Dose Audits and Dose Reference Levels in Radiotherapy Imaging: The UK Experience

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Optimisation in practice – CBCT

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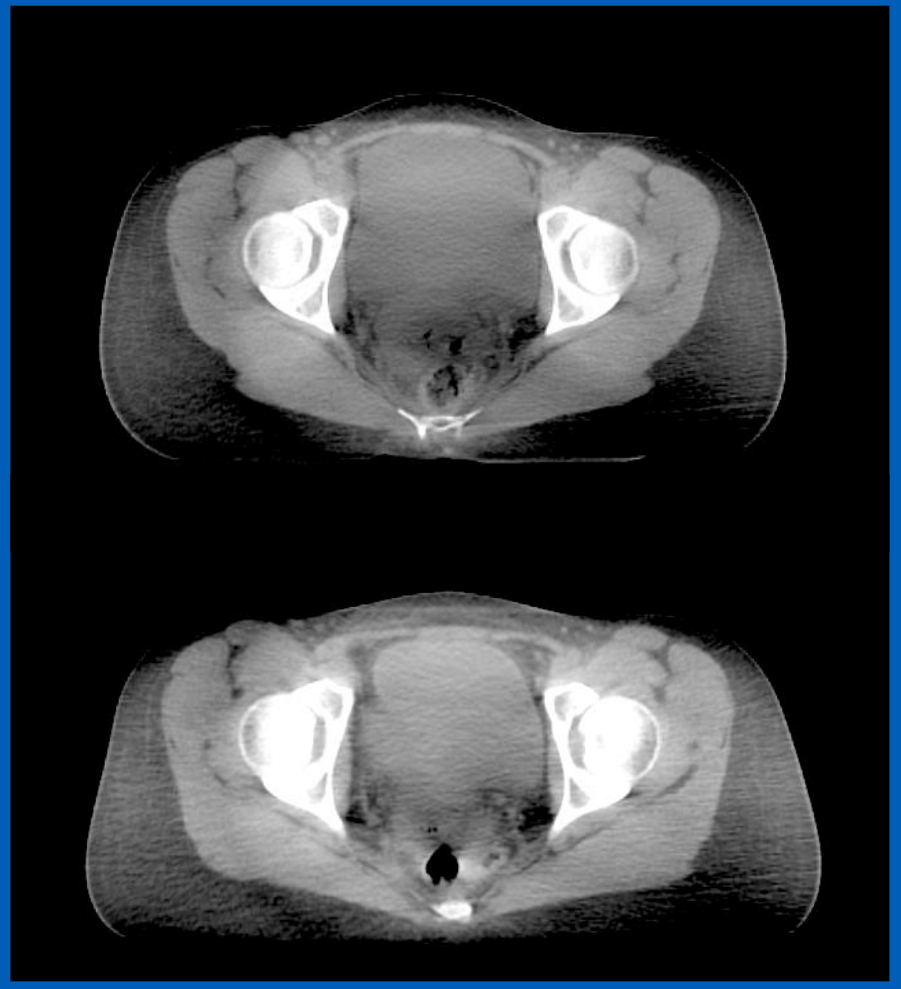
- Many years ago in Hull, UK…
- Concerns were raised about the imaging dose burden for a 56 kg (very slim) patient imaged with Varian default exposure factors
- Over a couple of fractions, and a few repeat exposures (for setup issues), kVp and mA were reduced
- **No adverse effect on image quality, BUT 'DOSE' WAS REDUCED BY A FACTOR OF THREE**



Optimisation in practice – CBCT

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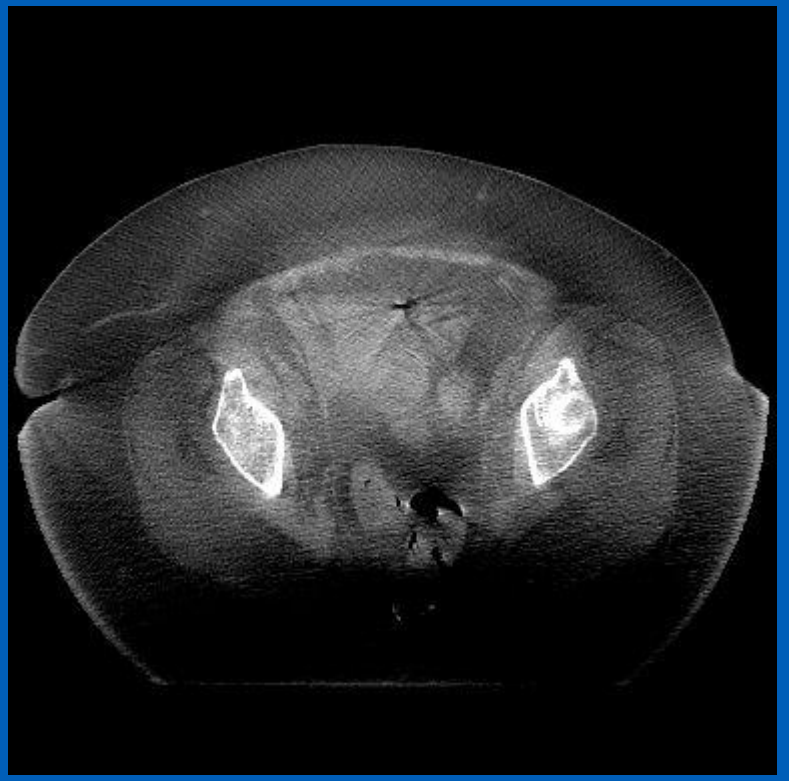
- At the same time, we were presented with problems related to poor image quality on a very large patient (116 kg)
- This exposure was not optimised (or justified) as the Radiographers couldn't see what they were looking for
  - The 'intended purpose' was lost in the noise & artefacts!
- The only option was to increase exposure factors
  - We had to double pulse width (and hence dose) to reduce the noise to improve soft-tissue contrast



Optimisation in practice

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- But should we be doing all of this in complete isolation?
- What are others doing in response to these challenges?

- **Can we audit and benchmark our practice with relatively simple techniques?**

- Take some long-established concepts from diagnostic imaging and apply to RT…

The IPEM RT Imaging Dose Working Party

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The IPEM RT Imaging Dose Working Party: Aims

- To undertake an audit of typical imaging doses for a range of common X-ray imaging procedures undertaken in Radiotherapy departments
  - This includes planning CT scans and on treatment CBCT imaging
- To publish a range of typical ‘doses’ for common procedures
  - Should allow adoption as national dose reference levels for RT imaging
- **Make data available to the UK Radiotherapy community that will enable better optimisation of imaging**
  - Identify ‘best practice’ that will ultimately benefit patients

Patient ‘dose’ audits

- Collect a sample of ‘many’ patient dose indices for a range of specific clinical indications, alongside base protocol information
- **Median** from each scanner was used to define scanner average $CTDI_{vol}$, DLP, scan length
  - More robust against outliers e.g. very obese patients
  - In accordance with guidance from the ICRP on ‘Diagnostic Reference Levels in Medical Imaging’
- **Third quartile** (‘national reference’) and **median** (‘achievable’) of the **scanner median data** were calculated in Excel

CT planning scans

The ‘easy’ one?

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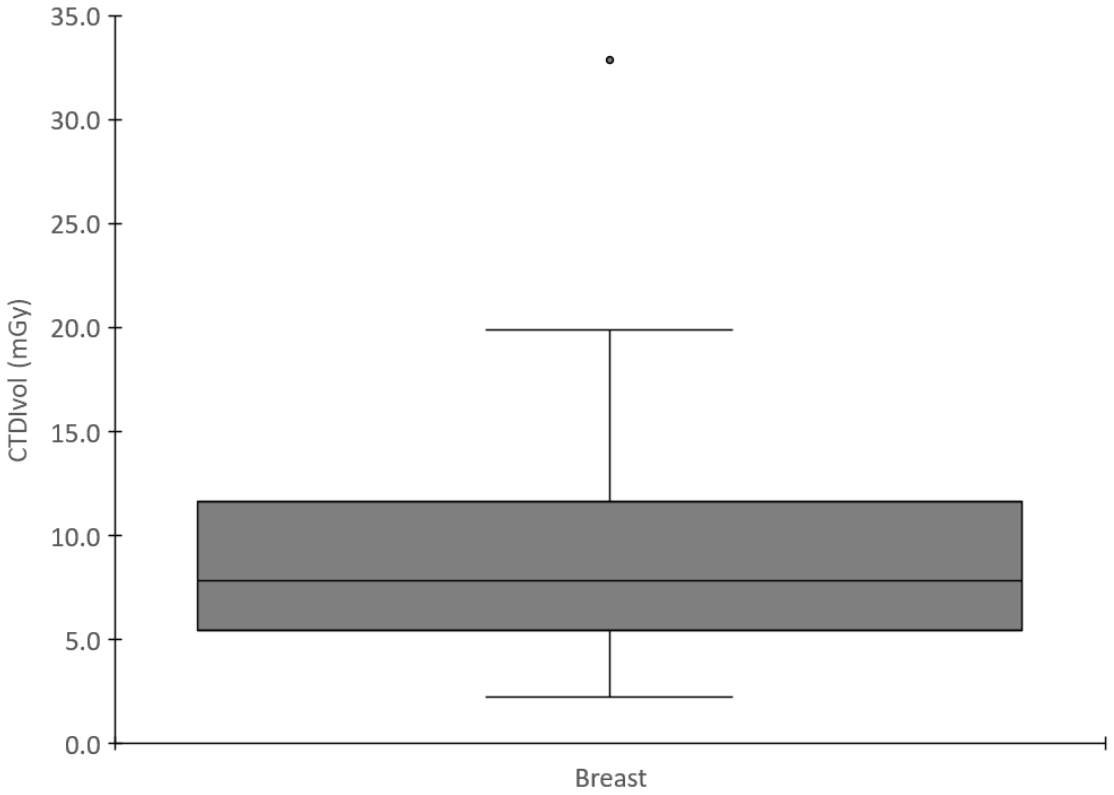
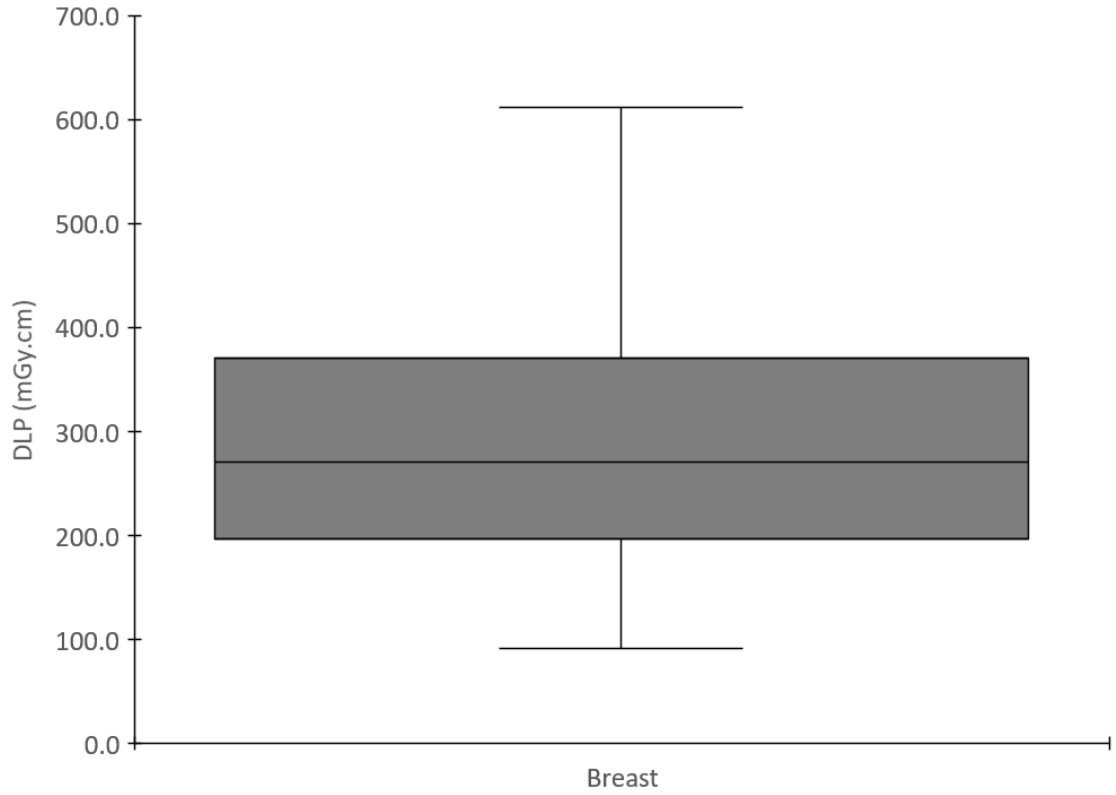
CT planning scans

- Data collection in Feb 2017-Sept 2017
- 7 clinical indications included in the audit:
  - Brain; Head & Neck; Breast; Lung 3D; Lung 4D; Prostate; Gynaecological
- Data received from 68 CT scanners in 57 RT centres
  - Scanner mix: GE: 22%; Philips 40%; Toshiba 20%; Siemens 18%

- **T Wood**, A Davis, J Earley, S Edyvean, U Findlay, R Lindsay, R Plaistow, A Nisbet, A Palmer and M Williams, IPEM topical report: the first UK survey of dose indices from radiotherapy treatment planning computed tomography scans for adult patients, Phys. Med. Biol. 63 185008

Breast CT planning





CT Planning scans – UK NDRLs

Examination	Phantom diameter (cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Scan length (mm)
Breast	32	10	390	360
Gynaecological	32	16	610	400
Lung 3D	32	14	550	390
Lung 4D	32	63	1750	340
Prostate	32	16	570	340
Brain	16	50	1500	290
Head and neck	16	49	2150	420

CT Planning scans – Achievable values

Examination	Phantom diameter (cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Scan length (mm)
Breast	32	8	280	330
Gynaecological	32	12	510	390
Lung 3D	32	10	410	370
Lung 4D	32	36	1170	330
Prostate	32	13	420	310
Brain	16	42	1110	250
Head and neck	16	26	1080	400

CBCT scans

Now things get tricky…

On-treatment volumetric scans

- Need to consider:
  - Use of manufacturer defaults/size-specific protocols and difference between vendors
  - Lack of ‘dose display’ on some systems/poorly defined (typed in for the protocol)
- Data collection October 2019-September 2020
  - **Protocol data** on all clinical modes in use at the centre
  - **Patient sample data –** if variations between patients, a sample of patient exposure information was requested
  - **Dosimetry information –** measurements with 100 mm pencil chamber in standard CTDI phantoms were requested **– Cone Beam Dose Index (CBDI)**
- Not all centres were able to provide all information
  - Had 55 data submissions for Varian linacs, and 23 for Elekta

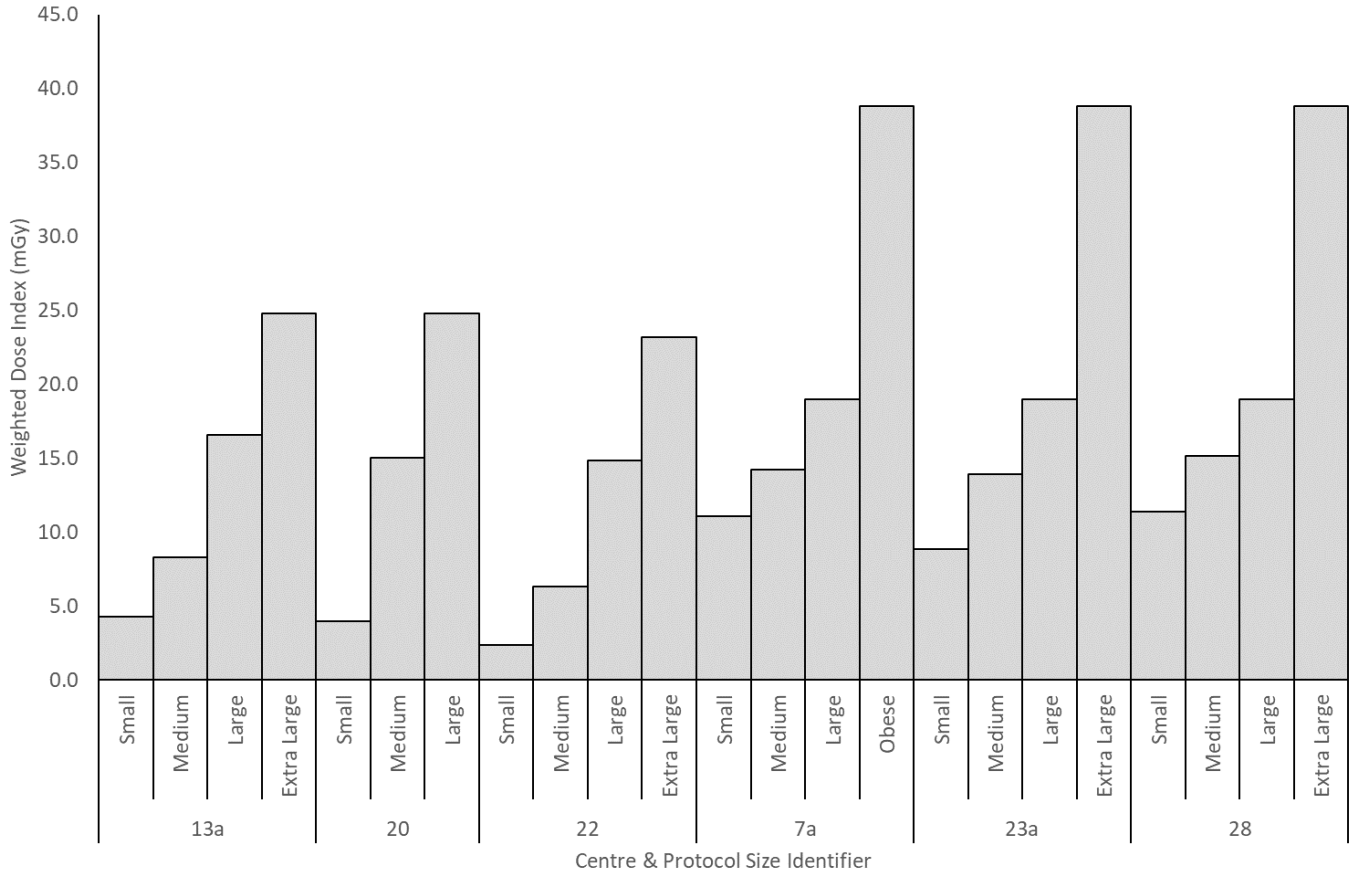
Data analysis

- The basic idea of the analysis was:
  - Collect and compare **dosimetry information** between systems
    - As we knew not all centres would be able to measure, defined the **normalised CBDI** for an ‘average’ system of that type i.e. Elekta, TrueBeam and Clinac/Trilogy
  - Assign a **weighted CBDI** to each protocol submitted by each centre, based on the average model data defined above
    - Compare **protocol CBDI** between centres
  - Where variations were allowed between patients (e.g. size specific modes), use a sample of patients to determine the median dose index for the ‘standard’ patient in each centre, for each clinical indication
    - Compare **median CBDI** for each clinical indication between each centre

Dosimetry information – 'Body' normalised CBDI

Model	Varian TrueBeam	Elekta XVI	Varian Clinac/Trilogy	Elekta XVI
kVp	125	120	125	120
Filter	Half-fan	F1	Half-fan	F0
Collimator	Max	M20	Max	M20
Trajectory	'Full'	'Full'	'Full'	'Full'
Number of measurements	43	20	11	18
Median central CBDI (mGy/mAs)	0.013	0.013	0.021	0.019
Standard deviation	0.001	0.003	0.003	0.002
Median weighted CBDI (mGy/mAs)	0.018	0.019	0.030	0.036
Standard deviation	0.001	0.003	0.002	0.004

Prostate protocol doses – size based (some examples)



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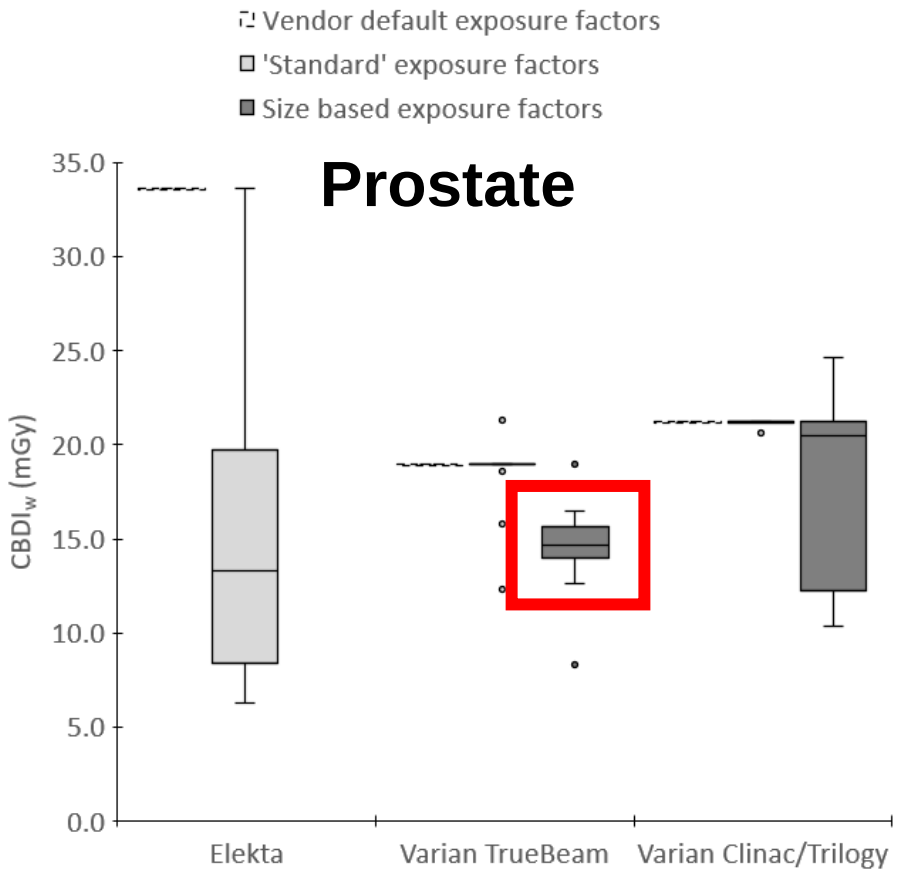
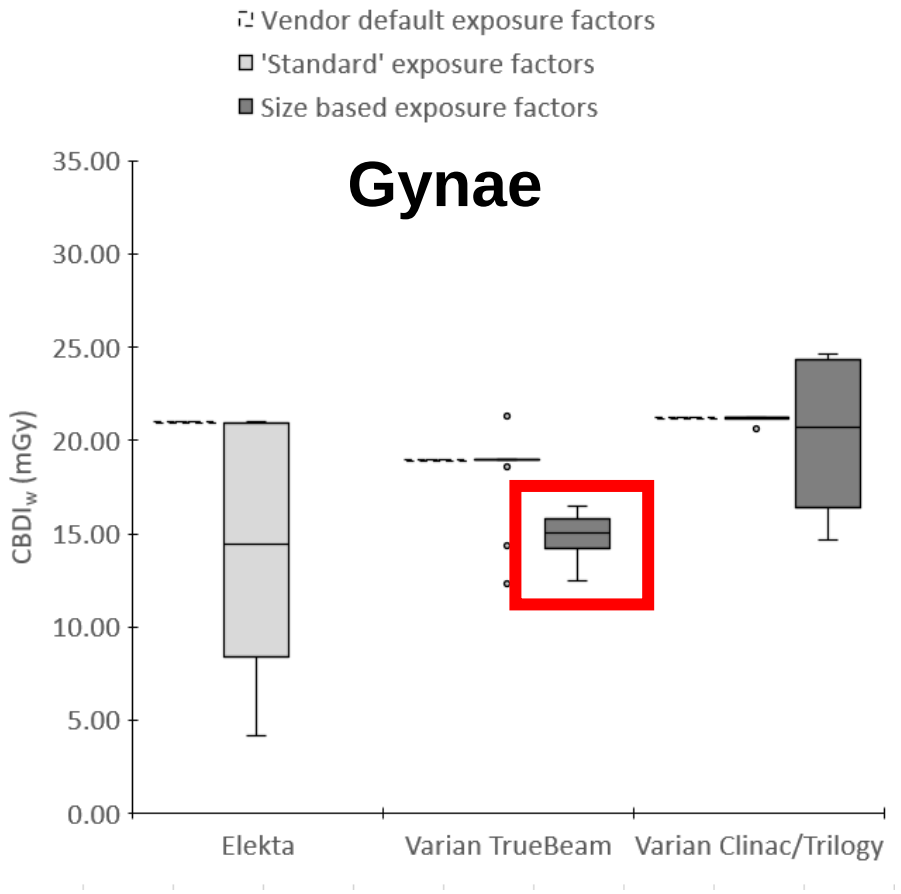
Size based - implementation

- Range of techniques for defining size
  - e.g. AP/lateral dimensions at isocentre, planning CT factors, water-equivalent diameter from planning system, ‘by-eye’
  - The ‘by-eye’ approach was by far the least successful method as this rarely prompted change in protocols from a ‘standard’ one

Pelvic sites – Prostate and Gynae – CBDI





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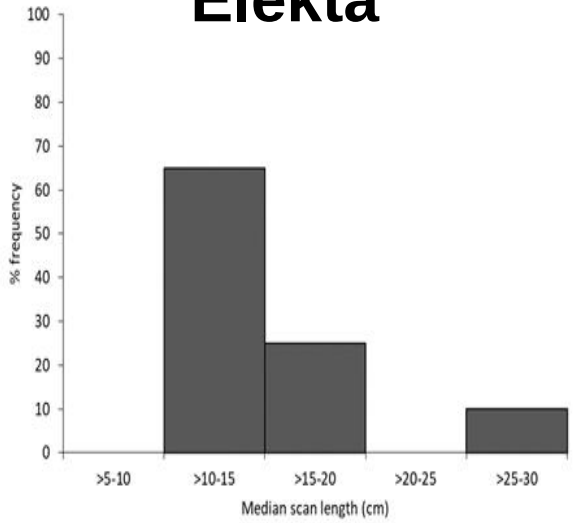
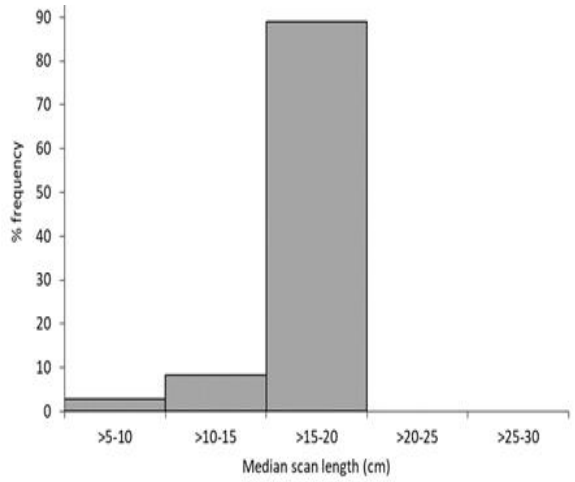
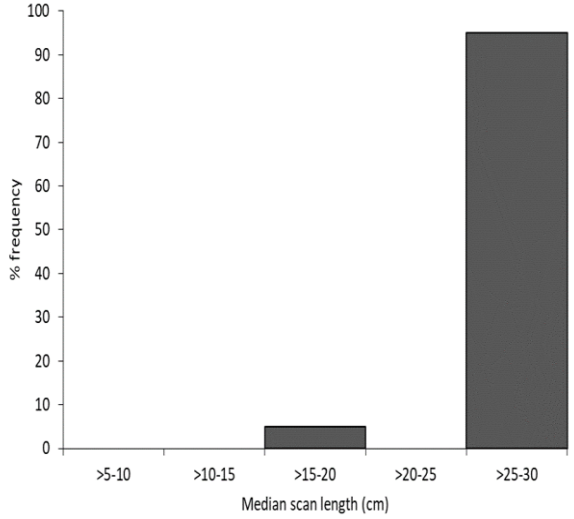
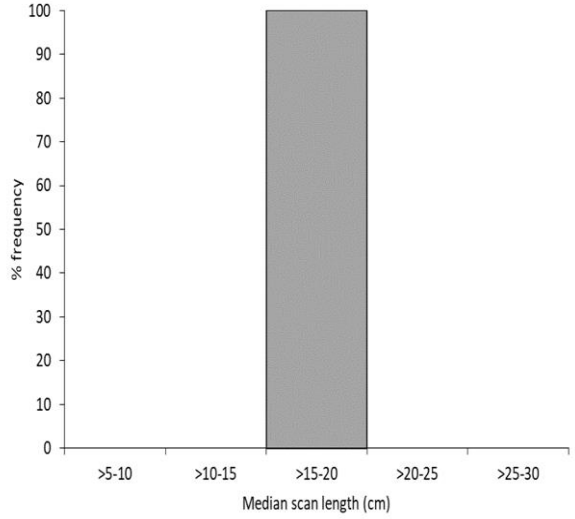
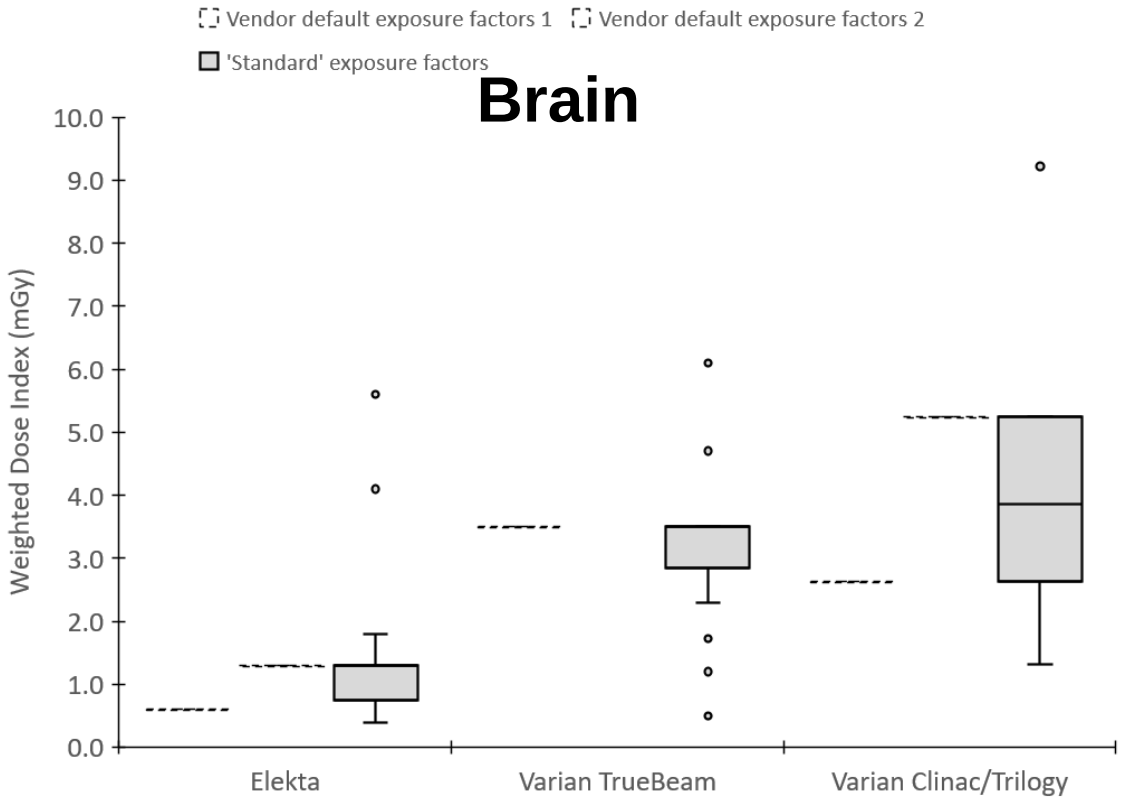
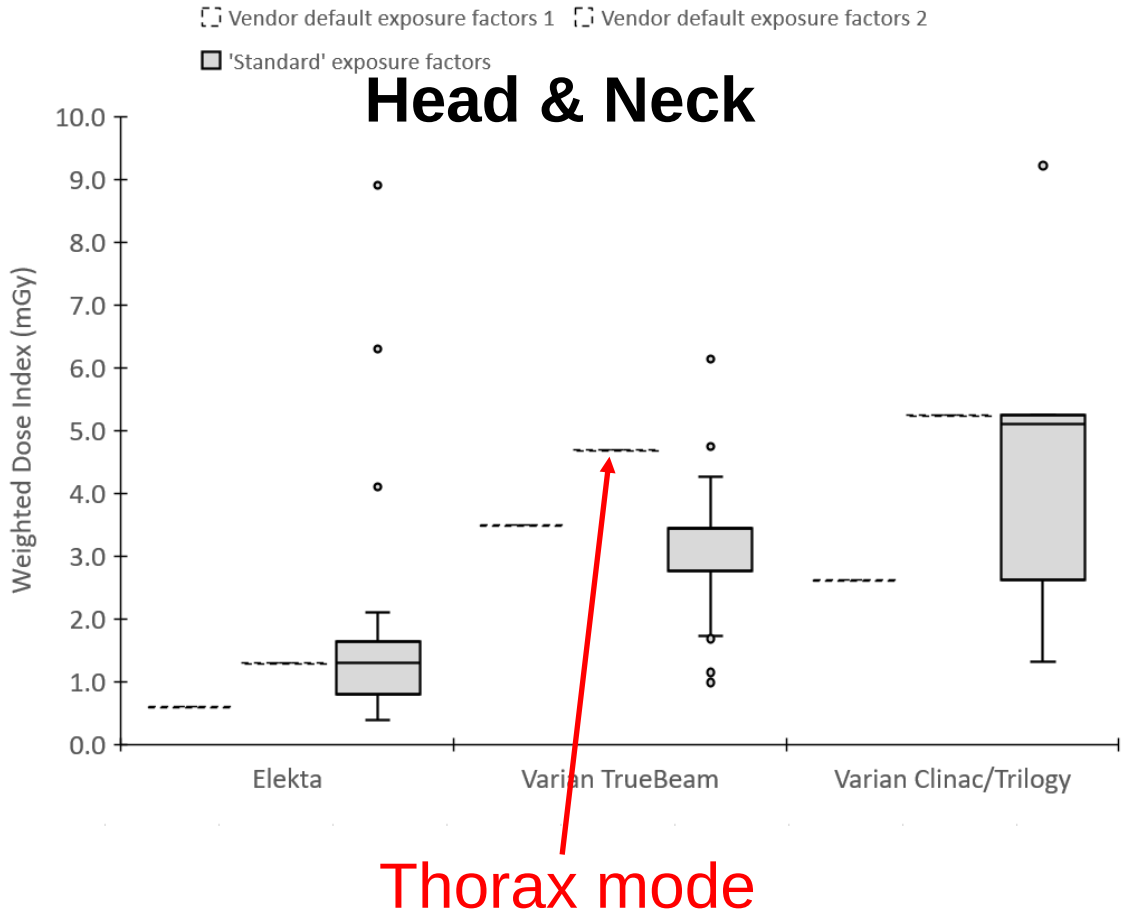
Pelvic sites – Prostate and Gynae – Scan Length

	Elekta	Varian TrueBeam
Prostate		
Gynae		

Brain and Head & Neck





Summary CBDI values – NDRLs?

Clinical site	Number of centres	UK wide $CBDI_w$ (mGy)		
		Median	3rd Quartile	IQR
Brain	51	2.6	3.5	2.2
Head & Neck	74	3.5	4.2	2.9
Breast	38	4.1	5.0	2.4
Lung 3D	75	4.7	6.0	1.3
Lung 4D	27	11.5	11.8	1.9
Prostate	73	19.0	20.6	6.2
Gynae	65	19.0	20.8	5.9

The papers

- Planning CT
  - https://iopscience.iop.org/article/10.1088/1361-6560/aacc87
- CBCT
  - https://iopscience.iop.org/article/10.1088/1361-6560/ad88d1

National **Dose** Reference Levels

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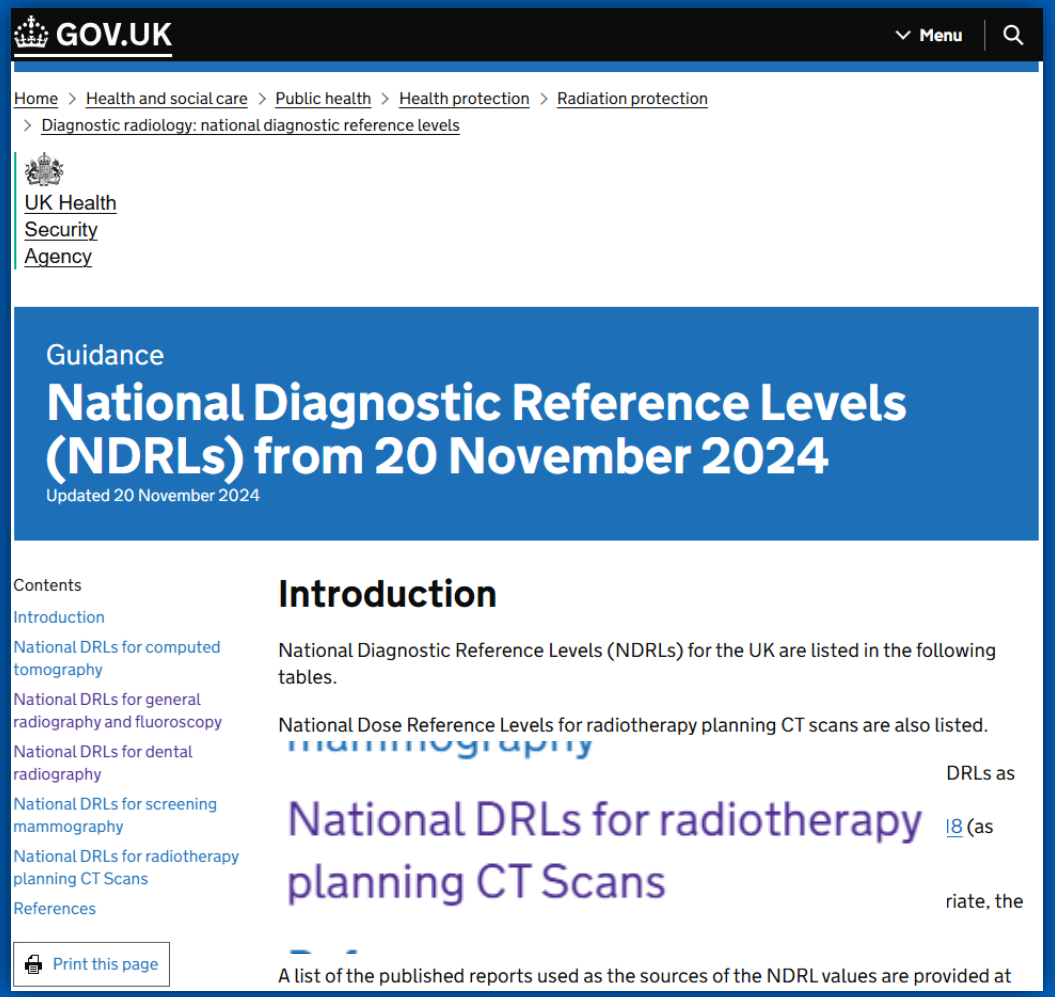
- National Diagnostic Reference Levels (NDRLs) from 20 November 2024 - GOV.UK



GOV.UK Menu

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UK Health Security Agency

Guidance

National Diagnostic Reference Levels (NDRLs) from 20 November 2024

Updated 20 November 2024

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National DRLs for computed tomography

National DRLs for general radiography and fluoroscopy

National DRLs for dental radiography

National DRLs for screening mammography

National DRLs for radiotherapy planning CT Scans

References

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Introduction

National Diagnostic Reference Levels (NDRLs) for the UK are listed in the following tables.

National Dose Reference Levels for radiotherapy planning CT scans are also listed.

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DRLs as

National DRLs for radiotherapy planning CT Scans

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A list of the published reports used as the sources of the NDRL values are provided at

National **Dose** Reference Levels

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National DRLs for radiotherapy planning CT Scans

Radiotherapy planning CT scans are not considered diagnostic scans, and therefore the use of the term Diagnostic Reference Levels is not appropriate. However, the use of dose reference levels is a useful method of demonstrating dose optimisation has taken place. The following table provides dose index values, which can be taken to be equivalent to formal NDRLs.

Table 10. National DRLs for radiotherapy planning CT Scans

Examination	$CTDI_{vol}$ per sequence (mGy)	DLP per complete examination (mGy cm)	Scan length (mm)	Year NDRL adopted
Breast	10	390	360	2018
Gynaecological	16	610	400	2018
Lung 3D	14	550	390	2018
Lung 4D	63	1750	340	2018
Prostate	16	570	340	2018
Brain	50	1500	290	2018
Head and Neck	49	2150	420	2018

Doses for the brain and 'head and neck' examinations only refer to measurements in the 16cm standard CT dosimetry phantom. All other doses refer to measurements in the 32cm standard CT dosimetry phantom.

Values taken from 'IPEM topical report: the first UK survey of dose indices from radiotherapy treatment planning computed tomography scans for adult patients'.

UK regulations

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- The UK **Ionising Radiation (Medical Exposure) Regulations 2017** are designed to protect **patients** from the effects of ionising radiation
- Amended 1st October 2024

STATUTORY INSTRUMENTS

2024 No. 896

HEALTH AND SAFETY

The Ionising Radiation (Medical Exposure) (Amendment) Regulations 2024

(4) After the definition of "diagnostic reference levels", insert—

""dose reference levels" means dose levels in radiotherapeutic practices for typical localisation or verification exposures for groups of standard-sized individuals or standard phantoms for broadly defined types of equipment;".

UK regulations – IR(ME)R 2017

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Optimisation

12.—(1) In relation to all exposures to which these Regulations apply except radiotherapeutic exposures, the practitioner and the operator, to the extent of their respective involvement in an exposure, must ensure that doses arising from the exposure are kept as low as reasonably practicable consistent with the intended purpose.

(2) In relation to all radiotherapeutic exposures the practitioner must ensure that exposures of target volumes are individually planned and their delivery appropriately verified taking into account that doses to non-target volumes and tissues must be as low as reasonably practicable and consistent with the intended radiotherapeutic purpose of the exposure.

(3) Without prejudice to paragraphs (1) and (2), the operator must select equipment and methods to ensure that for each exposure the dose of ionising radiation to the individual undergoing the exposure is as low as reasonably practicable and consistent with the intended diagnostic or therapeutic purpose and in doing so must have regard, in particular to—

(a) quality [F1 control];

(b) assessment and evaluation of patient dose or administered activity; F2...

(c) adherence to such diagnostic reference levels for radiodiagnostic examinations [F3 and interventional radiology practices] falling within [F4 regulation 3(1)(a)], (b), (e) and (f) as the employer may have established, [F5 and

(d) adherence to such dose reference levels for radiotherapeutic practices for typical localisation or verification exposures falling within regulation 3(1)(a) as the employer may have established,]

as set out in the employer's procedures.

Dose records and auditing

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- Successful ‘dose audit’ requires good quality data that is readily accessible, filtered and analysed
- Options for recording parameters relevant to dose include;
  - Dose Management Systems are an effective solution, but check the records are complete and accurate (particularly for CBCT systems)
  - Oncology Management Systems can also be used to capture and audit dose information
- Need to clearly define your ‘clinical indications’
  - Avoid mixing data into generic sites – e.g. prostate and gynae separately, rather than just ‘pelvis’
  - Think about special applications and the image quality requirements of those e.g. SABR
- Validate your dose indices
  - Check you are comparing like-for-like and accurate numbers, especially for CBCT
- UKHSA Safer RT Newsletter – September 2022
  - https://www.ukhsa-protectionservices.org.uk/cms/assets/gfx/content/resource_5117csae0e08163d.pdf

RT patient dose audits in Hull University Teaching Hospitals NHS Trust

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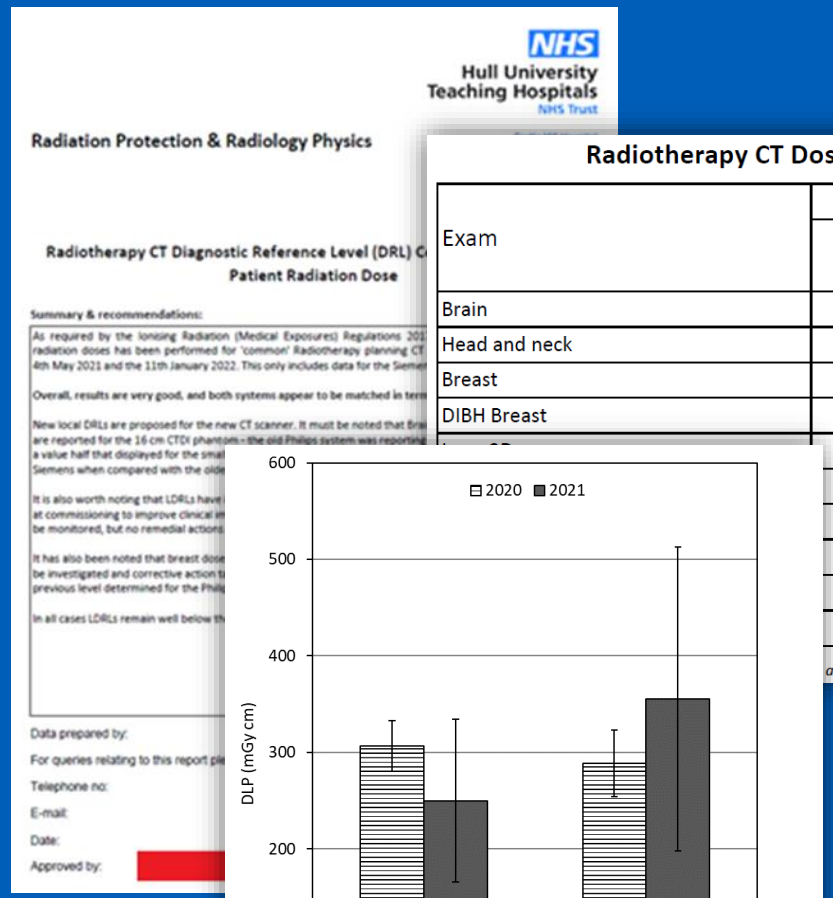
- Perform annual dose audits and check compliance with established local DRLs
  - Relies on co-operation between the diagnostic and radiotherapy physics teams
- Use the tools (e.g. OpenREM), expertise and staff in these teams to do this efficiently and feedback to RT
  - Report through RT governance structures



Radiotherapy CT Dose Reference Levels

Exam	DLP (mGy cm)	
	Local DRL	National DRL†
Brain	980	1500
Head and neck	380	1050
Breast	230	390
DIBH Breast	470	-
	310	550
	800	1750
	1450	-
	550	-
	380	610
	320	570

al (Phys. Med. Biol. **63** 185008)

ICRP TG116

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- **Key recommendation in the new guidance is to adopt the concept of DRLs and patient dose audits for imaging in RT**

> **Doses from x-ray imaging exposures are measured in terms of quantities based on air kerma. Surveys of these quantities and comparisons of median dose values with dose reference levels (DRL_{RT}s) for imaging in radiotherapy will help to promote standardisation of imaging practices and encourage optimisation.**

- Work has been undertaken to look at alternative methods of CBCT dose measurement where 100 mm pencil chambers and CTDI phantoms are not available:
  - Cone beam CT (CBCT) in radiotherapy: Assessment of doses using a pragmatic setup in an international setting - Physica Medica: European Journal of Medical Physics, Djukelic, Mario et al., Physica Medica: European Journal of Medical Physics, Volume 131, 104937
- Work ongoing on the collection and audit of data across the world

Summary

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- Patient dose audits and **Dose Reference Levels** are a useful guide to help start the optimisation process in Radiotherapy imaging
  - Allow benchmarking against practice established in other centres
- They are just one tool in the optimisation toolbox
  - Just establishing DRLs does not mean you have achieved your goals towards optimisation – **you need to interpret and use the information it provides you with**
  - They are based on dose indices – they are not patient dose
  - You must review clinical image quality (ideally as part of a rolling programme)
- Quality data collection and clear clinical indications are essential
  - Don’t just audit ‘Pelvis’!
- They become especially useful when centres optimise local imaging protocols and move away from vendor default settings

United By Compassion: Driving For Excellence