CT revolutions: the impact of CT imaging on the role of the medical physicist

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Outline

- Four decades of CT scanning
- The changing role of the medical physicist
  - Quality control testing
  - CT dosimetry
  - Optimisation
- What does the future hold?

CT scanning over a career

- Single-slice, step-and-shoot CT (1987)
- Electron beam CT (1991)
- Single-slice helical CT (1999)
- Multi-slice CT (2002)
- Dual-source CT (2010)
- Photon-counting CT (too late?)

Quality control: getting started

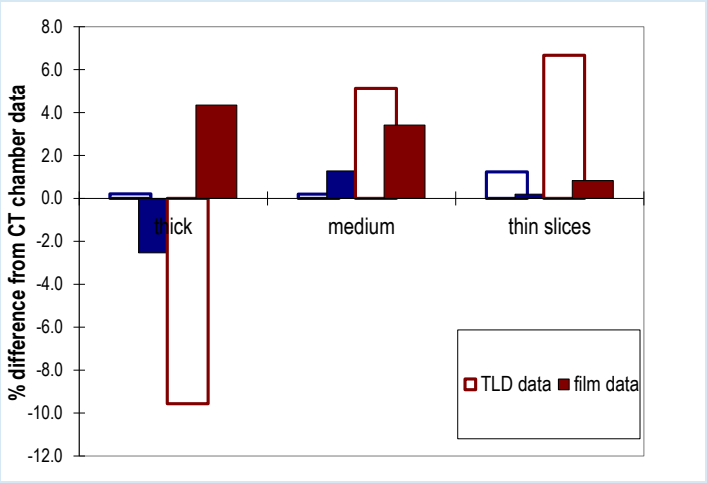
- Philips SSCT step-and-shoot scanner in teaching hospital with busy A&E
- Multiple attempts to implement QC testing
  - Asked, warned, socialised for 4 years
- Tip: do not implement QC testing on A&E CT scanner

The heyday of QC: 1991-2002

- 2 SSCT scanners (Somatom DR2, Plus)
- EBCT scanner (Imatron)
- Monthly QC testing
  - Set up after acceptance (EBCT)
  - Implemented after scanner fault (DR2)
  - Service transferred (Plus)

The heyday of QC: 1991-2002

- Routine performance tests
  - CTDI, image noise, CT number accuracy, uniformity, artifacts, spatial resolution, slice thickness
  - CTDI using film, TLDs, CT chamber (from 1996)
  - Image quality using water and Scanplas phantoms
  - ROI analysis on scanner



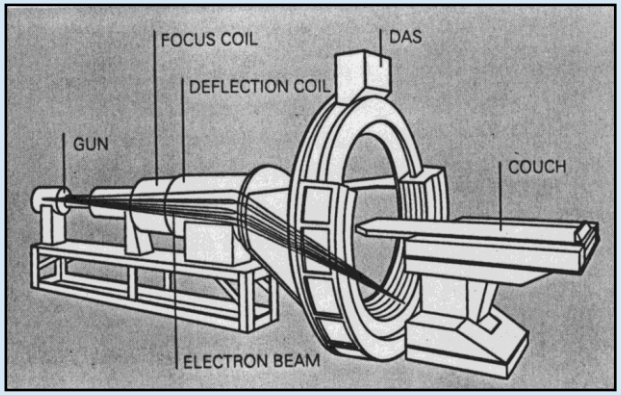
1996 (blue DR2, red Plus)

The heyday of QC: 1991-2002

- Commissioning tests
  - Tube and generator
  - CTDI-in-Perspex (from 1996)

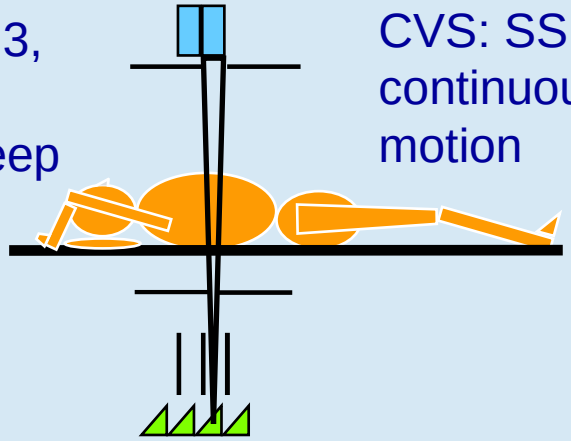
EBCT

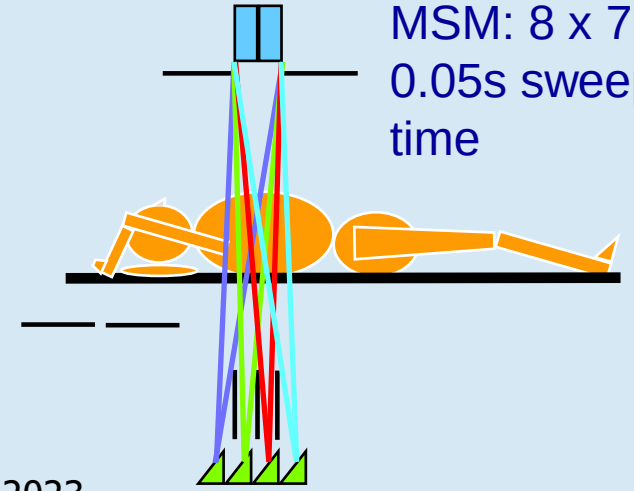
- 4 W targets, 210° arc
- 2 detector rings, 216 ° arc
- 4th generation geometry
- 130 kVp, 630 mA
- SSM, MSM and (later) CVS modes
- ECG gating



SSM: 6, 3, 1.5 mm, 0.1s sweep time

CVS: SSM with continuous table motion

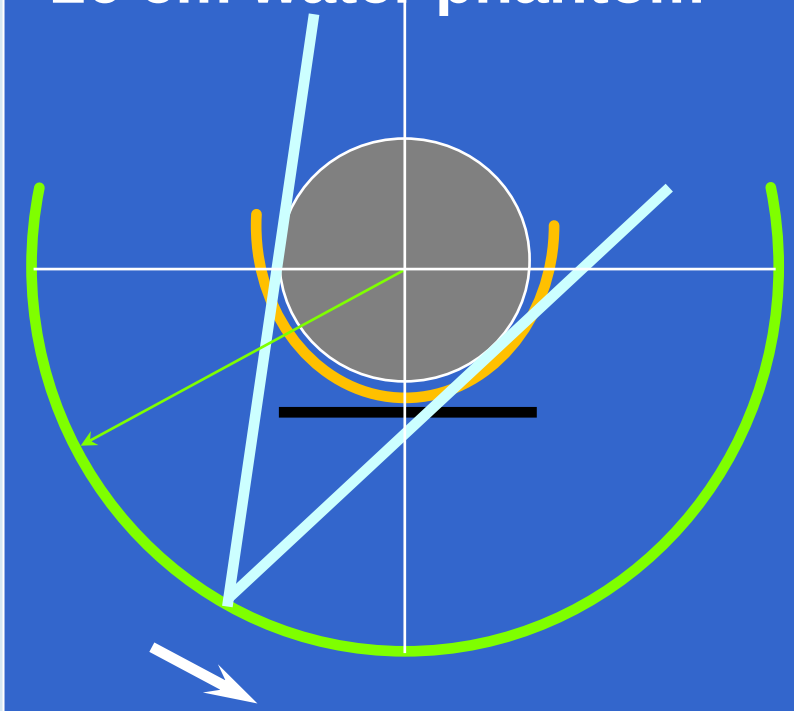




MSM: 8 x 7 mm, 0.05s sweep time

EBCT-specific QC

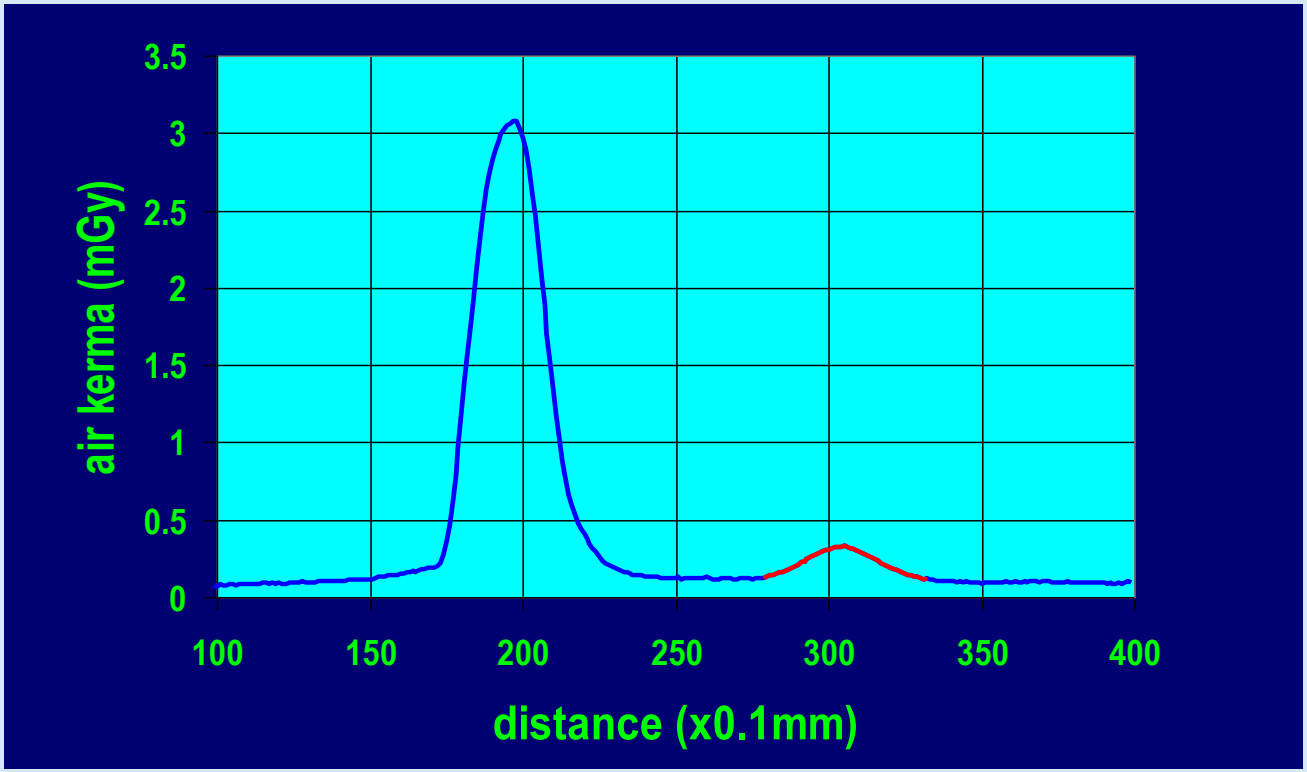
- Beam profiles – measured monthly



	FWHM (mm)
3 mm SSM	3
6 mm SSM	10
2x7 mm MSM	19-27

EBCT-specific QC

- Beam profiles – satellite ring



EBCT-specific QC

- Structured noise

SSCT helical scanning

- First helical scanners installed in 1999 (CT/i, Somatom Plus 4)
- First CT scanners accepted and commissioned
  - With a little help from friends
- Additional QC tests introduced to monitor effect of helical pitch
  - Helical CTDI
  - CT number accuracy, noise, uniformity and slice thickness in helical mode along z-axis

MSCT and scanner proliferation: 2002-2014

- Between 2002 and 2006 all radiology scanners replaced with MSCT scanners

hospital	scanner	MSCT	year
RMH (C)	LS32	32	2006
RMH (S)	LS16	16	2003
RBH	Volume Zoom	4	2002

- The number of radiology CT scanners doubled between 2010 and 2014 (3 -> 6)
- MSCT scanners were also installed in RT (3) and NM departments (8)

QC testing of MSCT

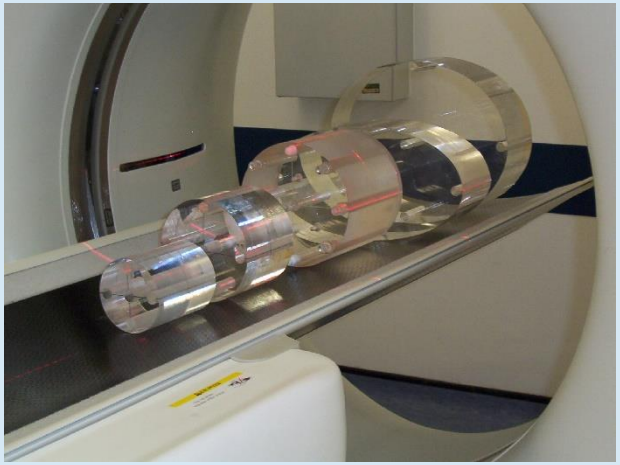
- QC tests reviewed /tests added
  - Standard slice10 -> 5 mm
  - Variation of CT number accuracy, noise and uniformity with slice collimation and detector row

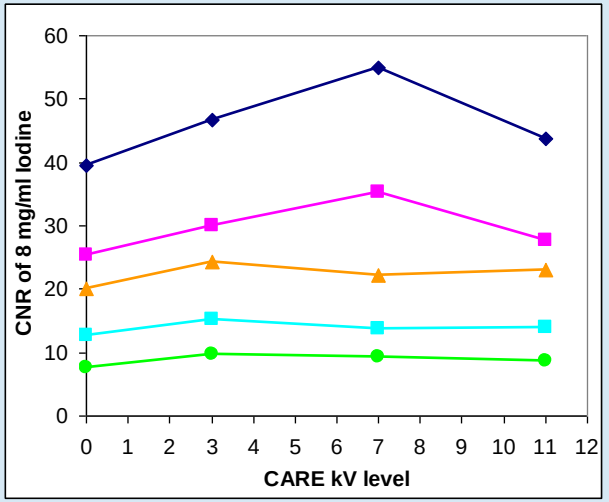
	axial slice thickness						
collimation	0.63	1.25	2.5	3.75	5	7.5	10
2 x 0.63 mm	2i						
1 x 1.25 mm		1i					
4 x 1.25 mm		4i	2i		1i		
4 x 2.5 mm			4i		2i		1i
4 x 3.75 mm				4i		2i	
4 x 5 mm					4i		2i

	axial slice thickness						
collimation	0.63	1.25	2.5	3.75	5	7.5	10
1.25 mm	2i	1i					
5 mm							
10 mm	16i	8i	4i		2i		1i
15 mm				4i		2i	
20 mm		16i	8i		4i		2i

QC testing of MSCT

- QC tests reviewed /tests added
  - Tube current modulation tests with phantom family
  - Later auto kV selection tests with iodine inserts (commissioning)





Dual-source CT scanners

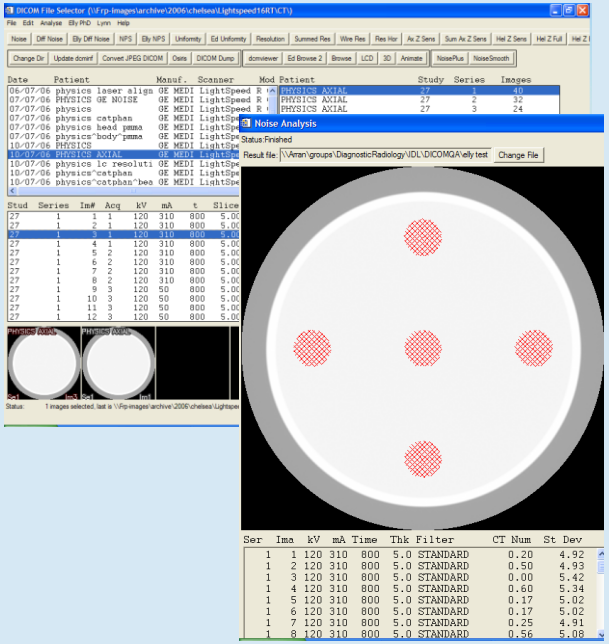
- 3 DS scanners installed between 2010 and 2014
- One week for acceptance and commissioning!
- Additional QC tests implemented for A+B modes
  - CTDI, slice alignment, CT number accuracy, noise and uniformity in DS mode (cardiac, DS or DECT modes)
  - Iodine calibration in DECT mode (commissioning)

Streamlining QC testing

- CT pencil ionisation chambers (from 1996)
- Manufacturer's performance phantom and tests
- Catphan phantom (from 2004)
- Updated tests w.r.t. IPEM report 91 (2005) and IPEM report 32 part III (2003)
- Routine QC frequency reduced:-
  - 4 h every 6 months for single-source CT
  - 4 h every 4 months for dual-source CT
- X-ray tube acceptance streamlined
  - For a time X-ray tubes replaced every 6-12 months

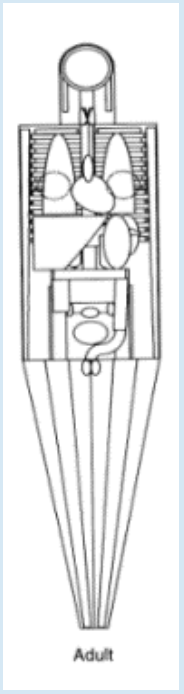
Streamlining QC testing

- Physics CT scan protocols
  - Set up at acceptance, modified in year 1 for routine testing
- Automated image analysis for batch image processing
  - IDL, IQWorks, ImageJ
- Tip: always review images at scanner side



CT dosimetry

- CT dose indicators were not available on SSCT scanners
- Landmark NRPB national CT dose survey in 1989
  - NRPB reports R248 – R250
  - Fixed scan parameters collected for common exams
  - CTDI-in-air measured using TLDs
  - Normalised organ doses calculated using MC techniques -> E

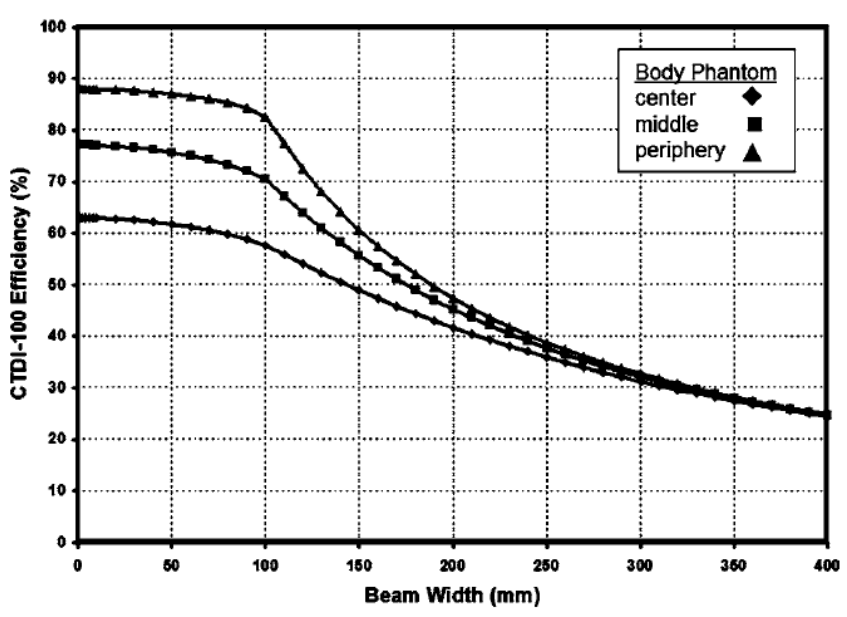


CT dosimetry

- $CTDI_w$ proposed in 1995 (Leitz *et al* 1995)
- In 1998 $CTDI_{vol}$ and DLP recommended by CEC for CT dosimetry
- Turned out to be controversial in US
  - Publications by John Boone and Bob Dixon
- Adopted as IEC standard
  - Available on CT scanners from MSCT onwards

CT dosimetry

- Definitions of $CTDI_{vol}$ and DLP revised for wide-beam CT scanners c. 2010
  - Platten *et al* 2013
- Further controversy in the US
  - Counter-proposal: equilibrium dose



Boone 2007

CT dosimetry

- CT dose surveys carried out since c. 1995

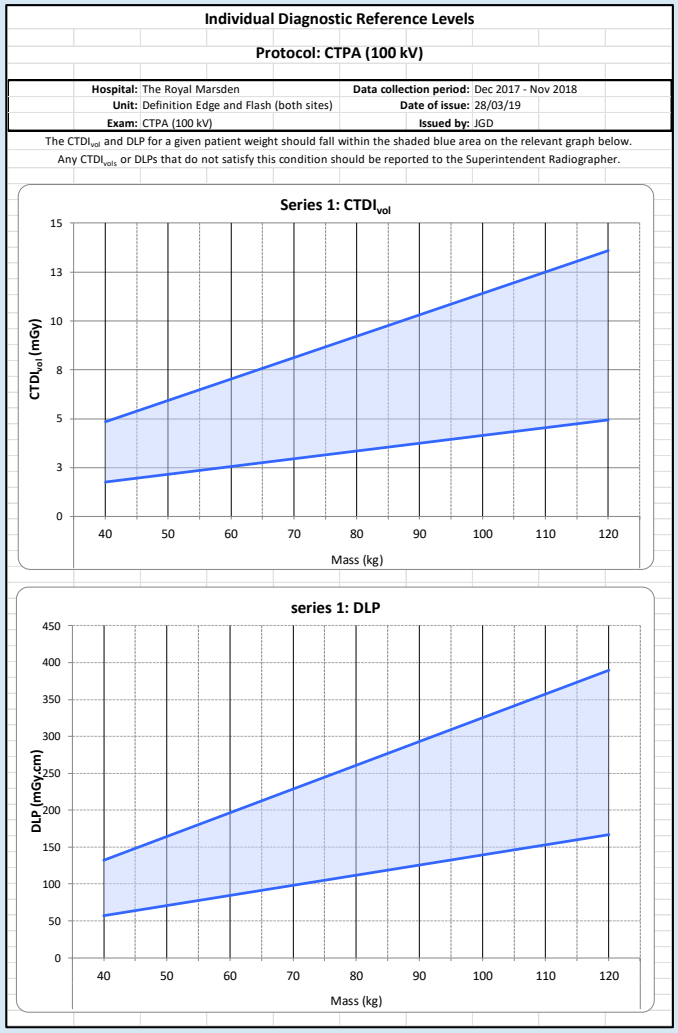
period	Scanner type	CT dose indices	H&W	Scan protocol	CTDI measurement	Effective dose estimate
1990s	SSCT	n/a	n/a	manual	CTDI-in-air (TLDs)	Manual calculation
2000s	SSCT	n/a	n/a	manual	CTDI-in-air (CT chamber)	ImPACT calculator
2000s	MSCT	Paper Excel	H&W AP+LAT	manual	CTDI-in-air	ImPACT CT-Expo
2012+	MSCT	OpenREM	H&W	Protocol listing	CTDI-in-air	ImPACT CT-Expo

CT dosimetry

- CT dose surveys have become easier through advent of DMSs…
- …but more problems now come to light
- Is it dose audit or is it optimisation?

Local and individual DRLs

- With information on patient size, we can go beyond local DRLs
- IDRL charts being used for operator-led audit



Individual Diagnostic Reference Levels

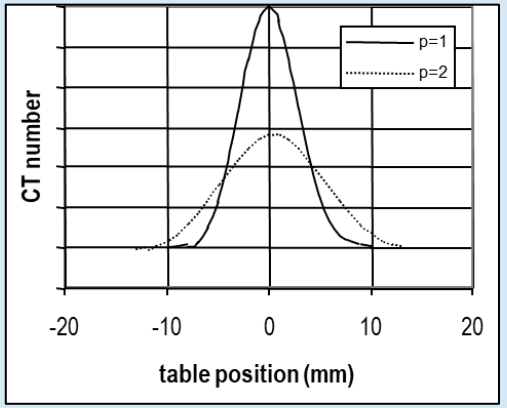
Protocol: CTPA (100 kV)

Hospital: The Royal Marsden	**Data collection period:** Dec 2017 - Nov 2018
Unit: Definition Edge and Flash (both sites)	**Date of issue:** 28/03/19
Exam: CTPA (100 kV)	**Issued by:** JGD

The $CTDI_{vol}$ and DLP for a given patient weight should fall within the shaded blue area on the relevant graph below.
Any $CTDI_{vol}$s or DLPs that do not satisfy this condition should be reported to the Superintendent Radiographer.

Early attempts at optimisation

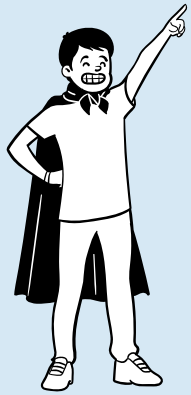
- In 2000s, shared learning from commissioning
  - IQ and mAs changes with pitch
  - Behaviour of tube current modulation



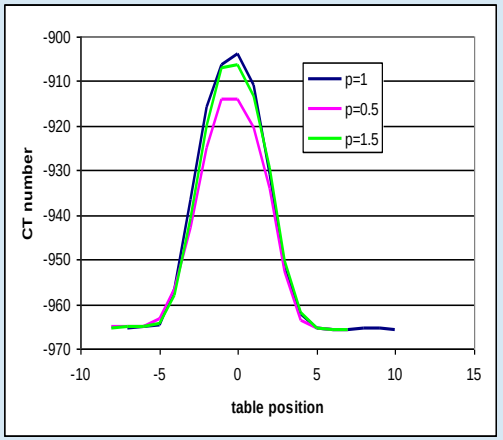
Helical SSCT

SPR	AEC mode	$CTDI_{vol}$ mGy
90º then 0º	Auto mA	5.7
0º then 90º	Auto mA	10.1

GE LS16



Physicist who cracked Philips TCM



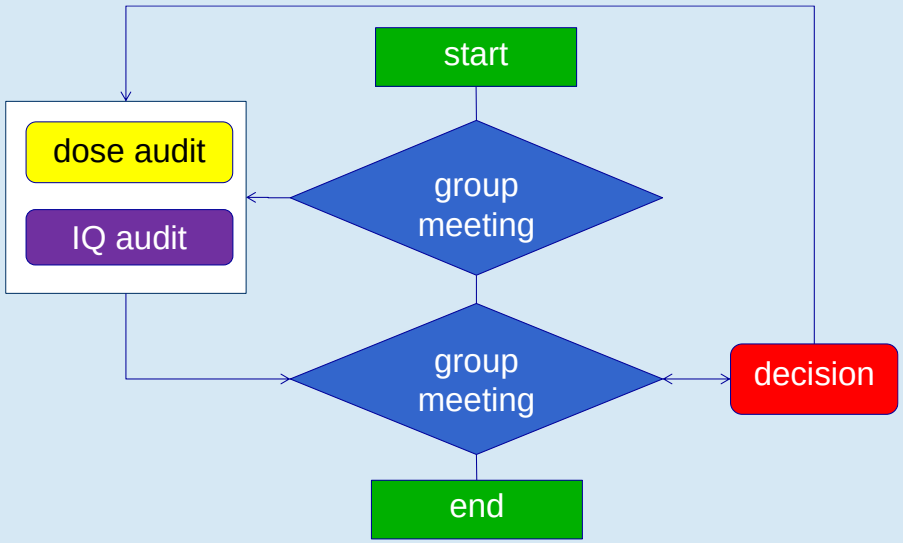
Helical MSCT

Early attempts at optimisation

- Transferred knowledge between hospitals
  - HRCT of the chest
- Transferred scan protocols between scanners
  - Often doses for default scan protocols on new scanner were higher than for local (optimised) scan protocols
    - Need to be careful about how to say this
- Configured tube current modulation
  - With detrimental consequences at times
  - Tip: use anthropomorphic phantoms

Optimisation MDTs

- Started in 2012
- Poor IQ provided impetus
- Meeting format chosen to suit clinical team



RMH CT optimisation meeting, 13 Feb 2017

Present: Elly Castellano (IAC), Ed McDonagh (ETM), Laurence King (LRK), Jamie Dormand (JGD), Jonathan Frazer-McRobert (JFM), Cate Savidge (CS), Angela Riddell (AR), Michelle Peters (MP)
Location: Dovehouse Street basement meeting room.

Redmine RMH optimisation page: http://frp-vm-svn:5000/projects/rmh

Last meeting: CTOptimisationMeeting2016x03

Optimisation projects

See last meeting page for table of ongoing projects: These will be updated in minutes of this meeting.

Revision 2 of this page contains the minutes taken at time of this meeting on the 13th February.

project name	project type	objective in brief	started	scanners	project team	Redmine	status	meeting notes
CT DIEP scans	clinical	Improve quality of images surgeons use and achieve protocol parity across sites	March 13	Chelsea Flash, Chelsea Edge, Sutton Flash, Sutton Edge	CS, DM, DG		in progress	show Mar16 minutes show Feb17 minutes
CT NTAP scans	clinical	match neck and TAP series over shoulders	November 12	Chelsea Flash, Chelsea Edge, Sutton Flash, Sutton Edge	CS, DM, DG	redmine link	in progress	show Mar16 minutes show Feb17 minutes
HRCT scans	clinical	review volume v interspaced techniques	July 14	Chelsea Flash, Chelsea Edge, Sutton Flash, Sutton Edge, LS16	CS, DM		in progress	show Mar16 minutes show Feb17 minutes
CT Colonoscopy	clinical	reduce dose for prone scan?		Chelsea Flash, Chelsea Edge, Sutton Flash, Sutton Edge, LS16	CS, DM / Sandy, AR, EM			show Mar16 minutes show Feb17 minutes
5 to 3 mm imaging	clinical	move to 3 mm axial recons as standard	August 14	Chelsea Flash, Chelsea Edge, Sutton Flash, Sutton Edge	EM, AR, CS, DM	redmine link	in progress	show Mar16 minutes show Feb17 minutes

Optimisation today

- Configure global TCM settings
- Set up / modify scan protocols with CT lead
  - For new scanners (with Apps)
  - As part of optimisation project
- Troubleshoot scan settings
  - With CT lead and Apps
- Carry out before-and-after dose audits
  - Using OpenREM
- IQ assessed by radiologists / IQ measurements
  - CNR, NPS, MTF using appropriate phantoms

Optimisation

- First optimisation project is the hardest
- Optimisation is a continuous process
  - Expect flurry of activity for a new scanner
    - Agree principles for setting up scan protocols in advance
- Each project requires different resources
  - Interspaced HRCT: protocol change; CT lead; 10 min
  - CT DIEP angio: several technique iterations on 3 scanners; 3 CT leads, radiologist, surgeon; 7 years
- The more you do, the more there is to do
- Publish what you do to help others

What does the future hold for the medical physicist?

- Less quality control testing!
- Focus on commissioning to aid optimisation
- Manufacturer training for physicists
  - Reduce amount of reverse engineering required
- Automated routine QC testing
  - We set up the scan protocols
  - Radiographers scan phantoms
    - Do we need to measure CTDI and beam profiles?
    - Will we lose the skill to drive the scanner?
  - Images analysed automatically
    - We review results

What does the future hold for the medical physicist?

- Less routine patient dosimetry!
- Universal access to DMSs
- Automated generation of local DRLs
  - Mapping of scan protocol names onto DMS is a pre-requisite
- Greater emphasis on achievable dose indicators
- Focus on patient dose audit for optimisation purposes

What does the future hold for the medical physicist?

- More CT optimisation!
- Lots exciting things coming up:-
  - Photon counting CT
  - AI-based reconstruction

Acknowledgements

- Sue Edyvean and UKHSA team
- ImPACT team
- Ed McDonagh
- RMH DR physics group through the ages
- Tim Wood