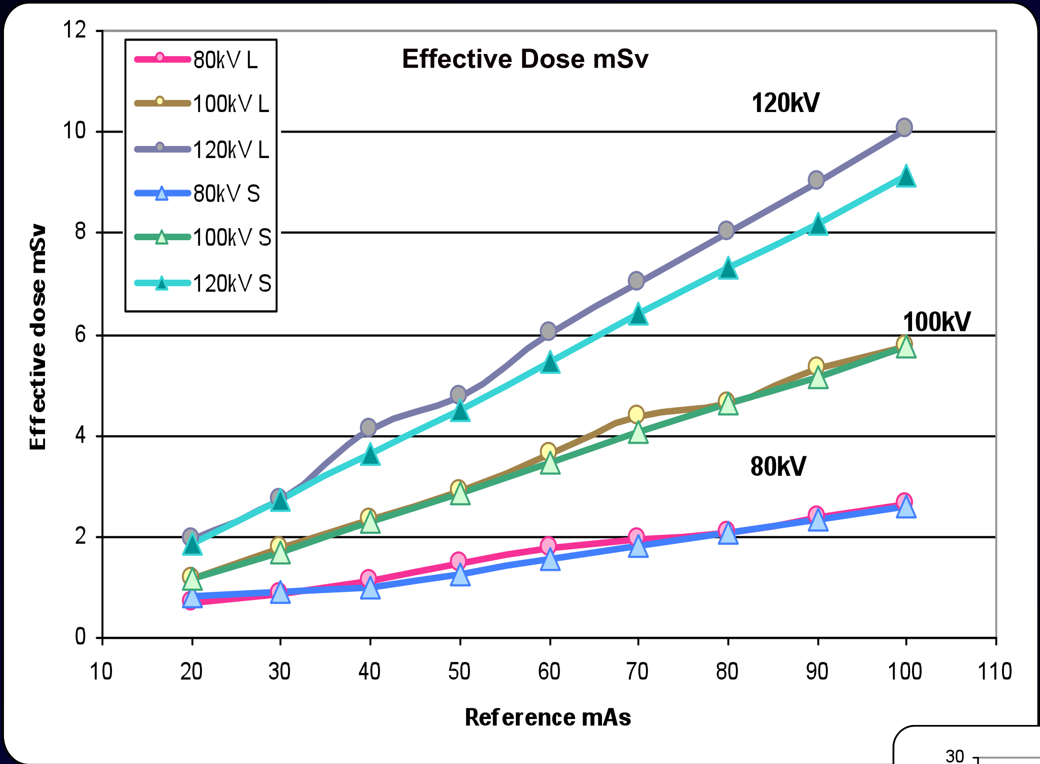
Great Ormond Street Hospital
for Children NHS Trust

Optimisation - Thin Tube Collimation (0.6mm)

- Isotropic data
- Increase spatial resolution
- But increase image noise so either increase mAs to compensate or reconstruct thick slices, use of MPR post processing to view data
- Spiral acquisition requires additional coverage of one detector width for ‘run-up’ & ‘run-down’
- 1.2mm collimation increase dose by 12%

Optimisation – 4D Dose Modulation

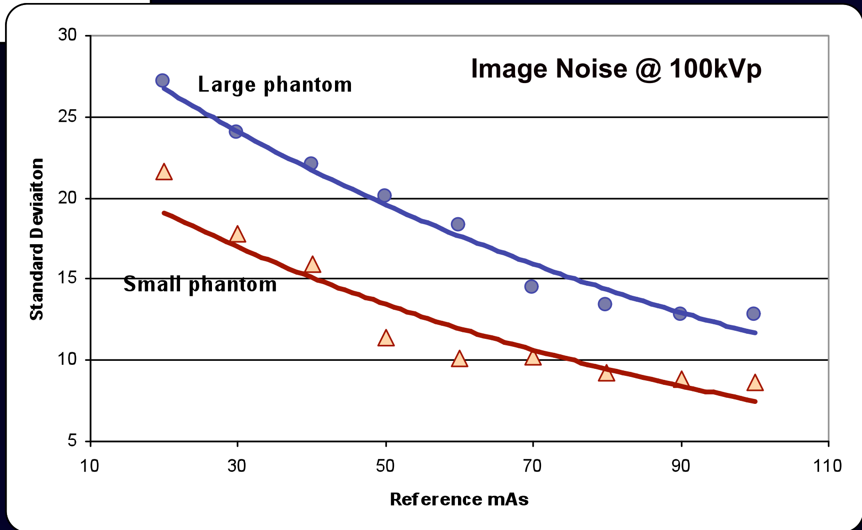
- Real time adaptation of tube current determined by:
  a) Patient size
  b) Attenuation of the patient long axis
  c) Angular attenuation for each tube rotation
- Consistent & optimal image quality throughout study
- mAs may increase to achieve set image noise level (shoulders & below diaphragm)
- If DM is OFF, 45% dose reduction is achieved (at same mAs values), but image noise increased by 26%, i.e. the mAs need to be increased



Phantom study

No significant difference noted in the effective dose between different size phantoms at 3kVp range

Significant improvement in image noise noted in the small phantom at same kVp level



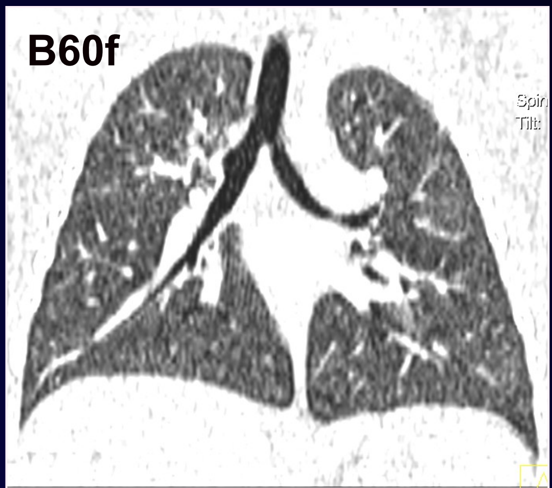
Exposure can/should be reduced in smaller children

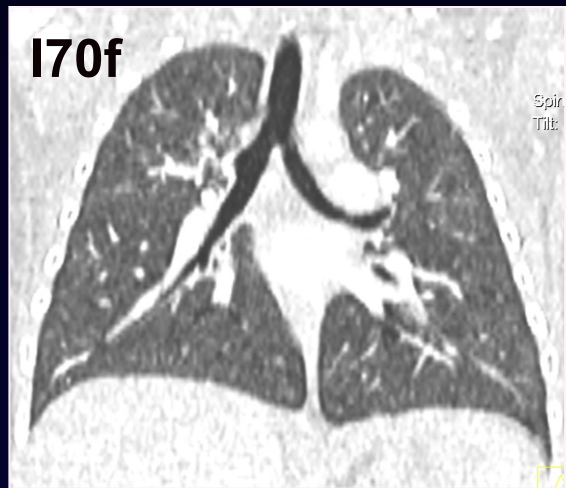
Effects of tube current & ECG dose modulation

	kVp	mAs/ rot	Eff mAs	Dose Mod	ECG	CTDI	% reduction	
<15kg	80	-----	150	no	no	8.62	51%	62%
		-----	150	no	yes	4.16		
		150	60	yes	no	3.48	6%	
		150	57	yes	yes	3.27		
<35kg	100	-----	136	no	no	17.30	62%	78%
		-----	136	no	yes	6.53		
		136	56	yes	no	7.29	47%	
		136	30	yes	yes	3.85		

Optimisation - Iterative Reconstruction

- Widely available on new scanners
- Enhance spatial resolution at high object contrast
- Reduce image noise in low contrast areas
- Enable use of lower exposure factors. Reported dose reduction of 27% - Chest CT, 25% - Abdominal CT





'IRIS' software
(Siemens Healthcare)

7 month old female

SCID

Image Noise
= 17SD

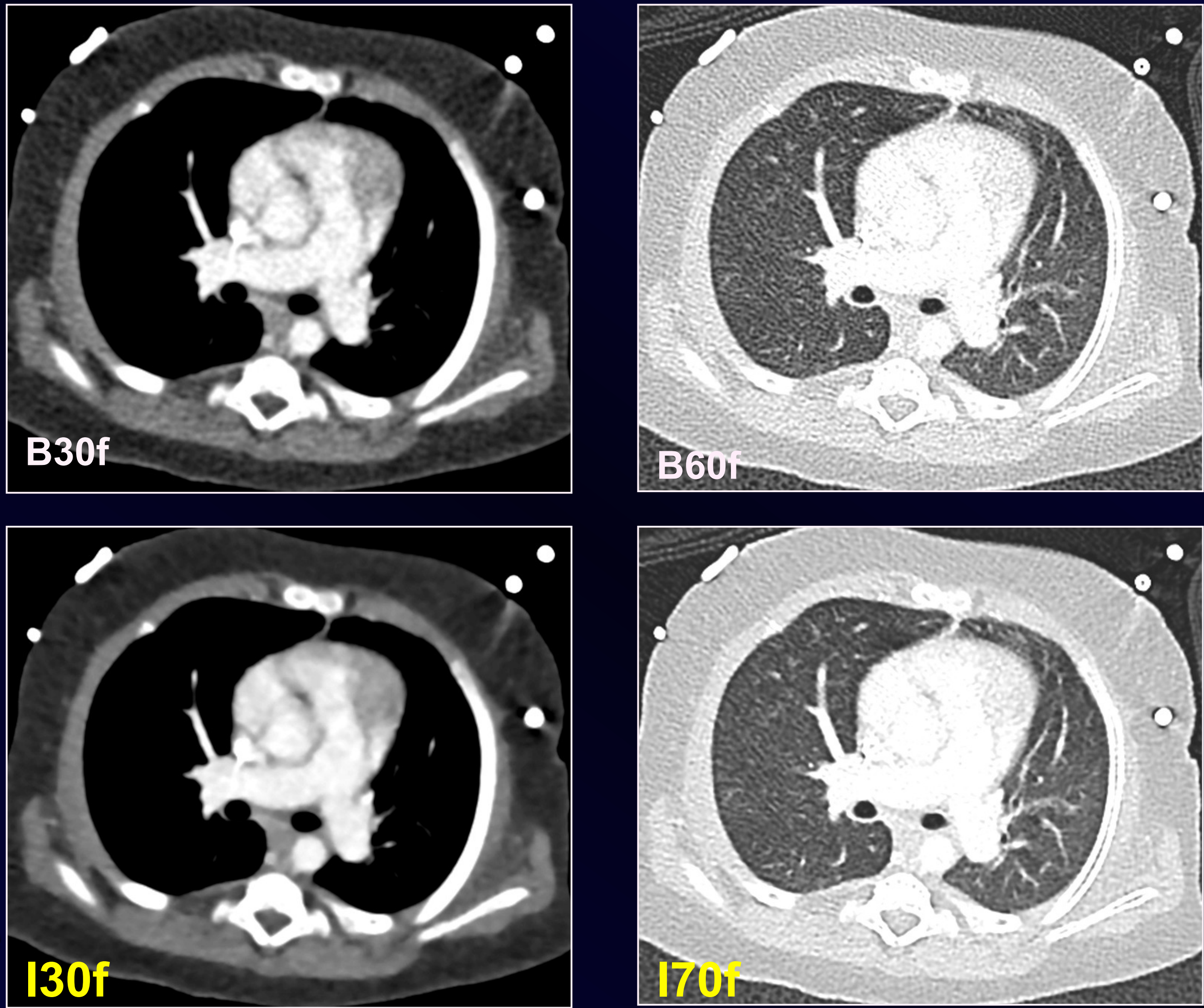


Image Noise
= 10SD

41% image noise reduction achieved at same parameters

Great Ormond Street Hospital
for Children NHS Trust

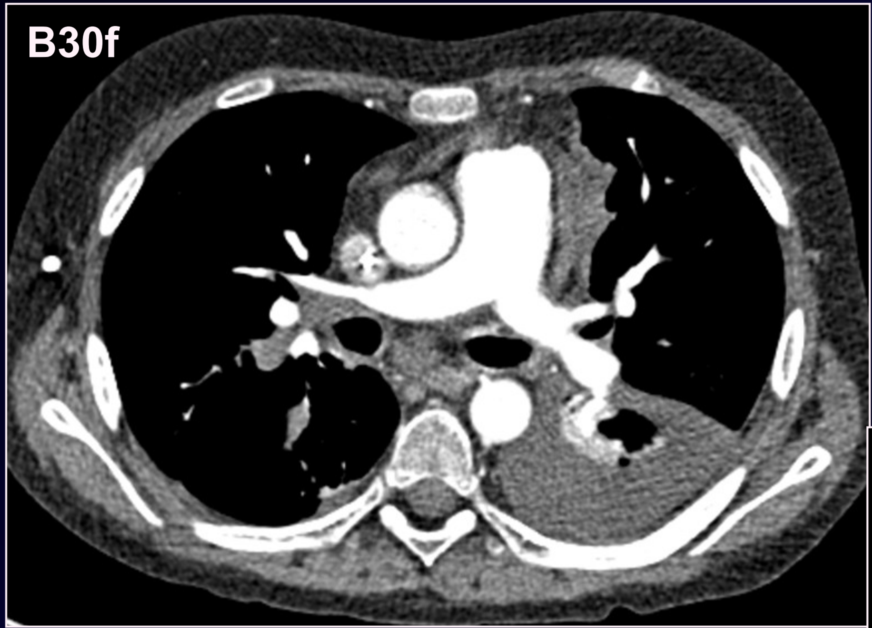


Image Noise = 24SD

11yr old male

L sided pleural effusion

Mediastinal adenopathy &

R hilar soft tissue mass

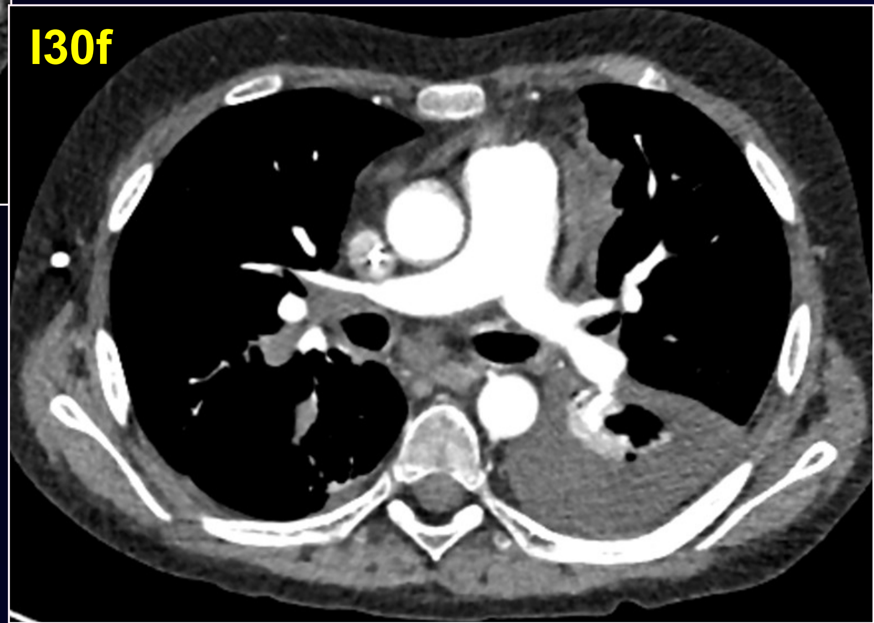


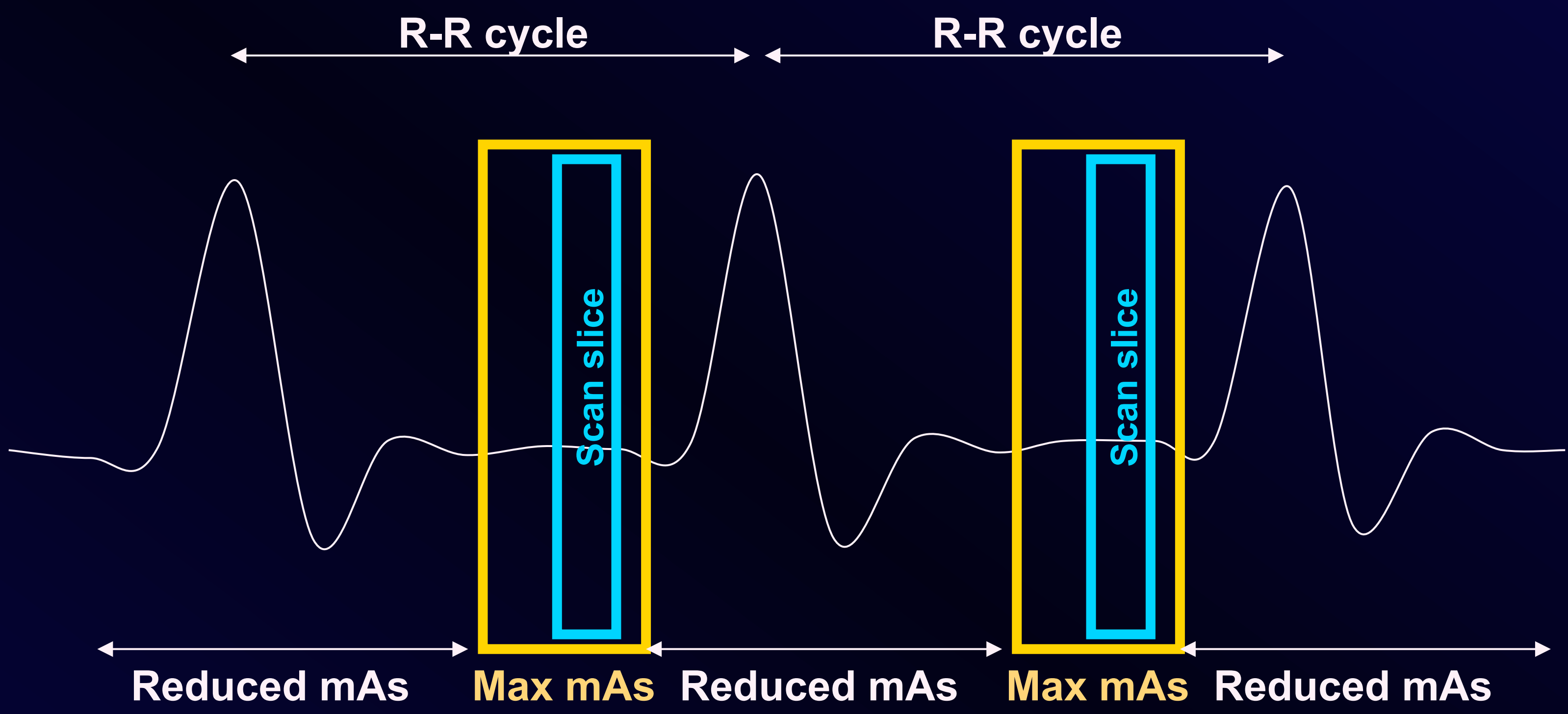
Image Noise = 15SD

Optimisation - Cardiac Imaging
ECG Gated vs Non-Gated

Non-gated	Retrospective gating	Prospective gating
• low radiation burden	• high radiation burden	• similar to non-gated study
• no additional radiation reduction	• radiation reduced during systolic phase	• radiation on in diastolic phase only
• image sharpness poor	• improved image sharpness	• improved image sharpness
• fast scan time	• scan time dependent on heart rate	• prolonged scan time
• used if child is restless	• possibility of mis-triggering	• susceptible to breathing artifact

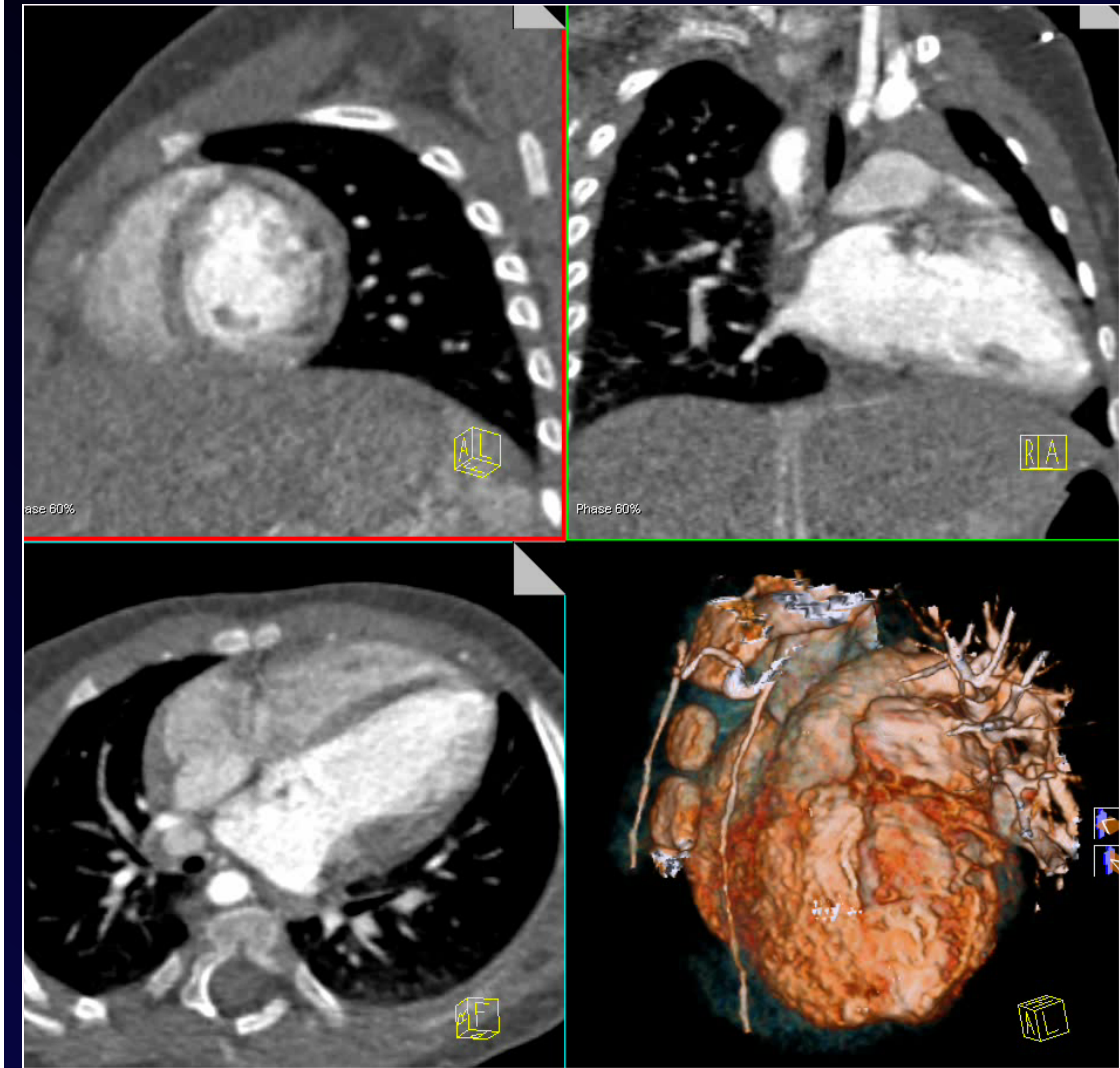
Retrospective Gating	Prospective Gating
Spiral acquisition	Sequence acquisition
Diastolic & Systolic phase	Diastolic phase only
Recon 10-100% phase	% phase set at scan start
Adjusted for arrhythmias	Not suitable irregular HB
Functional data	Static image
Fast acquisition time	Slow scan time- scan every 2nd or 3rd heart beat
High radiation burden	Reduced radiation burden

Retrospective ECG-Triggered Dose Modulation



Reduces mAs coverage
- ‘auto’ mode = 25% dose
- ‘min dose’ mode = 4% dose

Max mAs coverage dependent on heart rate
60 – 70% for <60bpm
30 – 80% for >80bpm



Retrospective study with ECG-triggered dose modulation

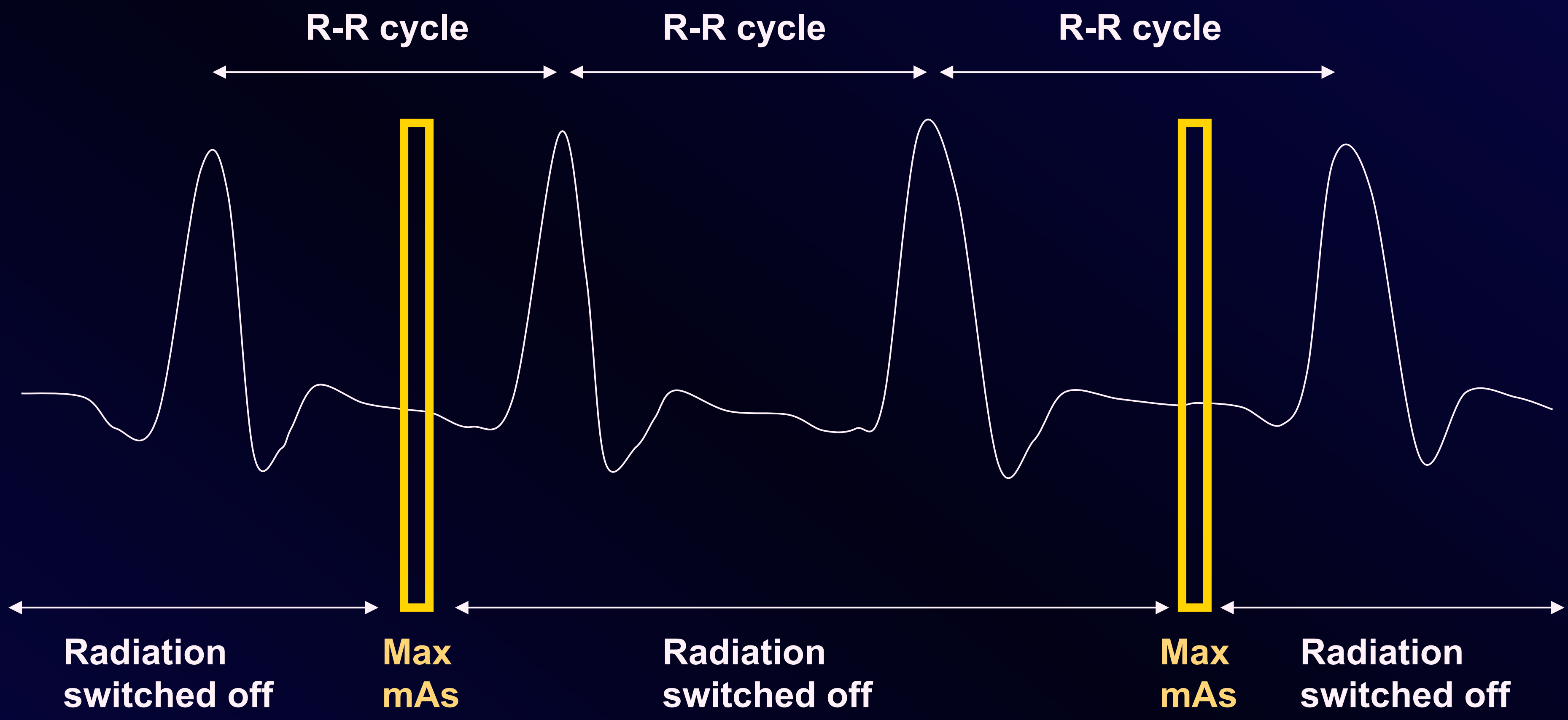
- **Note difference in image quality between diastolic & systolic phase**
- **Diastolic = max dose**
- **Systolic = 4% dose**

1yr old 10kg male

CTDIvol = 1.52mGy

Eff dose = 1.2mSv

Prospective ECG-Triggered Dose modulation



<65bpm - scan triggered every cardiac cycle

<100bpm - scan triggered every alternate cardiac cycle

>100bpm - scan triggered every 3rd cardiac cycle

Non – Gated

3month old, 6.2kg
CTDIvol = 0.68mGy
Eff dose = 0.76mSv

VS

ECG - Gated

Retrospective
2month old, 3.5kg
HR 130BMP
CTDIvol = 2.65mGy
Eff dose = 2.7mSv

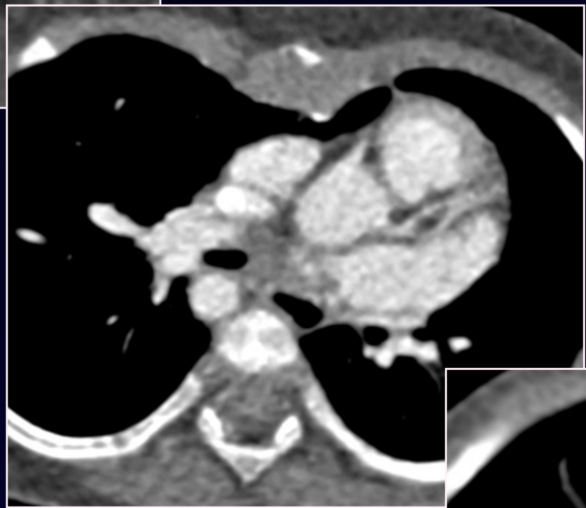
74% dose reduction

Prospective
I year old, 8.4kg
HR 114 BPM
CTDIvol = 0.92mGy
Eff dose = 0.7mSv

Retrospective gating
6mth old, HR104bpm
CTDIvol = 2.24mGy
Eff dose = 1.9mSv

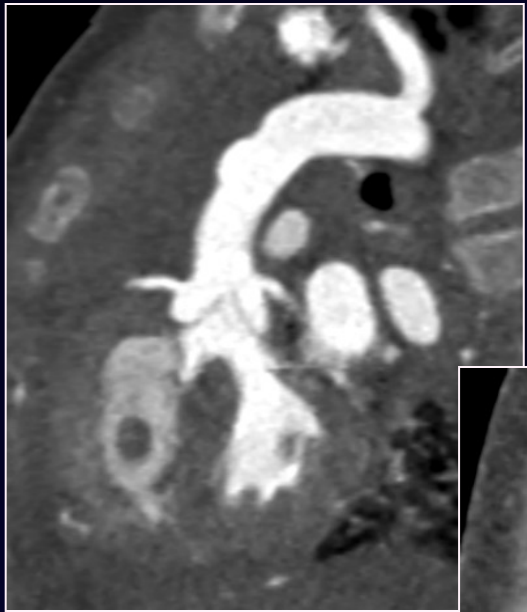
ECG-gated study shows

- **clear anatomical definition of aortic root**
- **Improved image sharpness**



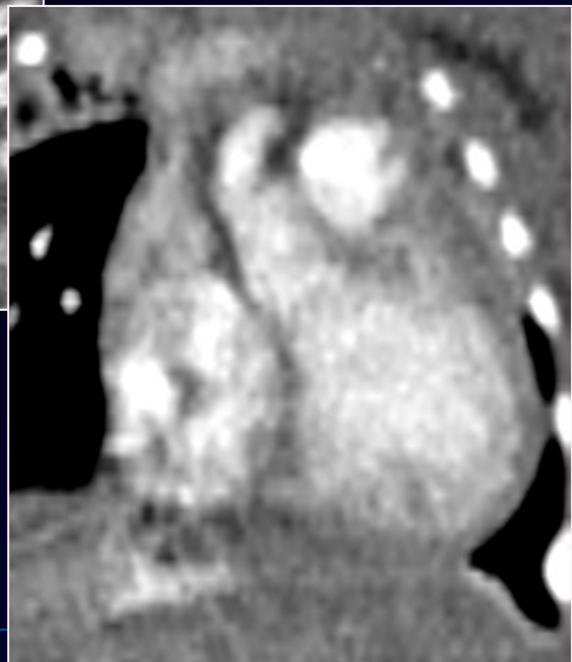
Prospective gating
1 year old, HR144bmp
CTDIvol = 0.92mGy
Eff dose = 0.69mSv

Non-gated study
6mth old
CTDIvol = 0.62mGy
Eff dose = 0.54mSv



Retrospective ECG-gated

Prospective ECG-gated



Non-gated

Radiation Dose in Chest Imaging

	Chest	CTA Non-gated	Cardiac ECG-Gating Retrospective	Cardiac ECG-Gating Prospective
Under 7kg	80kV 60mAs		80kV 80mAs	80kV 62mAs
CTDIvol mGy	0.8 ±0.1	0.8 ±0.1	2.4 ±0.1	0.7 ±0.01
Effective Dose mSv	0.6 ±0.1	0.7 ±0.3	2.1 ±0.4	0.5 ±0.08
Under 15kg	100kV 30mAs	80kV 60mAs	80kV 150mAs	80kV 112mAs
CTDIvol mGy	1.1 ±0.3	0.9 ±0.2	1.4 ±0.4	0.6 ±0.1
Effective Dose mSv	1.0 ±0.3	0.9 ±0.3	1.3 ±0.5	0.4 ±0.1
Under 35kg	100kV 45mAs	100kV 45mAs	100kV 136mAs	100kV 132mAs
CTDIvol mGy	2.2 ±0.7	2.3 ±0.9	4.4 ±1.5	2.8 ± 1.6
Effective Dose mSv	1.6 ±0.5	1.9 ±0.6	2.6 ±0.9	1.3 ± 0.5

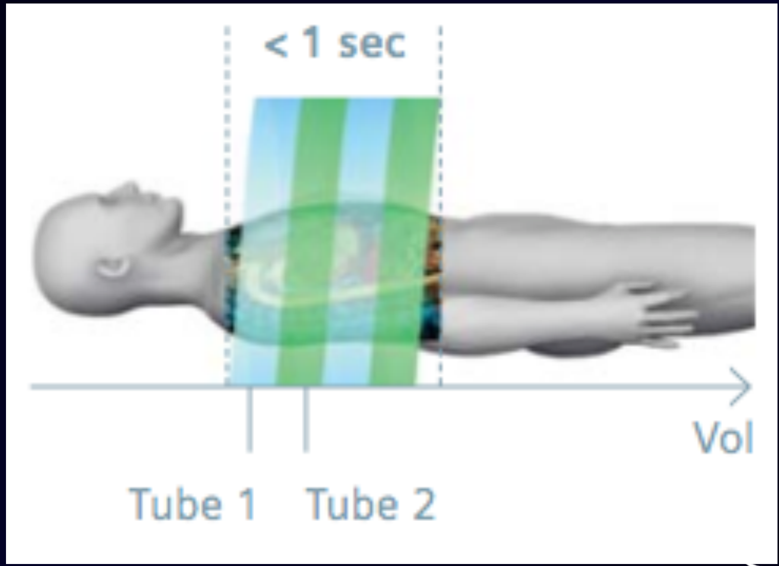
New Generation of Dual-Source CT Technology - dose saving features

1st generation DSCT

- Both tubes used in cardiac & DE imaging (acts as single tube)
- 19.2mm coverage (0.6 collimation)
- 0.33sec tube rotation
- 83ms temporal resolution
- Cardiac requires overlapping slices

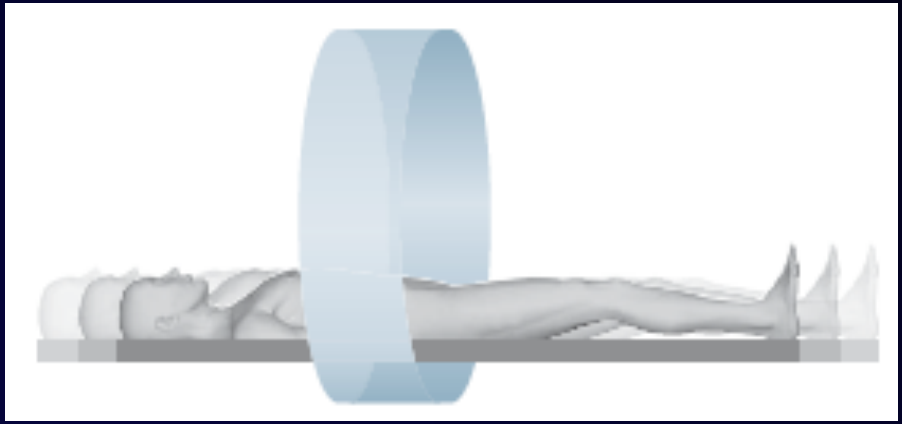
2nd generation DSCT

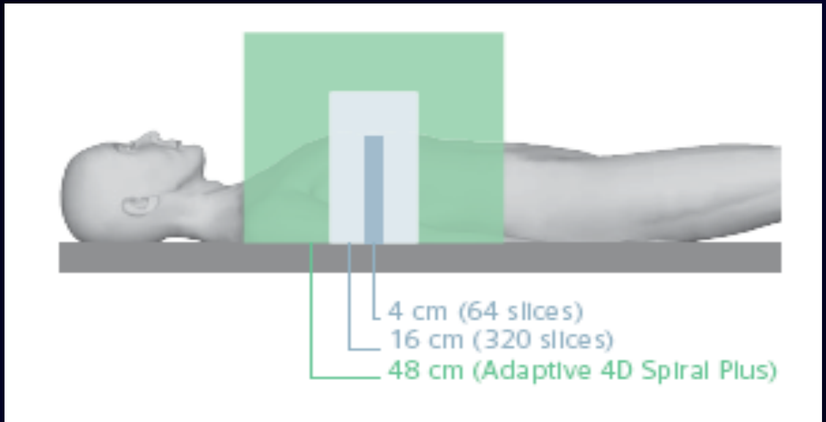
- Utilises both tubes simultaneously for routine scanning
- 38.4mm coverage (0.6 collimation)
- 0.28sec tube rotation
- 75ms temporal resolution
- Entire heart in 1 cardiac cycle



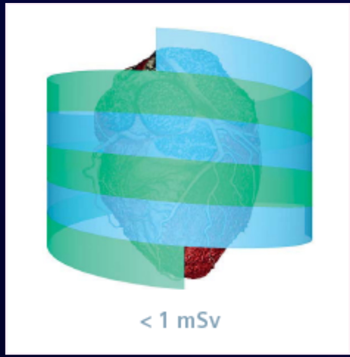
Adaptive 4D spiral

- Bi-directional table movement allows up to 48cm coverage
- Enables dynamic imaging e.g.
  - Stroke assessment of the whole brain
  - Perfusion study of entire organ
  - Myocardium perfusion
- Capture arterial and venous phase in single scan



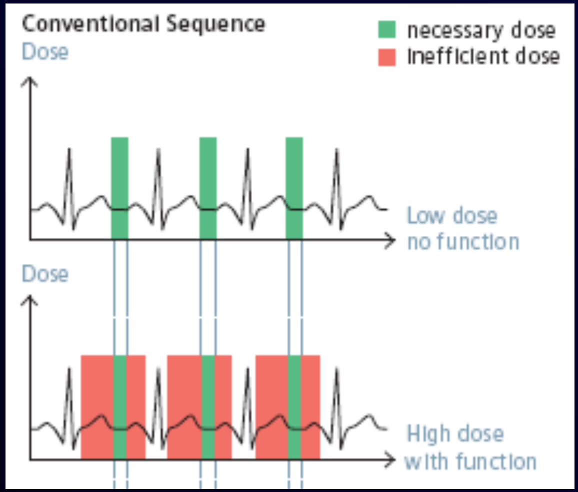


Flash Spiral Sequence



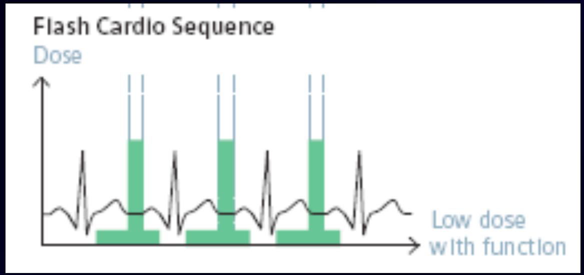
- Collect data projections in 250ms within single diastolic phase

Flash Cardio Sequence



- Dual-step pulsing maintains low dose during systolic phase - functional evaluation
- Reacts to arrythmia – stops scanning until HR normal

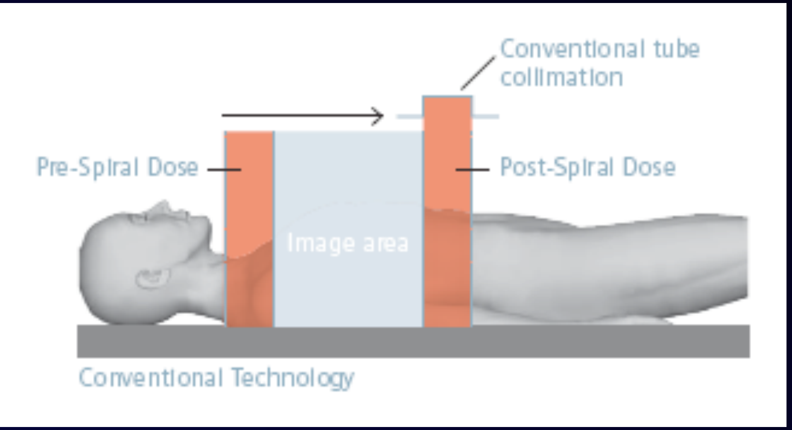
Dual-Energy Flash Cardio

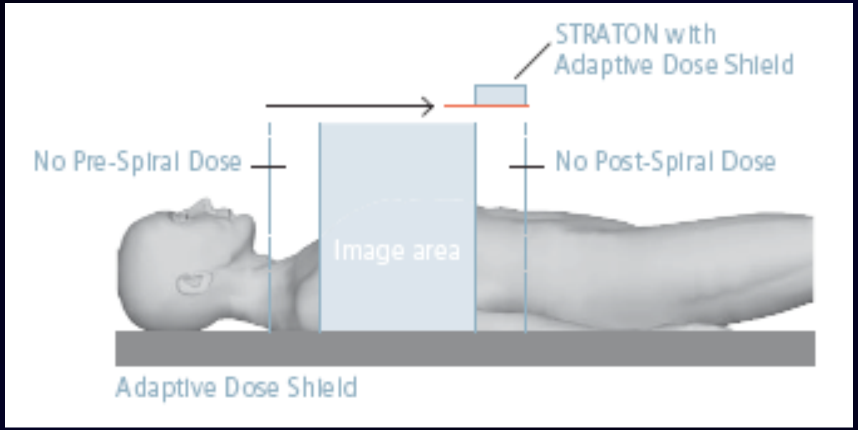


- Intra-cardiac imaging together with perfusion data in a single scan

Adaptive Dose Shield

- Spiral imaging require a 'run-up' and 'run-down' extra coverage - usually 1 detector length
- Additional collimation blades dynamically shields irrelevant radiation
- 25% dose saving

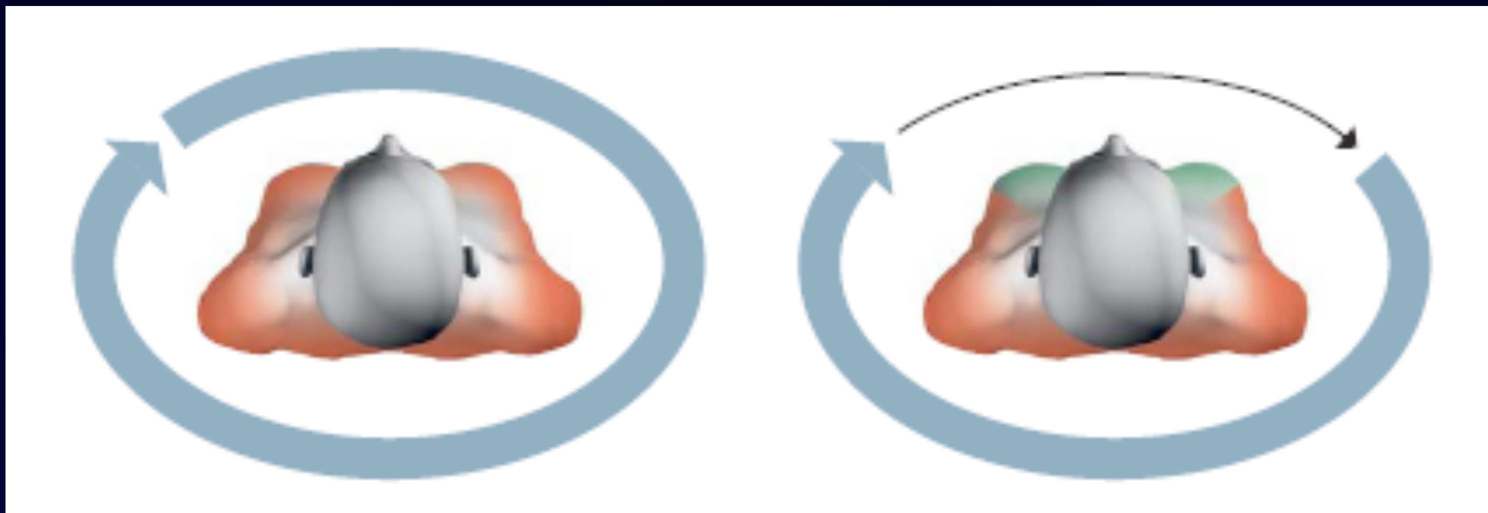




X-Care

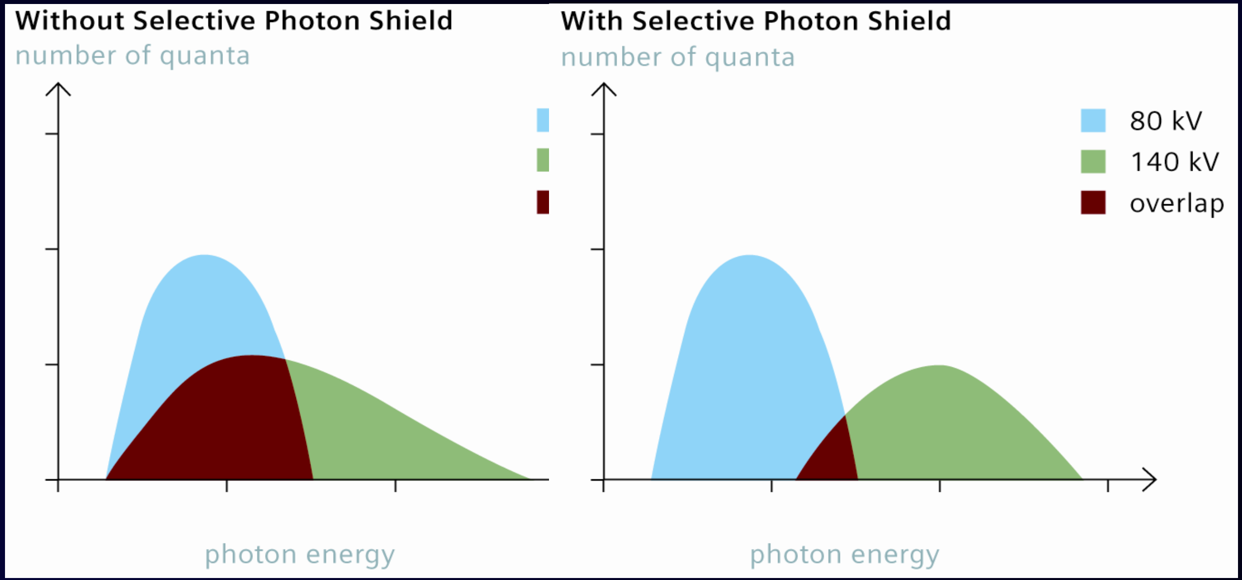
- Radiation is switched off during tube rotation through dose - sensitive organs
- eyes and thyroid in head imaging,
- breast tissue in chest imaging (40% reduction)

Conventional Imaging | X-Ray switched off



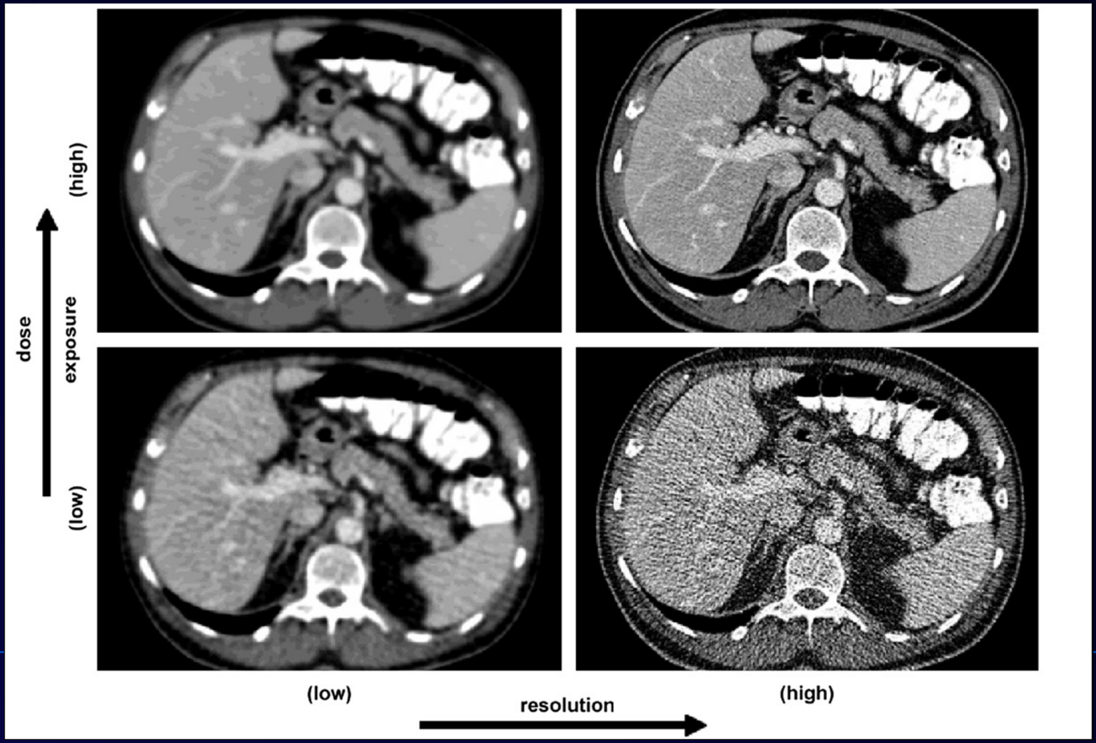
'Selective Photon Shield' in Dual-Energy application

- Increases dose efficiency
- low-energy photon in the high-energy spectrum is filtered out
- Enhance separation of attenuation between 2 x-ray source
- Increase bone-iodine differentiation
- Dose reduced to standard 120kVp scan



Dose Tutor (software) - VAMP GmbH, Erlangen, Germany

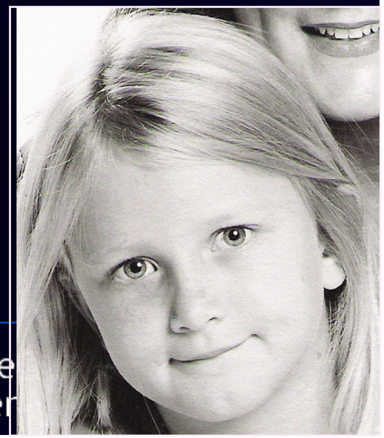
- Simulation software allow retrospective modification of mAs values and spatial resolution to image data set
- Mimic images that is equivalent to those that will be obtained at the respective settings
- Enable user to determine optimal noise level & resolution for given diagnostic task to set imaging protocol



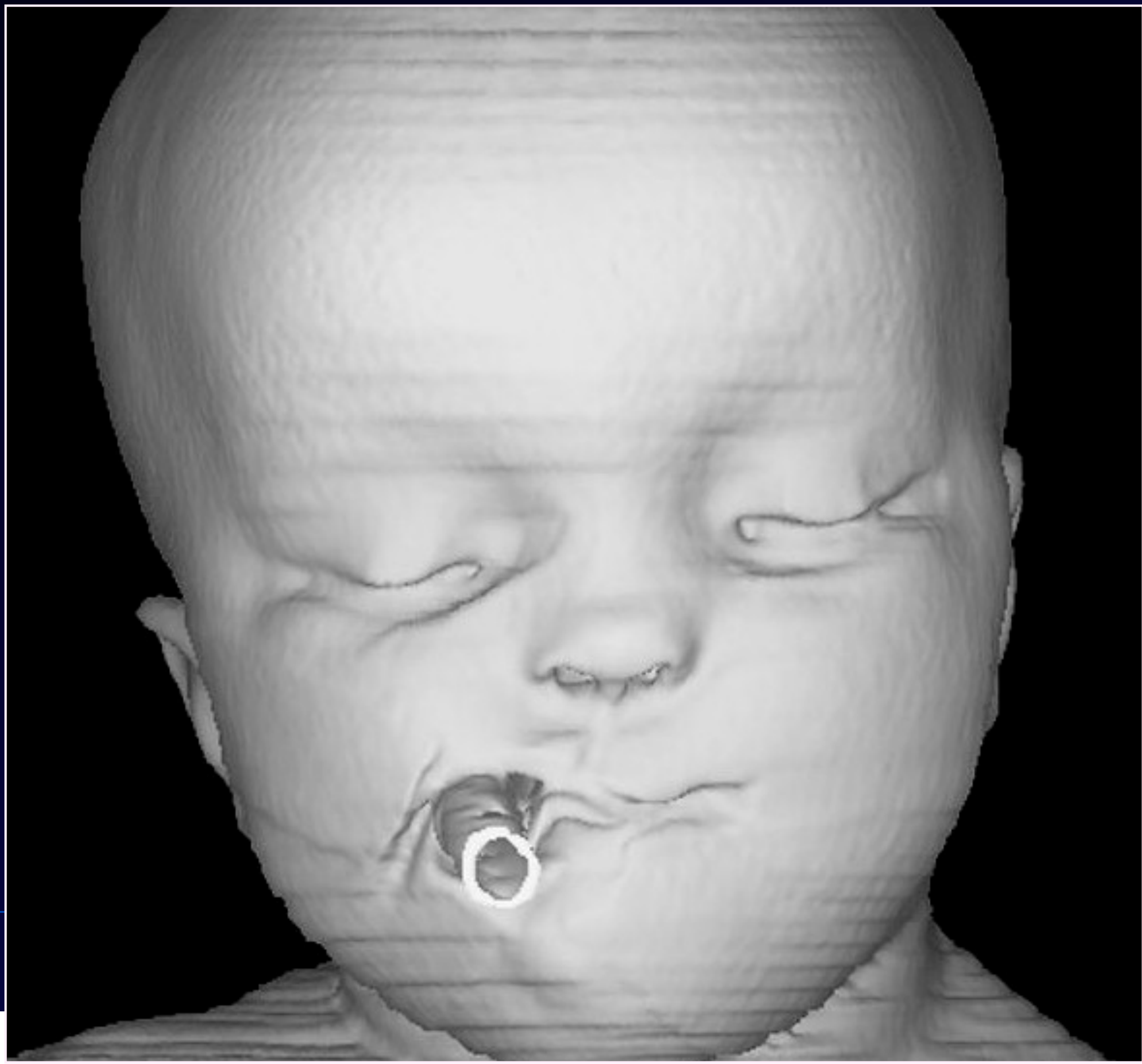
Kalender
Technical approaches to optimisation of CT
Physica Medica 2008 24, 71 - 79

Conclusion

- Important biological impacts of ionising radiation
- ALARA principle must be applied to all patients
- Compulsory radiation protection education & training is prerequisite in clinical radiology
- Manufacturers need to be accountable and lobbied by all of us
- Special caution imaging children and potentially pregnant women as young tissue is biologically more radiation sensitive
- 'Let's work together….' Roxy Music circa 1972



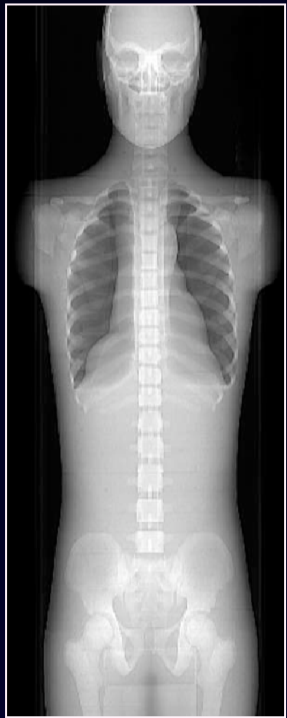
Lets work together to image INTELLIgently!



Tools that will aid research into radiation dose reduction

Anthropomorphic Phantoms

- Includes bone, lung & soft tissue
- Simulate actual patient size to allow accurate dose measurement
- Internal organ Dosimetry
- General purpose use




AARON
Anthropomorphic phantom
5 year old
Rivelatori TL
15
34
35
29
28
Rest of the world……

GOSH London UK….

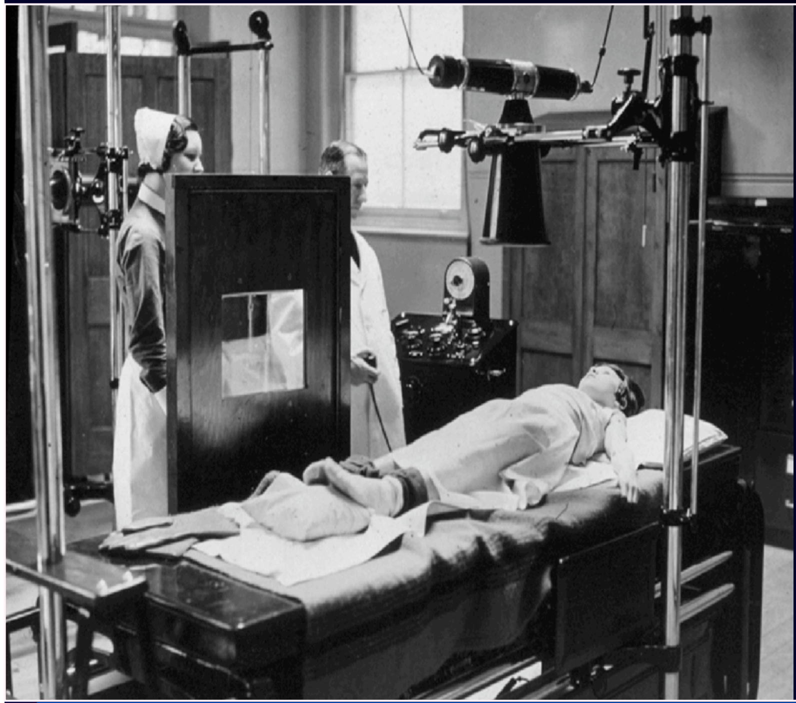
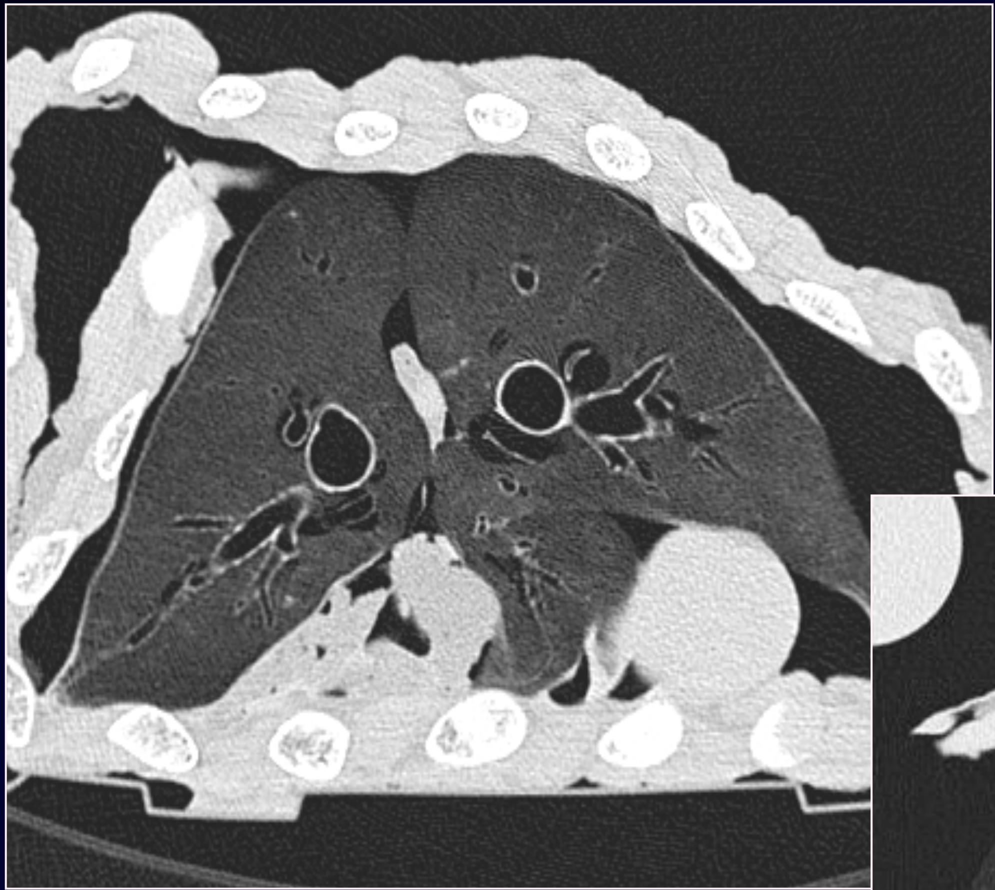


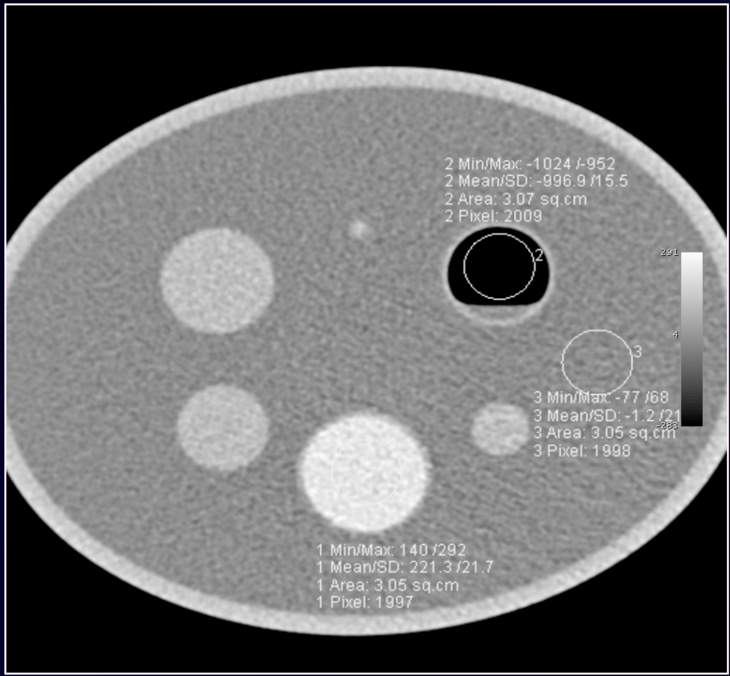
Image Acquisition

- Pig lungs used to simulate a 8-10 year old child
- Lamb lungs used to simulate a 5-6 year old child
- Inflated and held at maximum lung volume [TLC]

'Miss Piggy'
B60

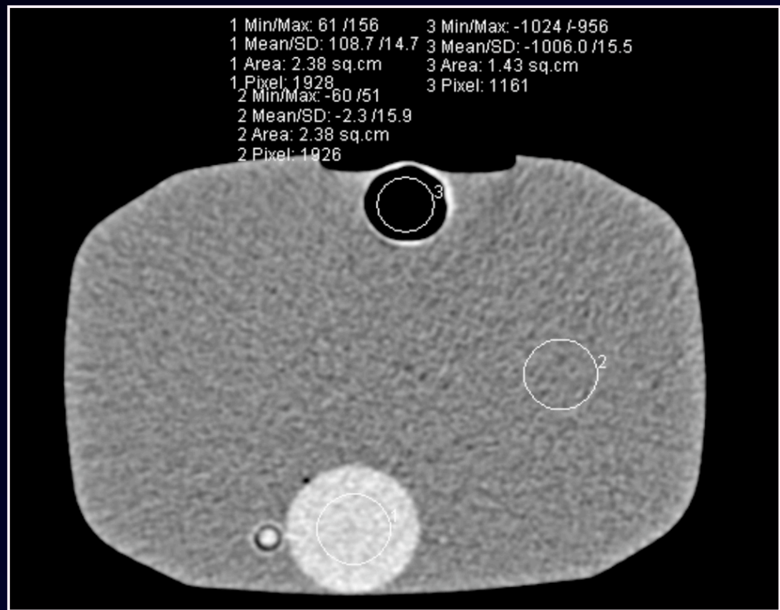


'Lamb Chop'
B30



Ellipse water phantom with 61cm circumference equivalent in size to 8 year

41cm circumference equivalent to 2 years old



Dual-Energy

- Simultaneous acquisition of two data set at different attenuation level
- Allows classification of tissue chemical composition
- Dose neutral or less

Relative risk

- **To individual :**
  - Lifetime risk of cancer: 20-25% (1 in 4 or 5)
  - Added risk: 0.05% (1 in 2000)

- **To population :**
  - 600,000 pediatric CT's in the US / year
  - Without CT: 135,000 will die of cancer
  - With CT: 135,300 will die of cancer

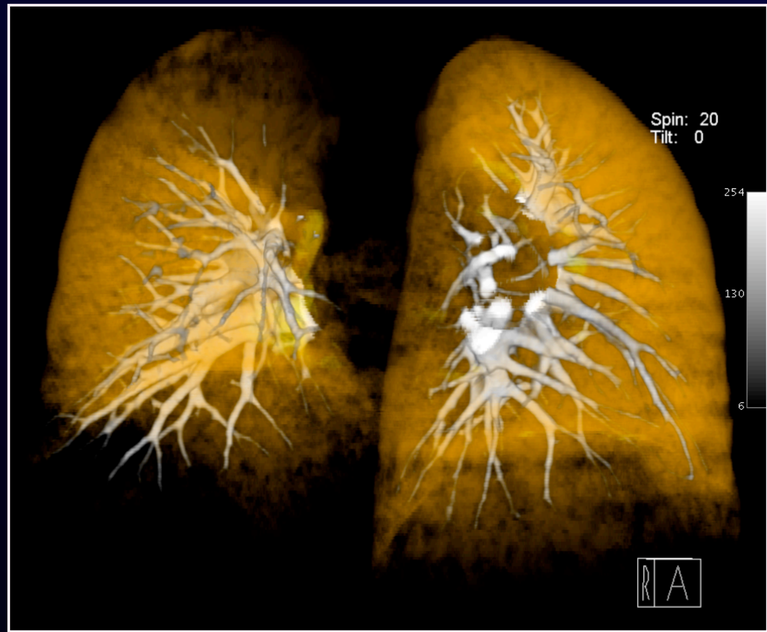
Marilyn Siegel

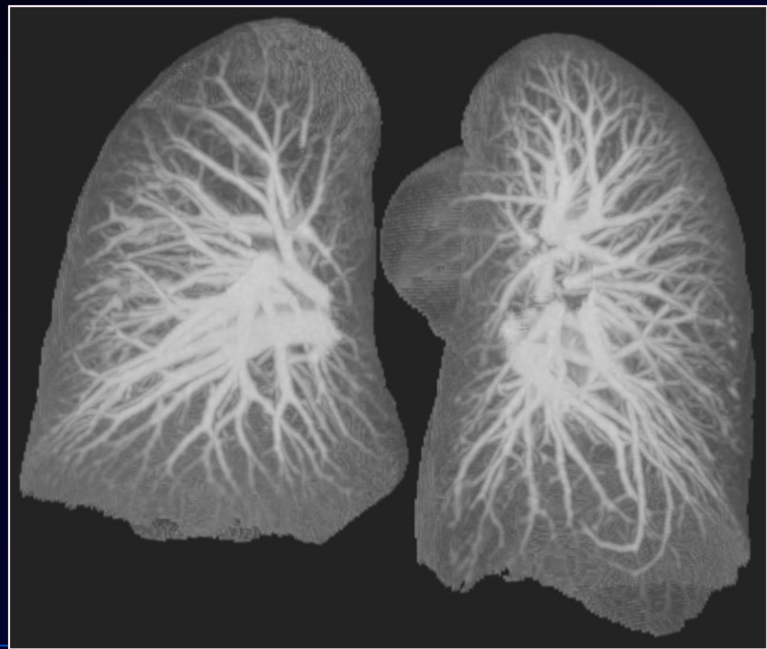
Diagnostic Procedure	Typical adult effective dose (mSv)	Equivalent natural background radiation	Lifetime additional risk of fatal cancer per exam - Adult
Teeth (single bitewing)	< 0.01	< 1.5 days	1 in a few million
Chest (single PA film)	0.02	3 days	1 in a million
Lumbar spine	1.3	7 months	1 in 15,000
Barium meal	3	16 months	1 in 6700
Barium enema	7	3.2 years	1 in 3000
CT head	2	1 year	1 in 10,000
CT chest	8	3.6 years	1 in 2500
CT abdomen/pelvis	10	4.5 years	1 in 2000
Bone scan (Tc-99m)	4	2 years	1 in 5000
Dynamic cardiac (Tc-99m)	6	2.7 years	1 in 3300
Myocardial perfusion (Tl-201)	18	8 years	1 in 1100

UK background
2.2 mSv pa

Risk to Paeds x2

Health Protection Agency, September 2008





8 year old, 24kg
140kV, 11mAs$_{eff}$
80kV, 46mAs$_{eff}$
CTDIvol = 2.15mGy
Eff dose = 1.7mSv

Dose reduction over the last decade

	DSCT 2007	MDCT 2003	SSCT 1996
< 15kg	1.0 CTDIvol 0.8 mSv	0.98 CTDIvol 1.0 mSv	1.9 CTDIvol 1.5 mSv
< 25kg	1.27 CTDIvol 1.0mSv	1.25 CTDIvol 1.3 mSv	2.7 CTDIvol 2.2 mSv
< 35kg	1.50 CTDIvol 1.2 mSv	1.75 CTDIvol 1.6 mSv	2.8 mSv
<45kg	1.76 CTDIol 1.4 mSv	2.68 CTDIvol 2.9 mSv	3.5 CTDIvol 2.9 mSv

Phantom study