The ROYAL MARSDEN
NHS Foundation Trust

Imaging protocols for low dose CT lung cancer screening

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NHS

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2. Starting points – what resources are out there?

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Overview of screening

- Screening CT offered to patients who are above a threshold lung cancer risk score
- Annual volumetric measurements of lung nodules enables calculation of a volume doubling time (VDT)
- British Thoracic Society guidelines give criteria for more frequent CT surveillance and further workup.
- Visualisation and subsequent quantification of nodule volume is key for the CT imaging protocol.
- This is essentially a high contrast task: soft tissue against air background.
- Nodules roughly ≥5 mm are of interest: good spatial resolution in all directions is of interest.

Starting points for a low dose lung protocol

- What existing protocols are out there?
- AAPM library of "reasonable" protocols includes:

Lung Cancer Screening CT Protocols Version 5.1 13 September 2019

LUNG CANCER SCREENING CT

NOTE: The Lung Cancer Screening Protocols described in this document are a set of reasonable protocols developed by the AAPM's Working Group on Standardization of CT Nomenclature and Protocols that are to be used in the specific context of Lung Cancer Screening. These protocols were based in part on manufacturers' Low Dose Chest protocols, but were adapted based on the Working Group's experience with the National Lung Screening Trial and other screening studies.

Key Elements

- One breath-hold (thoracic motion is problematic);
- Thin image thicknesses (≤2.5 mm, ≤1.0 mm preferred); reconstruction of coronal and sagittal reformations as well as MIPS may be helpful and are encouraged.
- CTDIvol ≤ 3.0 mGy for a standard sized patient (see table), with adjustments made for smaller and larger patients.
- This typically requires a 16 detector row (or greater) scanner to meet these requirements.

Starting points for a low dose lung protocol

- AAPM recommendations include <1 mSv for standard (70kg) patient using k-factor of 0.014 mSv/mGycm
- This factor used almost universally in literature.

Effective Dose

Effective dose is defined in ICRP 103 as a population dose metric and should not be used to estimate dose or risk to an individual. From a *screening population* point of view, one method to estimate the effective dose is to calculate the Dose Length Product (DLP) and then apply a conversion factor described in AAPM TG Report 96 to estimate the effective dose. For an idealized standard sized patient (defined above) and a 25 cm scan length, and using the k factor of 0.014 mSv/mGy*cm; these protocols should result in an effective dose below 1 mSv (see table below).

Dose values for an idealized standard sized patient (NOT for any individual)

Dose Descriptor	Value	Reported at Scanner (Y/N)
CTDIvol*	≤ 3.0 mGy	Y
DLP*	≤ 75 mGy*cm	Y
Effective Dose (DLP x .014)**	≤ 1.0 mSv	N**

* The CTDIvol and DLP values in this table are for an idealized patient only; individual patients may have higher or lower values to reflect adjustment for patient size.

** Effective Dose is calculated for a population and should NOT be reported for an individual

Starting points for a low dose lung protocol

- Published protocols from low dose CT lung screening trials include:
  - NLST
  - DLSCT
  - NELSON
  - UKLS
  - Manchester Lung Health Check pilot
  - Others
- Reported details of the CT imaging parameters are highly variable!

Some details of research CT exam protocols:

- NLST, NELSON, DLSCT recruitment dates between 2002-2006, UKLS & MCIP between 2011-2014.

Protocol	Scanner	kV	mAs / rot	TCM	$CTDI_{VOL}$	Slice (mm)	Kernel / IR
MCIP	Optima 660	100 120 140	40 40 40	none	1.5 2.5 3.5	1.25 / 1.25	Bone, ASIR
UKLS	Siemens 128, Brilliance 64	100 120 140		As per local practice	0.8 1.6 3.2	1.0 / 0.7	B30f; STD
NELSON	Philips Mx8000 or Brilliance16	80/90 120 140		none?	0.8 1.6 3.2	1.0 /0.7	
DLSCT	Philips Mx8000	120	40	none?		1.5 / 1.0	
NLST	No set protocol; 120-140 kV; estimated average effective dose <1.5 mSv						

Adapting existing protocols

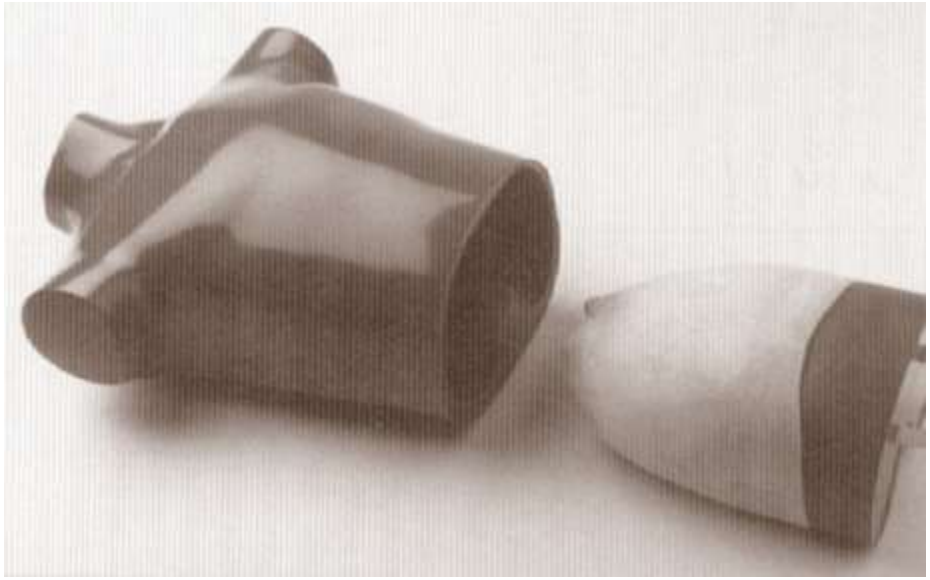
- Considerations include:
  - Dose level
  - CT scanner technology level
    - Detector coverage and minimum slice thickness
    - Detector design, noise reduction
  - Use of iterative reconstruction
    - Enables a certain level of dose reduction…
    - Does this affect volumetric measurements?
      - IR algorithms changes noise and MTF characteristics.

Creating the protocol

- Agree strategy beforehand with clinical leads
  - We decided mA modulation must be used.
- Review any existing lung protocols and get opinion on the clinical image quality
- Set up the protocol alongside clinical staff
- Size-specific protocols allows greater scope for optimisation for patient size, even when tube current modulation is used
  - Otherwise restricted by vendor's particular dose modulation strategy
- Use mA caps to limit dose or force selection of fine focus where possible.

Creating the protocol

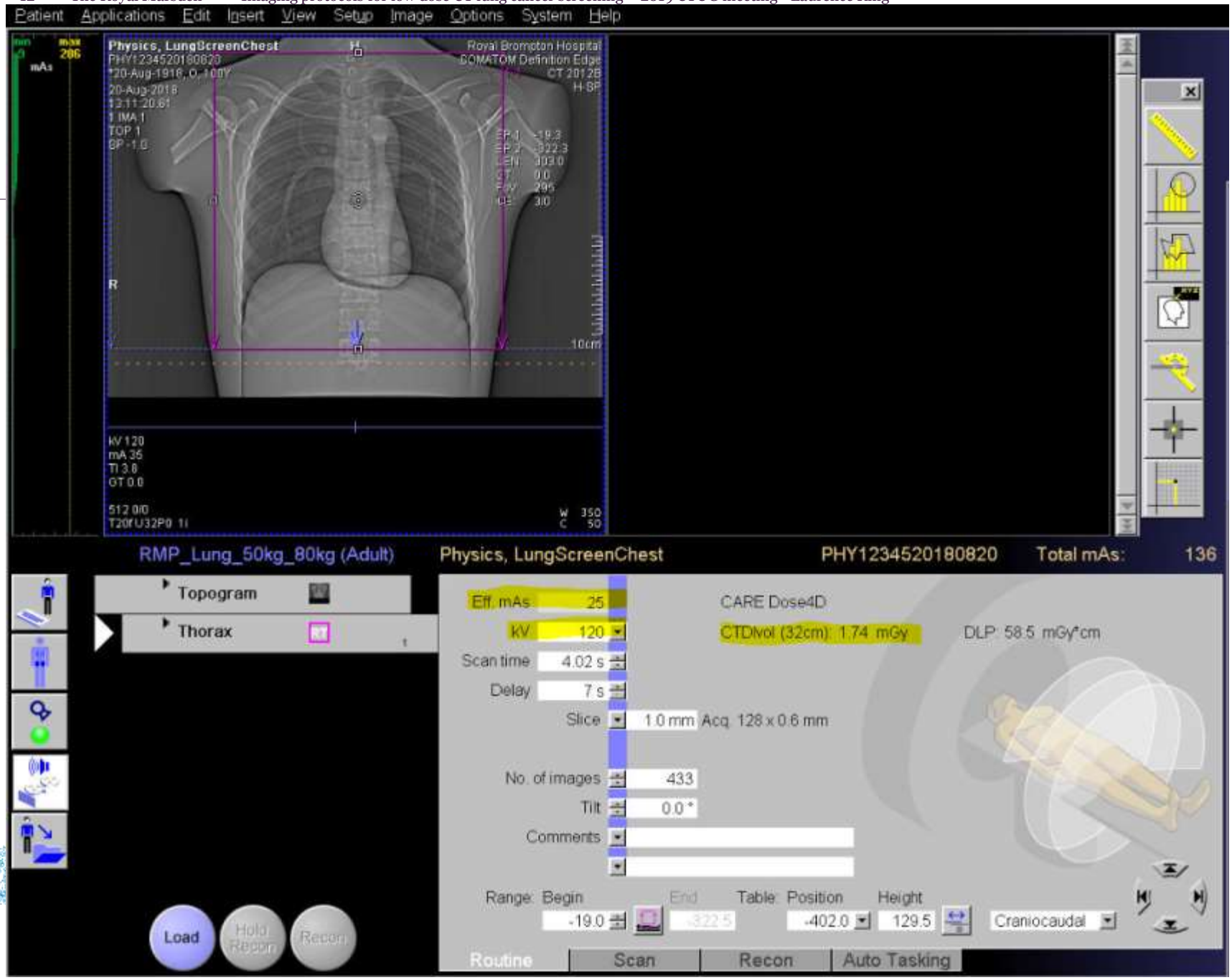
- Anthropomorphic phantom is very useful!
- Set up protocol to deliver target dose for the standard patient, and check image quality.
  - (assuming phantom is standard size…)
- RSD Alderson phantom with removable thorax insert:
  - Approximately representative of 70-75 kg patient



Creating the protocol: Siemens scanner

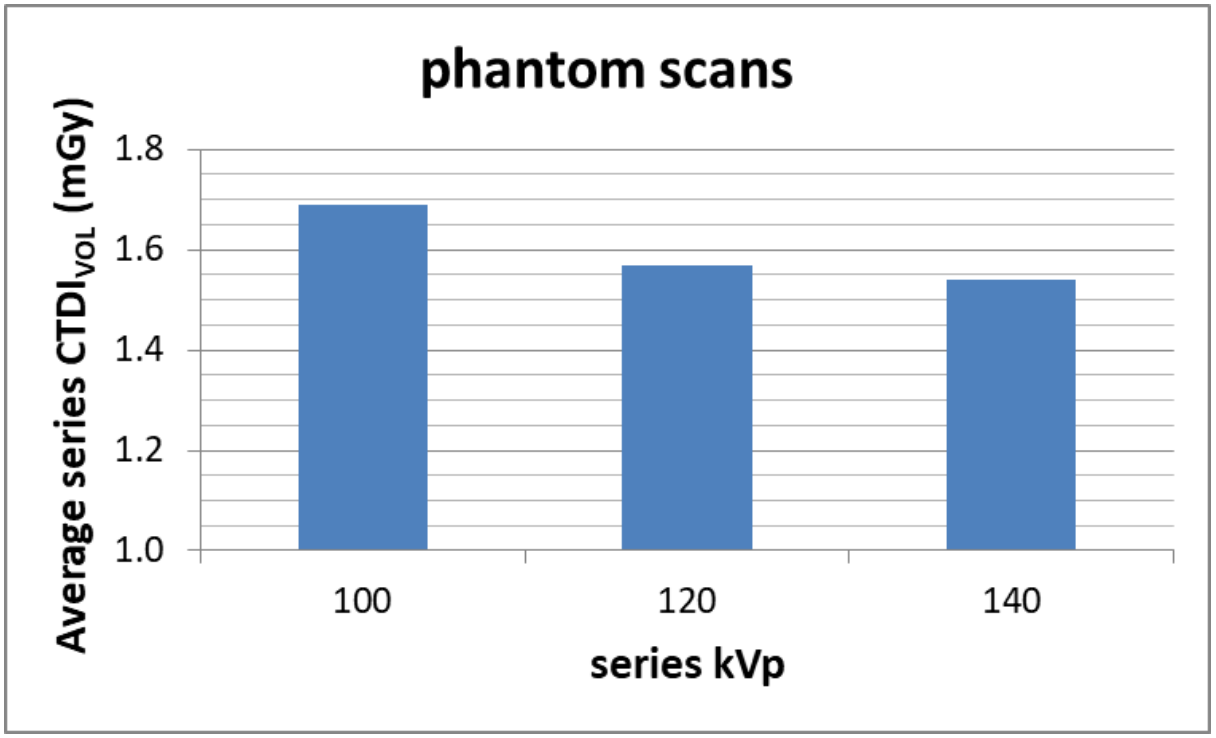
- Initial protocol was set up on Siemens Definition Edge (Stellar detectors – low electronic noise gives better noise performance at low dose)
- Medium patient protocol was based on existing low dose lung with 120 kV and reduced reference mAs_{eff}

- 100 kV small and 140 kV large protocols created (as per NELSON, MCIP and UKLS protocols).
  - Gives better modulation for small and large patients without hitting min or max tube mA.
  - Reference mAs_{eff} adjusted for small and large protocol to maintain the same $CTDI_{VOL}$ for the chest phantom as the 120 kV protocol.


Patient Applications Edit Insert View Setup Image Options System Help
Physics, LungScreenChest
PHY1234520180820
20-Aug-2018
Royal Brompton Hospital
SOMATOM Definition Edge
CT 2012B
H-SP
R
10cm
kV 120
mA 35
TI 3.0
GT 0.0
RMP_Lung_50kg_80kg (Adult)
Physics, LungScreenChest
PHY1234520180820
Total mAs: 136
Topogram
Thorax
Eff. mAs 25
kV 120
Scan time 4.02 s
Delay 7 s
Slice 1.0 mm Acq. 128 x 0.6 mm
No. of images 433
Tilt 0.0°
Comments
CARE Dose4D
CTDIvol (32cm): 1.74 mGy
DLP 58.5 mGy*cm
Range: Begin -19.0 End -322.5
Table: Position -402.0 Height 129.5
Craniocaudal
Load
Hold Recon
Recon
Routine
Scan
Recon
Auto Tasking

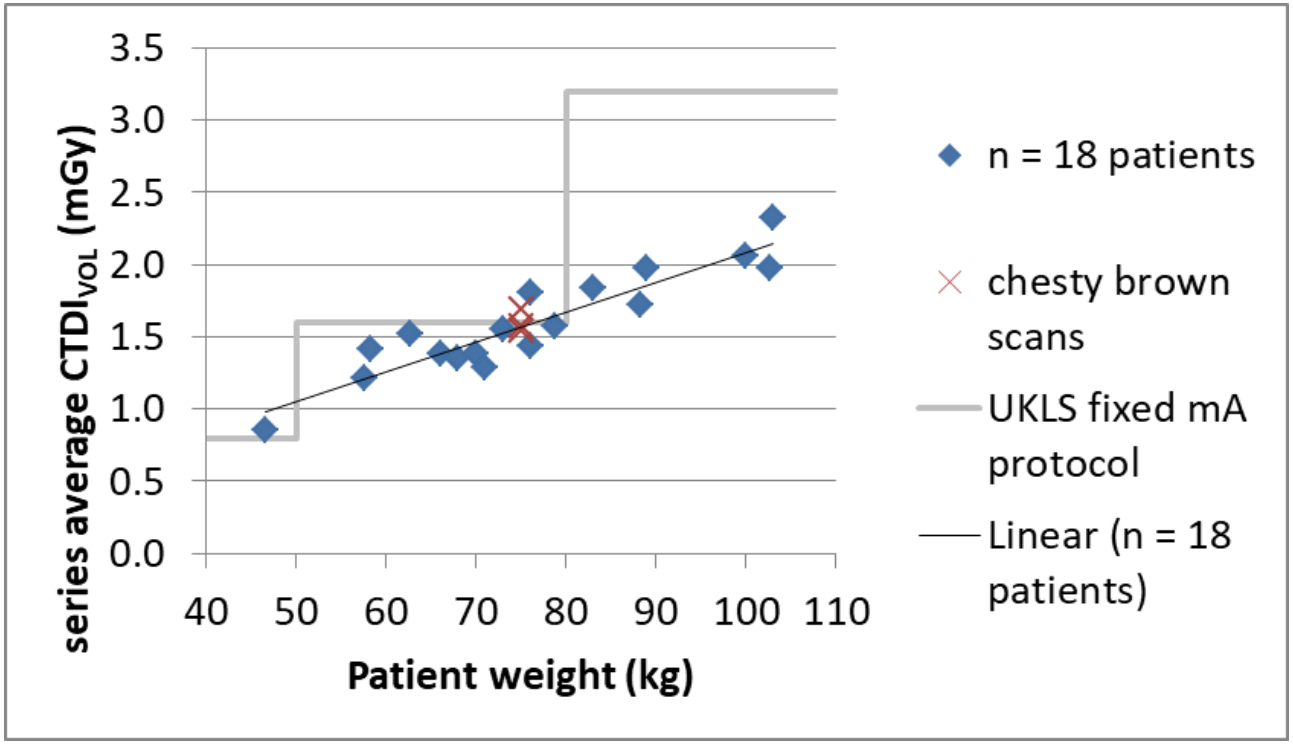
Creating the protocol

– Confirmation of small, medium, large protocol dose equivalence on chest phantom: <10% variation is satisfactory.



Creating the protocol

– Confirmation of patient doses once protocol is in clinical use: no inappropriate step changes between weight-specific protocols, and $CTDI_{VOL}$ values are at or below reference protocol.



Creating a matching protocol on a different scanner

- How does the tube current modulation response to patient size differ between scanners?
  - For the same body part / scan technique
  - Constant noise / image quality strategy
- How does image quality and noise compare?
  - For the same dose levels
  - Match reconstruction kernels
- How does slice thickness and resolution compare?
  - Does this affect volumetric measurement?

Creating the protocol: GE scanner

- Protocol set up was repeated on the GE scanner using closest matching scan parameters to achieve the same series average $CTDI_{VOL}$ and DLP when scanning the chest phantom.

- Bear in mind that matching series average dose will not necessarily produce matching image quality between two scanners!

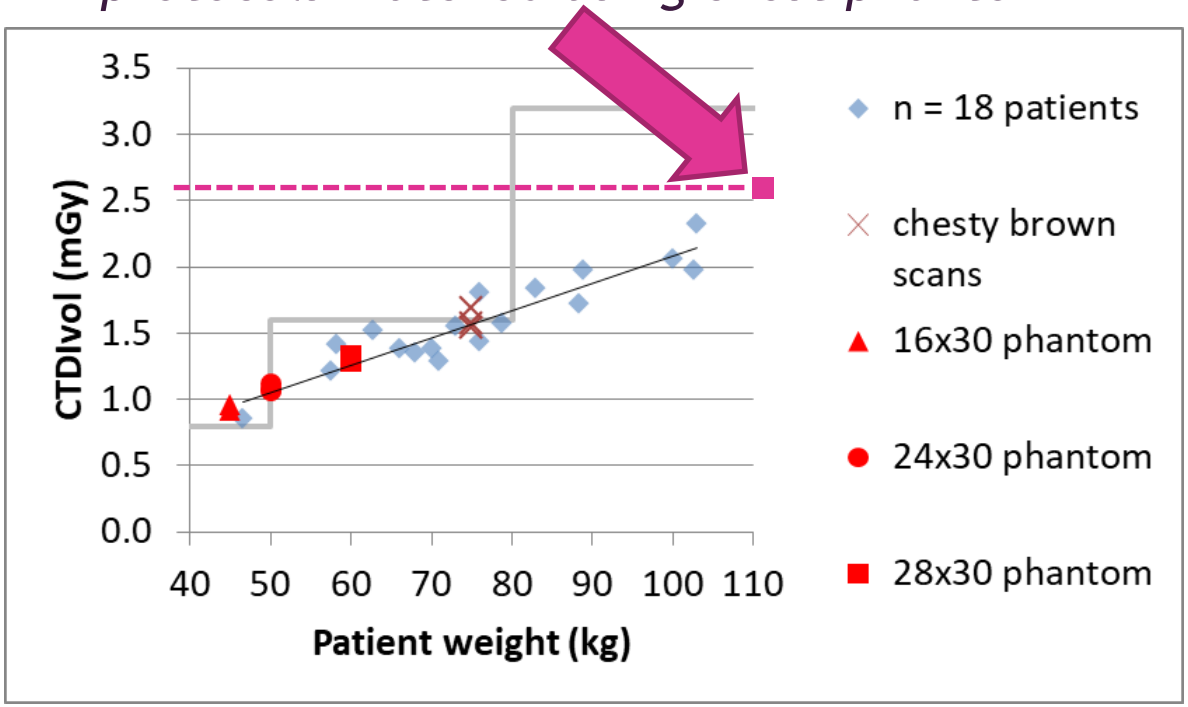
  - Different beam qualities and dose efficiencies, slice thickness options, detector technology & electronic noise, recon kernels, and in-scan mA modulation.

Matching protocols between scanners

- Use of an anthropomorphic phantom is strongly recommended when matching mA-modulated protocols on scanners from different manufacturers.

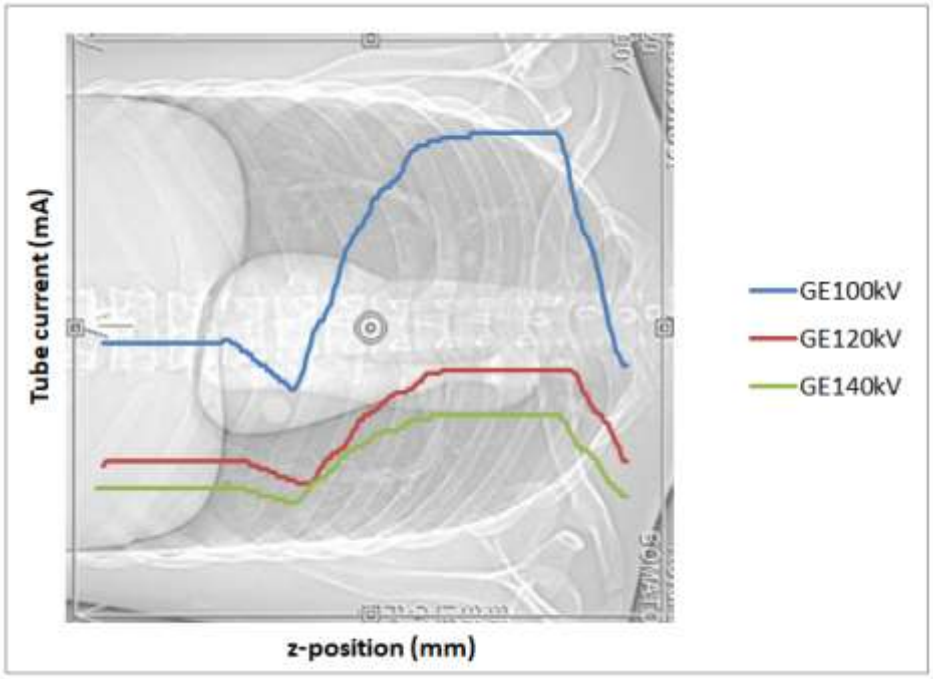
Siemens scanner thinks 28×30 cm phantom is smaller than chest phantom – GE scanner thinks it is significantly bigger!

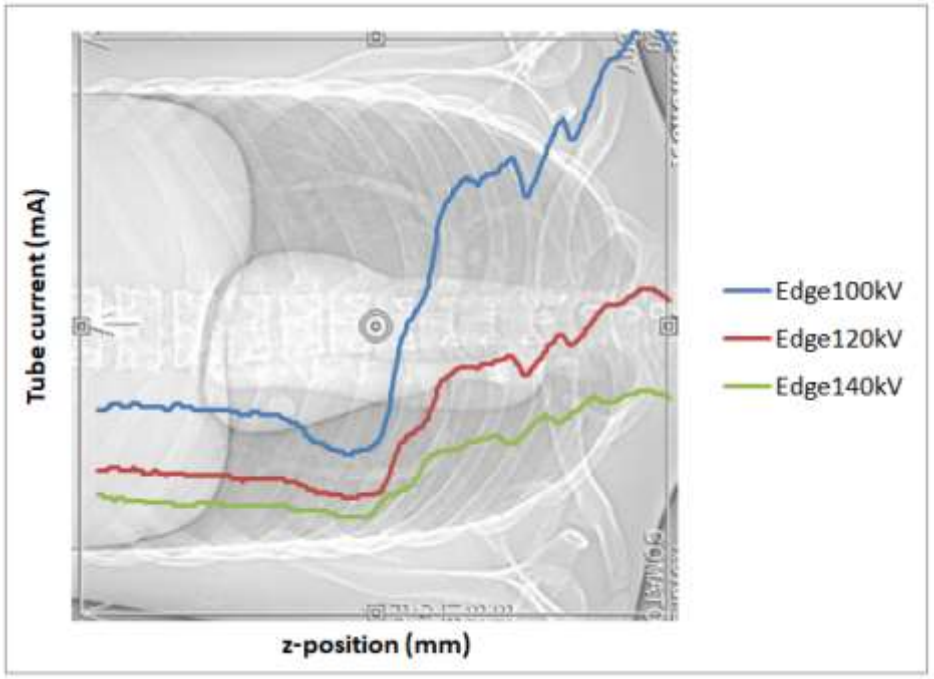
28×30 cm phantom scanned on GE once protocols matched using chest phantom



Matching protocols between scanners

- Different tube current modulation response between GE and Siemens scanners:
- series DLP is identical, but won't be able to match image noise in all anatomical regions due to different in-scan mA modulation

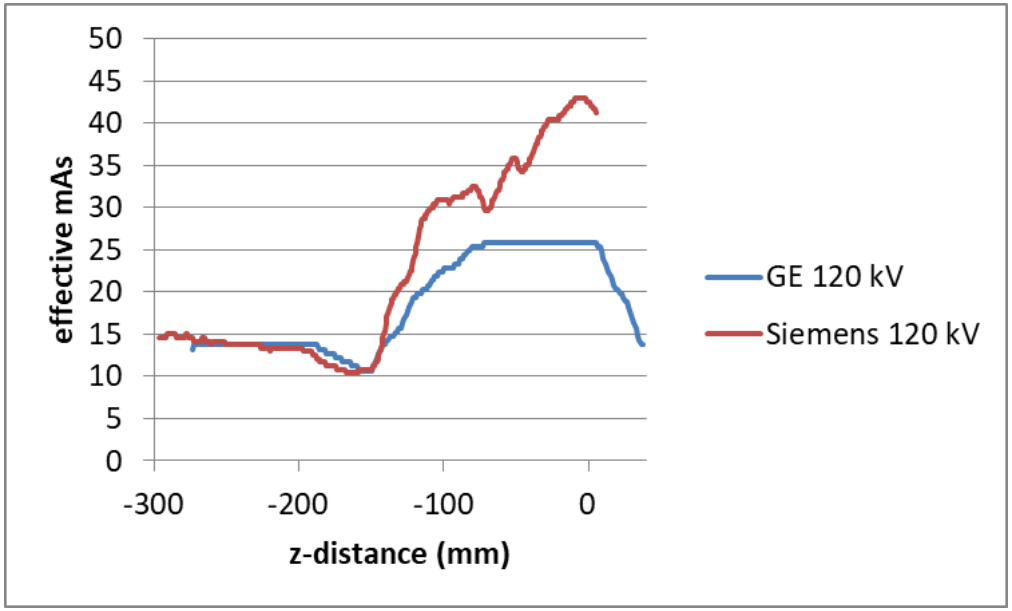


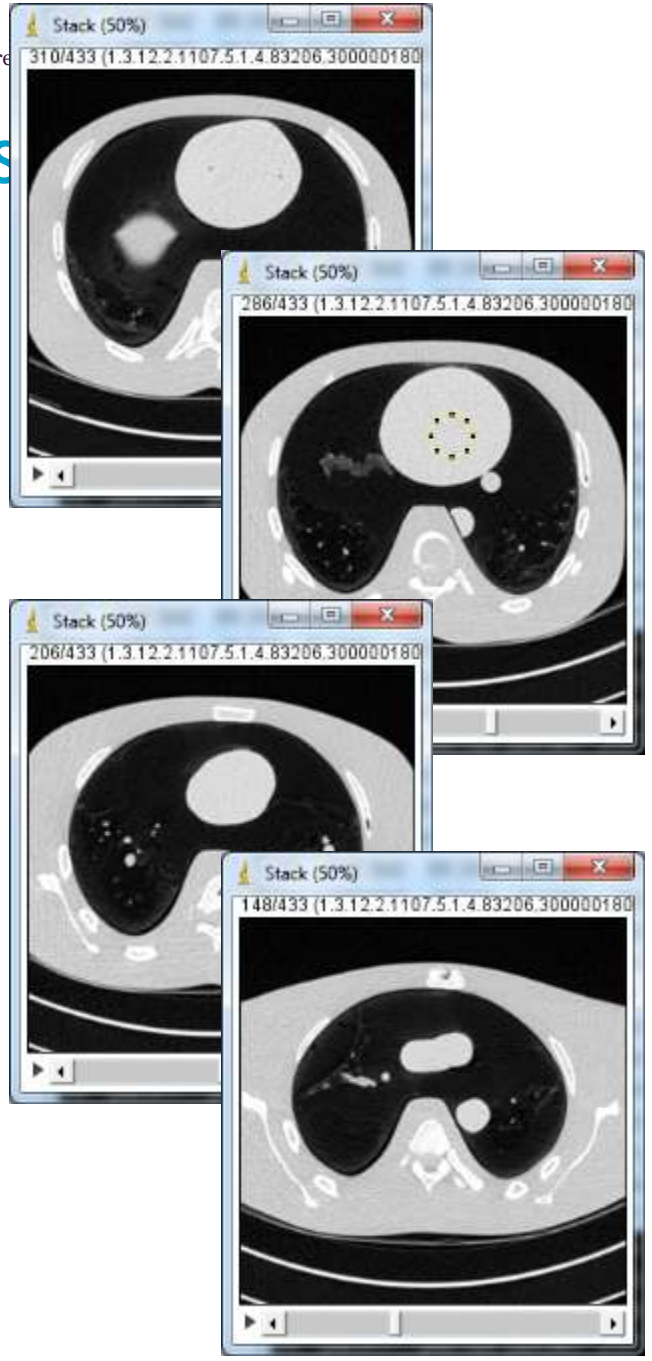


Matching protocols between s

- Comparing image noise

- GE noise was similar to Siemens apart from in upper thorax where GE images became noisier: different mA modulation





Matching recon kernels

- Ideally match reconstruction kernels by MTF and NPS
- Luckily someone's already done this for us

Quantitative comparison of noise texture across CT scanners from different manufacturers [http://dx.doi.org/10.1118/1.4752209]

6048 Med. Phys. 39 (10), October 2012

TABLE V. Closet matching GE kernel for a given Siemens kernel.

Siemens	GE	RMSD (mm^2)	PFD (mm^{-1})
B10f	Soft	0.14	0.09
B20f	Soft	0.08	0.05
B22f	Soft	0.03	0.02
B23f	Soft	0.03	0.02
B26f	Soft	0.04	0.03
B30f	Soft	0.02	0.02
B31f	Standard	0.02	0.01
B35f	Soft	0.01	0.00
B36f	Chest	0.02	0.02
B40f	Standard	0.03	0.02
B41f	Chest	0.01	0.01

Small RMSD indicates similar overall NPS shape;

Small PFD indicates similar kernel sharpness

Matching slice thickness

- Helical slice sensitivity profiles were measured on two scanners to ensure relationship of measured and nominal slice thickness is similar (IPEM 32 iii method)
  - This could affect nodule volumetry
  - Different recon modes on GE scanners affect the slice thickness
  - From GE CT user manual:

Full and Plus Recon Modes

The system provides the ability to manage dose, slice profile, and helical artifact through the Full and Plus recon modes. Full mode provides a thinner slice profile but requires 10–15 % more milliampere (mA) than Plus mode with equal image noise. Plus mode has up to a 20 % wider slice profile than Full, but requires 15–20 % less mA with equal noise for Helical scan types. At the same mA, Plus mode provides reduced image noise. Reduction of helical artifacts can be seen with Plus

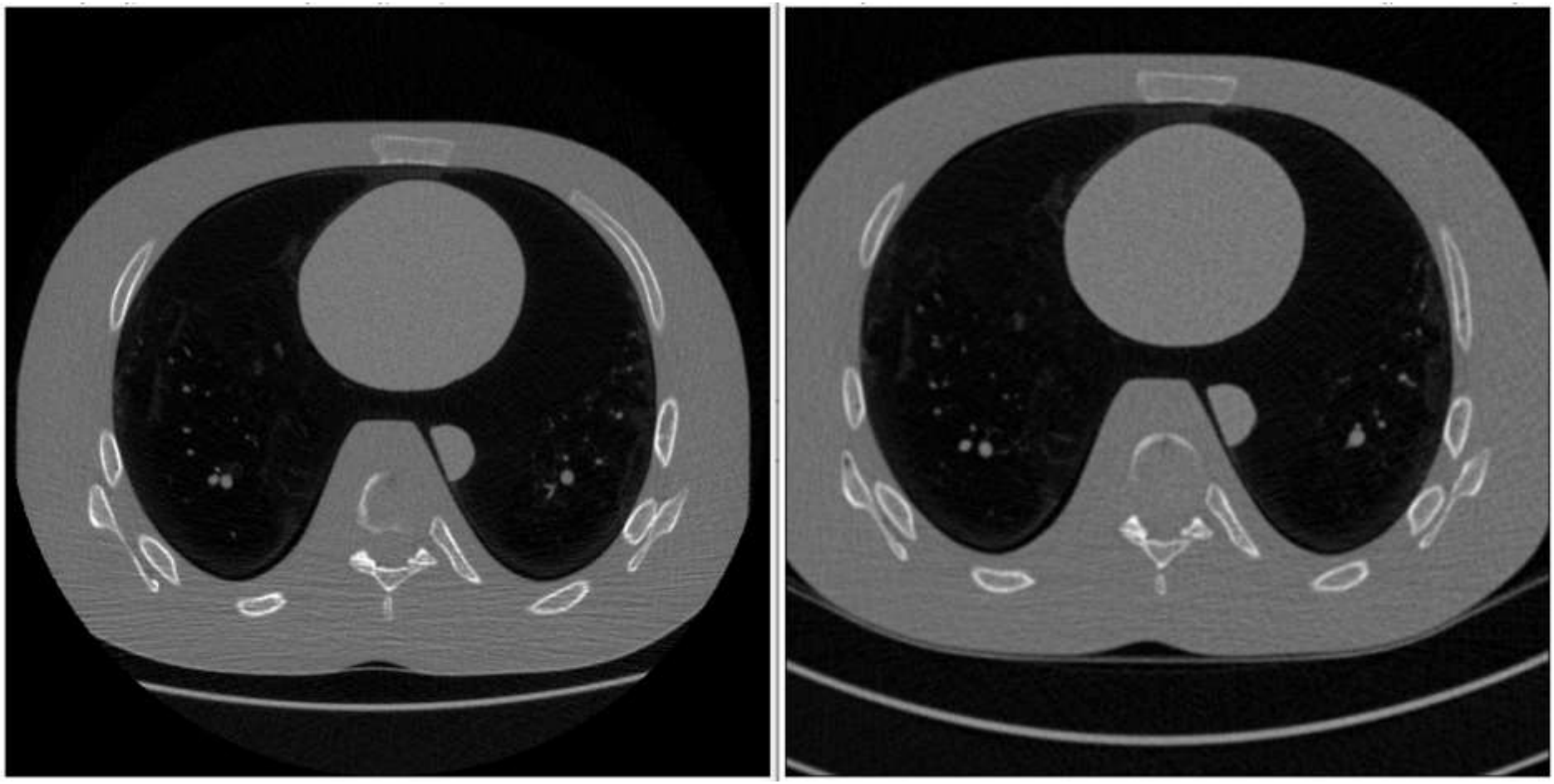
Matching slice thickness

– Helical slice sensitivity profiles were measured on two scanners to ensure relationship of imaged and nominal z-thickness is similar.

Scanner	Recon mode	Nominal slice thick	Measured FWHM	Ratio of measured/ nominal
GE Optima 660	FULL	1.25 mm	1.36 mm	1.09
	PLUS	1.25 mm	1.59 mm	1.27
Siemens Edge	Standard	1.00 mm	1.31 mm	1.31

Clinical review of images

- Side by side review of GE and Siemens images
- Radiologist happy with image presentation



Important points!

- Patients scanned on Siemens scanner –
  - follow ups performed on the same scanner.

- Patients scanned on the GE Optima –
  - Follow ups on a GE Revolution Evo: protocols set up a couple of months after start of screening.

- GE Optima on trailer: only in use for 6 months in first stage of pilot.

Disclaimer

- Protocols on next slide are provided with the following disclaimers:
- These are not the FULL listings of all scan parameters that may affect image quality and patient dose.
- These are not necessarily optimised in terms of image quality or dose: work in progress.

Resultant protocols

Please see disclaimer on previous slide!

Parameter	Siemens Edge	GE Optima 660	GE Revolution Evo
Detector	64 × 0.6 mm	64 × 0.625 mm	64 × 0.625 mm
kVp (s, m, l)	100 / 120 / 140	100 / 120 / 140	100 / 120 / 140 / 140
Rot time	0.5 s	0.5 s	0.5 s
Pitch	1.2	0.984	0.984
Reference effective mAs (s, m, l)	34 / 20 / 13	*n/a*	*n/a*
Noise Index (s, m, l)	*n/a*	57 / 63 / 66	38 / 40 / 42 / *45 [xl]*
Chest phantom average $CTDI_{VOL}$	1.57 mGy @ 120 kVp	1.59 mGy @ 120 kV	1.59 mGy @ 120 kV
Image thickness	1.0 mm	1.25 mm	2.5 mm (1st recon) 1.25 mm (2nd recon)
Image interval	0.7 mm	1.25 mm	1.25 mm (2nd recon)
Kernel	B30f, lung window	STD plus, lung window	STD plus, lung window

Resultant protocol doses by scanner

Weight ranges chosen to match NELSON trial patient weight groups

70 kg patient dose is at or below 1 mSv using k = 0.014 mSv/mGycm

	Siemens Edge				
	patients in group	ave. kg	mean dose indicators		
			$CTDI_{VOL}$	DLP	E (mSv)
small < 50 kg	20	46	1.13	37.7	0.53
med 50-80 kg	430	68	1.51	51.2	0.72
large 80-140 kg	284	92	2.01	69.0	0.97

	GE optima 660				
	patients in group	ave. kg	mean dose indicators		
			$CTDI_{VOL}$	DLP	E (mSv)
small < 50 kg	11	45	1.15	40.3	0.56
med 50-80 kg	240	68	2.18	70.8	0.99
large 80-140 kg	238	93	4.45	150.7	2.11

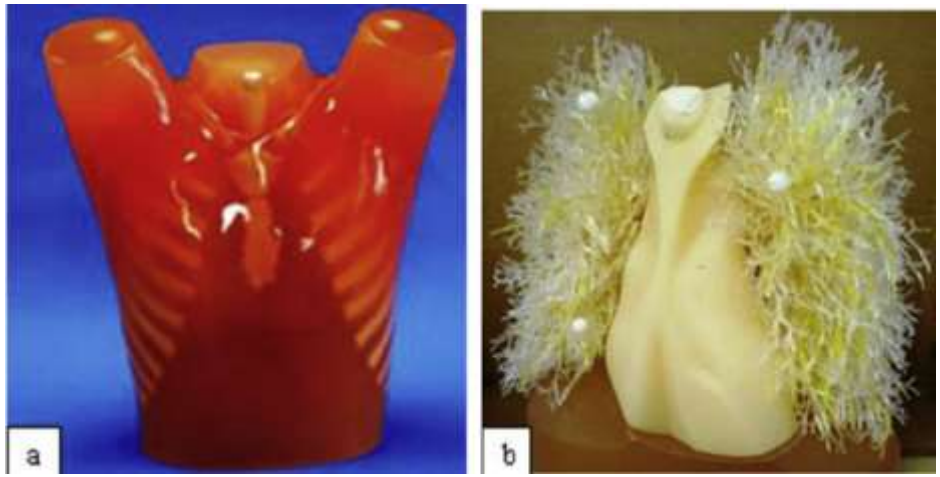
	GE Revolution EVO				
	patients in group	ave. kg	mean dose indicators		
			$CTDI_{VOL}$	DLP	E (mSv)
small < 50 kg	2	42	0.64	22.2	0.31
med 50-80 kg	59	69	1.76	62.7	0.88
large 80-140 kg	46	96	4.66	149.8	2.10

Tips

- Communication and feedback from clinicians is vital
- Need to agree in advance on a protocol by which further optimisation is achievable
  - E.g. a system of requesting protocol changes
- Make use of dose management systems collecting real-time data
- At low dose, the required GE Noise Index for 1.25 mm slices ends up near the maximum of 70, limiting scope for further dose reduction!
- GE Evo protocol set up with slice thick of 2.5 mm to enable a lower NI and further scope for change.

Improvements

- What could we have done better?
  - Communication between all stakeholders
  - Follow-up optimisation of protocols
  - Quantitative Image quality assessment
    - on clinical images, too
  - Protocol-specific scanner QA
- Limited by
  - Tight timelines
  - Communication
  - Available test tools



Other thoughts

- Dosimetry: what about topogram / scout dose?
- A thorax scout / topogram can result in an effective dose of 0.1 to 0.2 mSv
  - Depending on projection, single or double scan projection radiograph.
  - This becomes significant with a “sub-mSv” volume scan!
- Should we be using a 0.014 mSv/mGycm conversion factor, anyway?