Dose assessment and optimization of acquisition protocols for CT simulation

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Joint ICTP-IAEA Workshop on Radiation Protection in Image-Guided Radiotherapy (IGRT)

Summary

Dose assessment

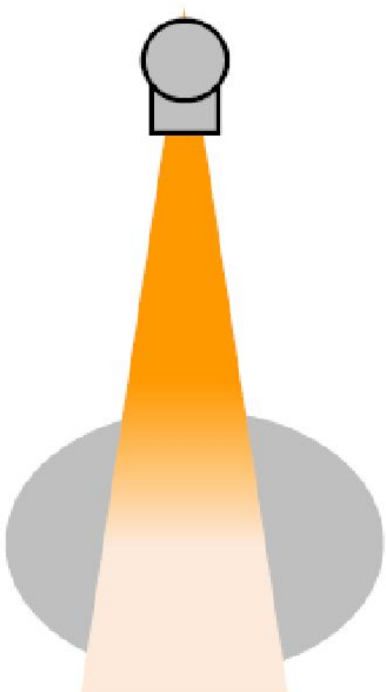
- Dose distribution from a CT scan
- Dose Metrics used in CT
  - CTDI ($CTDI_{\infty}$ CTDI100, CTDIair, CTDIw, CTDIvol)
  - DLP
  - Effective dose
  - CTDIvol Wide beam
  - SSDE (size specific dose estimate)
- $CTDI_{infinity}$

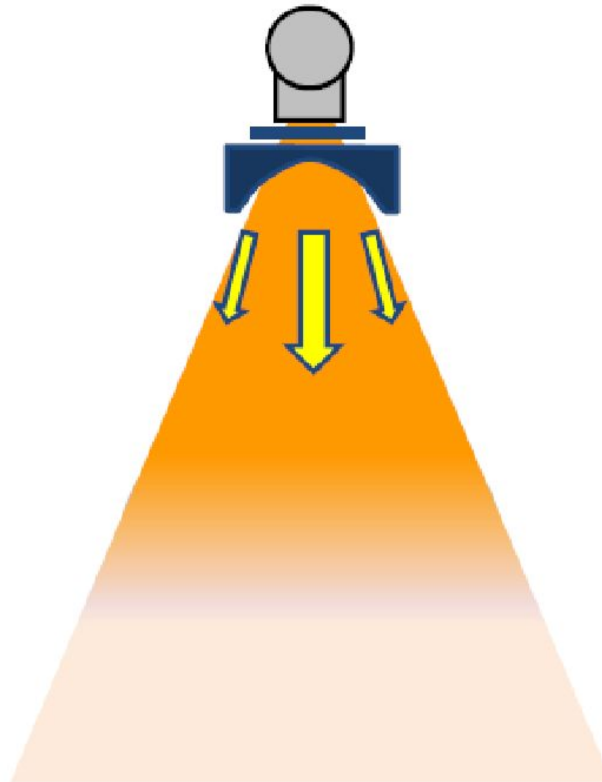
DRLs

Dose Optimization

Dose distribution in Scan Plane

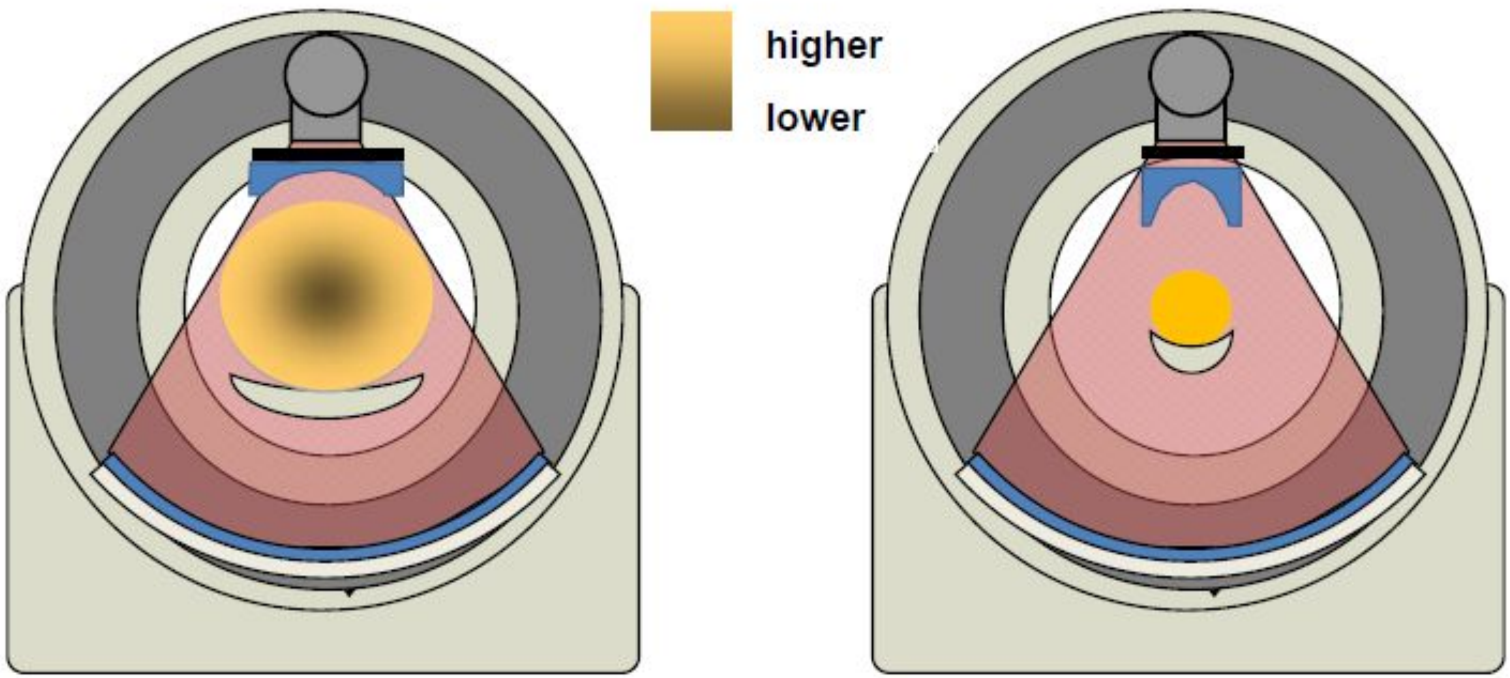
In PR part of the body irradiated





In CT whole body irradiated

Dose distribution in Scan Plane



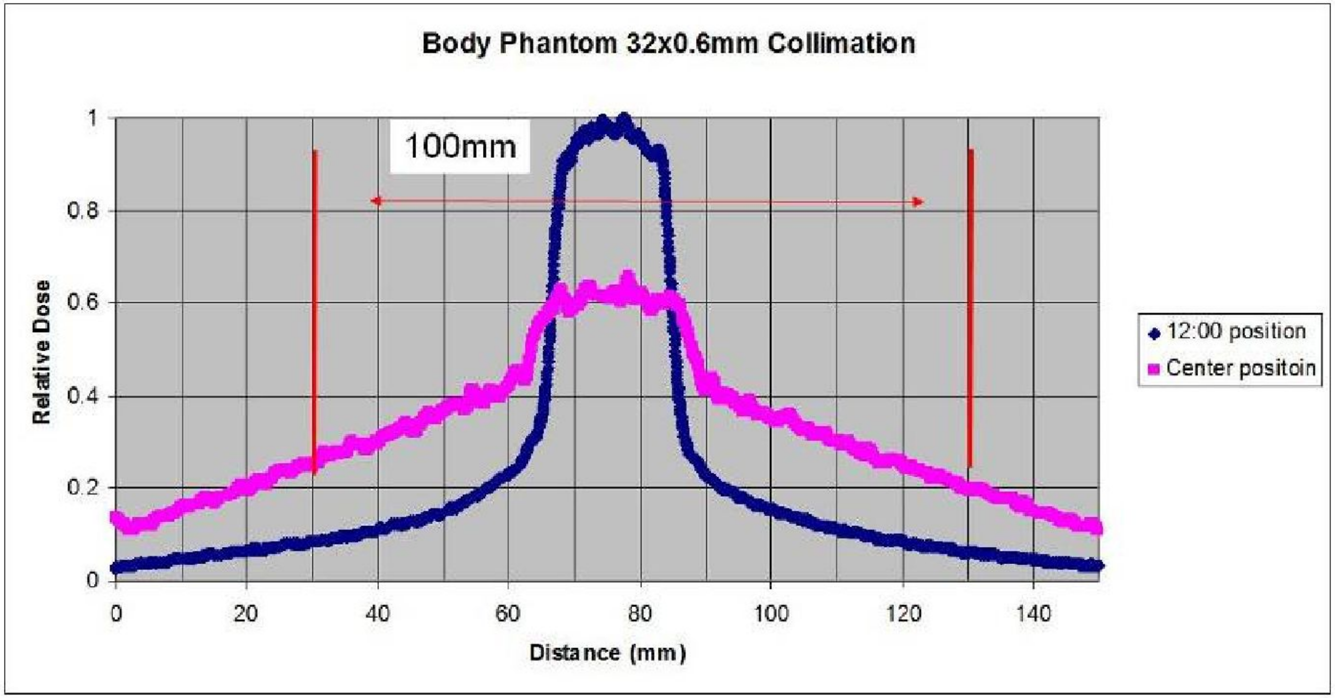
Periphery to centre ratio:

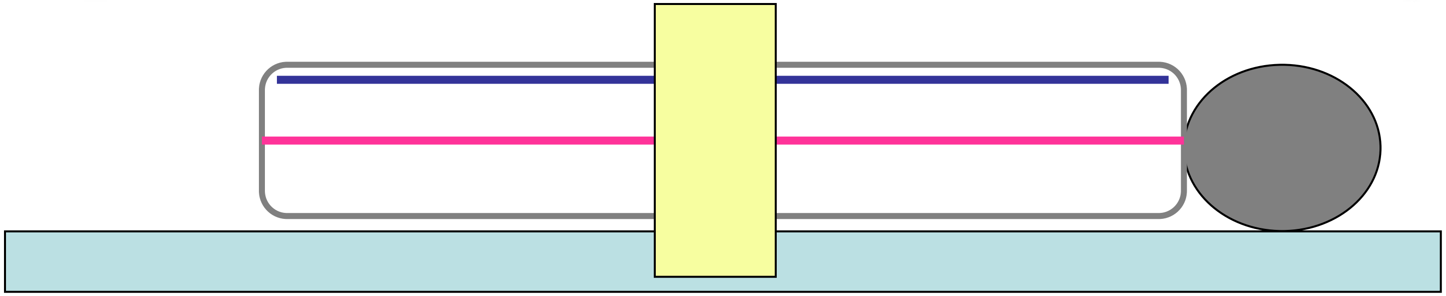
Body ~ 2:1

Head ~ 1:1

Dose distribution in CT

Dose profile from one slice





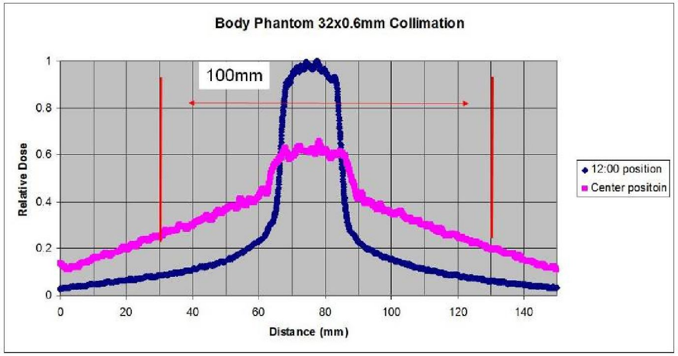
Dose metrics in CT

- MSAD Multiple Scan Average Dose
- CTDI Computed Tomography Dose Index*
- DLP Dose Length Product
- E Effective Dose
- SSDE Size Specific Dose Estimate

*

CTDIair
CTDI100
CTDIw
CTDIvol
CTDI∞

CTDI- general



A descriptor telling about the type of CTDI
(integration length, or medium measured in)

The dose profile

$$CTDI_L = \frac{1}{NxT} \int_{-L/2}^{+L/2} D(z)\,dz$$

The nominal beam width

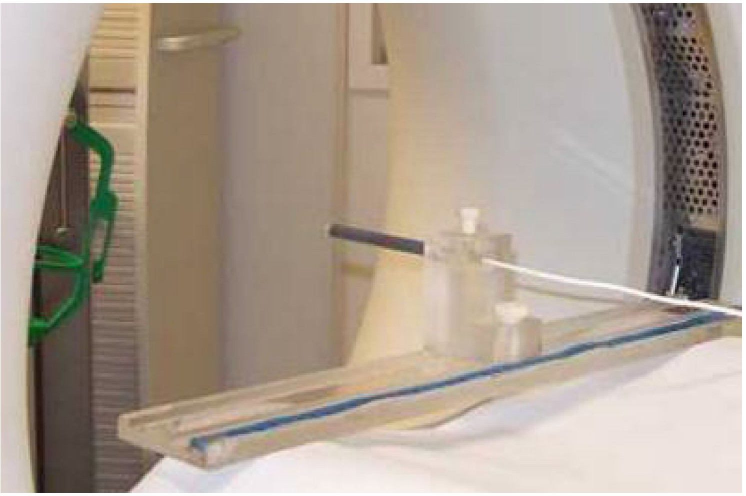
The nominal beam width

$CTDI_{air}$

CTDIair

- Standard 100-mm pencil chamber dosimeter, must be placed in air at the isocenter of the scanner.
- The measure is expressed in terms of the DLP for a single slice, mGy*cm
- To obtain the CTDIair It is necessary do divide by the nominal thickness of the slic

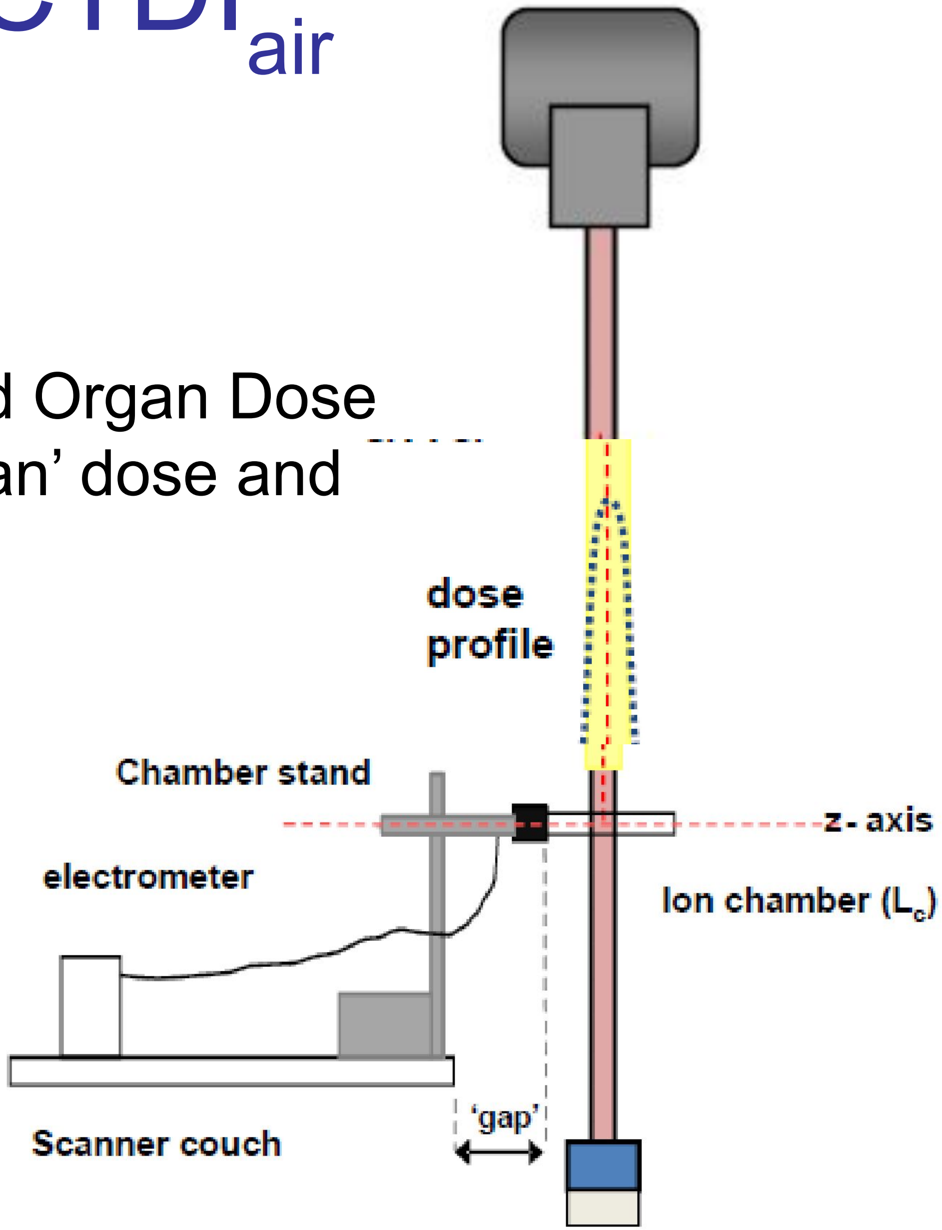
$$CTDI_{xyz} = \frac{dlp_{xyz}}{N \cdot h}$$



- N = n° of slices acquired simultaneously
- h = Slice thickness in cm

CTDI$_{air}$

- Very little scatter
- Used for QC
- Used to scale normalized Organ Dose datasets to obtain ‘organ’ dose and Effective dose



$CTDI_{air}$

Accuracy of set up

- iso-centre : +/- 10 mm, 0.1% error
- along chamber: +/- 10 mm, 0.3 % error
- tilt or twist: < 5 degrees, 0.1% error

Changes in CTDIair due to:

- Tube output
- Focal spot
- Beam width collimation
- Beam filtration

$CTDI_{air}$ is one of the most sensitive and valuable parameters to measure

$CTDI_{100}$

The queues before and after the slice thickness must be added to the dose in the slice thickness

The CTDI (CT Dose Index) is the standard dose D (z), imparted by a single axial acquisition to a standard 100-mm pencil chamber dosimeter inside a PMMA phantom along a line parallel to the axis of rotation, divided by the nominal thickness of the beam:

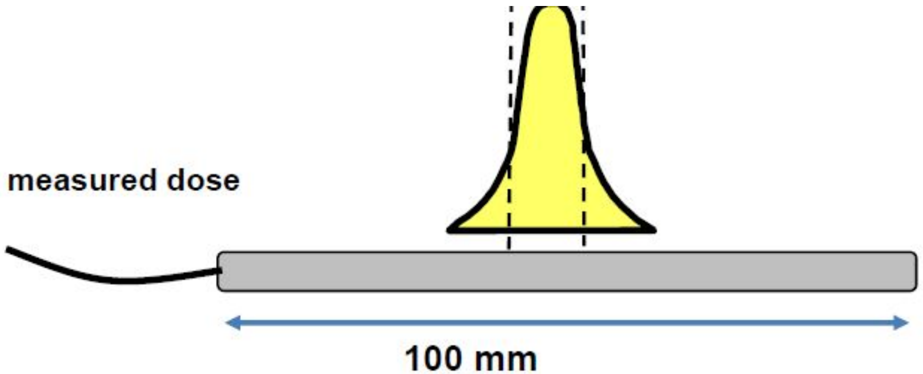
$$CTDI_{100} = \frac{1}{nh} \cdot \int_{-50}^{50} D(z)dz$$

$CTDI_{100}$

- 100 mm long ion chamber used
- One 'slice' scanned
- The dose from the profile is collected over 100 mm
- That value is divided by the nominal beam width

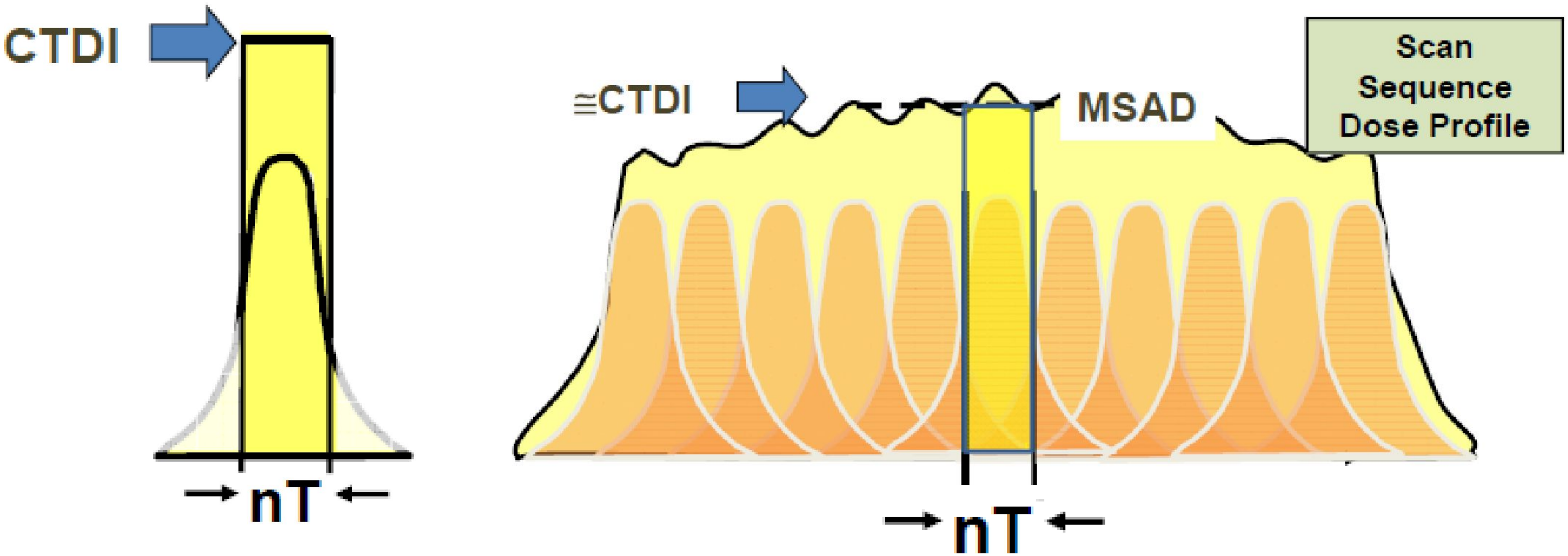
$$CTDI_{100} = \frac{1}{NxT} \int_{-50}^{+50} D(z)\,dz$$

$$CTDI_{100} = \frac{\text{integral dose 100 mm}}{\text{nominal beam width}}$$



$CTDI_{100}$

- Is a calculation from a single slice measurement
- It represents the average dose to the centre of a scanned length (100 mm)



How accurate is the manufacturer displayed $CTDI_{100}$?

Variability of the discrepancy between manufacturer and measured $CTDI_{100}$ values by scanner type, acquisition parameters and phantom size

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[a] *Medical Physics Department, University Hospital "Maggiore della Carità", Novara, Italy*
[b] *Radiology Department, University Hospital "Maggiore della Carità", Novara, Italy*

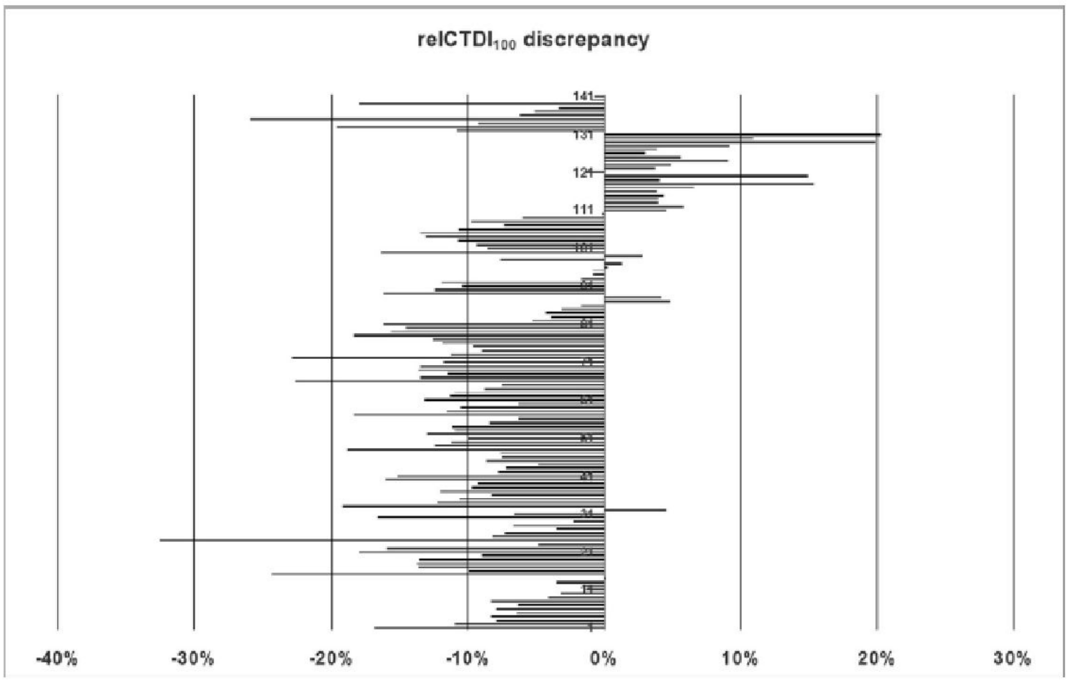


Fig. 1. Relative $CTDI_{100}$ discrepancy (%) for all the measurements taken.

- The inaccuracies in the CTDI100 can lead to higher than 20% inaccuracies in the displayed CTDIvol, which is the suspension level indicated in the EC RP N.162.
- There is need for individual calibration of every single X-ray tube in CT by the manufacturers and the necessity of including this check in the quality control programs for CT equipment.

Cannillo et al Phys Med 2018

How accurate is the manufacturer displayed $CTDI_{100}$?

National reference levels of CT procedures dedicated for treatment planning in radiation oncology

Ana Božanić [a,b,*], Doris Šegota [a], Dea Dundara Debeljuh [a,b,c], Manda Švabić Kolacio [a], Đeni Smilović Radojčić [a,b], Katarina Ružić [d], Mirjana Budanec [e], Mladen Kasabašić [f], Darijo Hrepić [g], Petra Valković Zujić [h,i], Marco Brambilla [j], Mannudeep K. Kalra [k,l], Slaven Jurković [a,b]

Table 1
Quality control results for $CTDI_{vol}$ verification and scout accuracy.

Center	Scout accuracy Δ/mm	$\Delta CTDI_{vol}$ (16 cm phantom)/%	$\Delta CTDI_{vol}$ (32 cm phantom)/%
1	0	−14.4	−9.4
2	0	12.0	14.7
3	0	6.2	9.1
4	0	−19.5	−16.7
5	0	−4.7	−1.6
6	0	−7.1	−10.5
7	0	7.3	8.9
8	0	11.7	−0.6

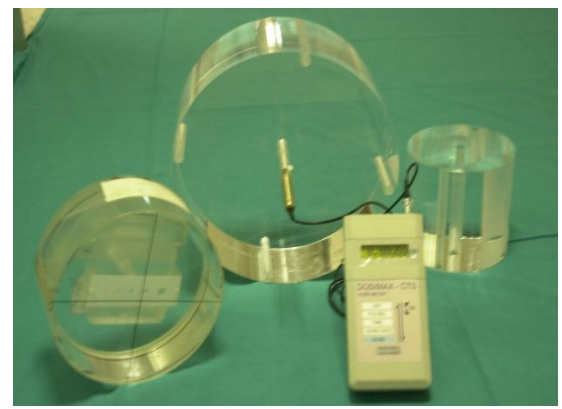
Bozanic et al Phys Med 2022

Weighted CTDI ($CTDI_{w}$)

The dose distribution imparted by a CT scan is much more homogeneous than that imparted by radiography, but is still somewhat larger near the skin than in the centre of the body. The *weighted* CTDI was introduced to account for this:

$CTDI_{head}$ - $CTDI_{body}$

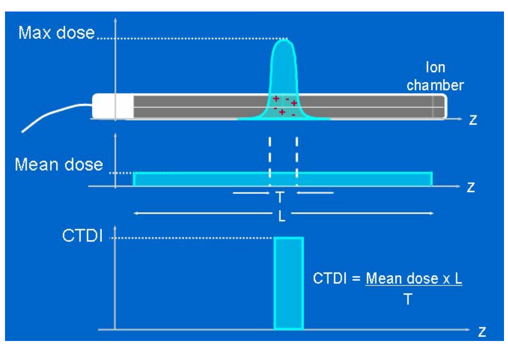
They are obtained by placing the pencil dosimeter inside two PMMA cylindrical phantoms of 32 and 16 cm diameter reprsenting an adult Body and a Head



$$CTDI_{w} = \frac{1}{3} \cdot CTDI_{100,C} + \frac{2}{3} \cdot \langle CTDI_{100,p} \rangle$$

Dividing by the mAs we obtained the normalized

$nCTDIw$



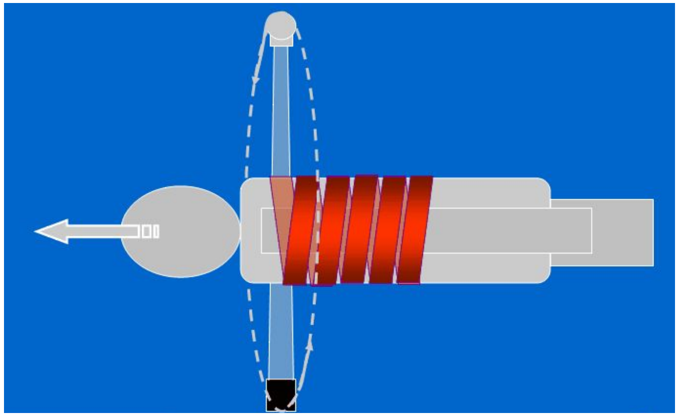
Must be shown in the console

Represents the average dose in scan plane of a 100 mm scan

Volume CTDI ($CTDI_{Vol}$)

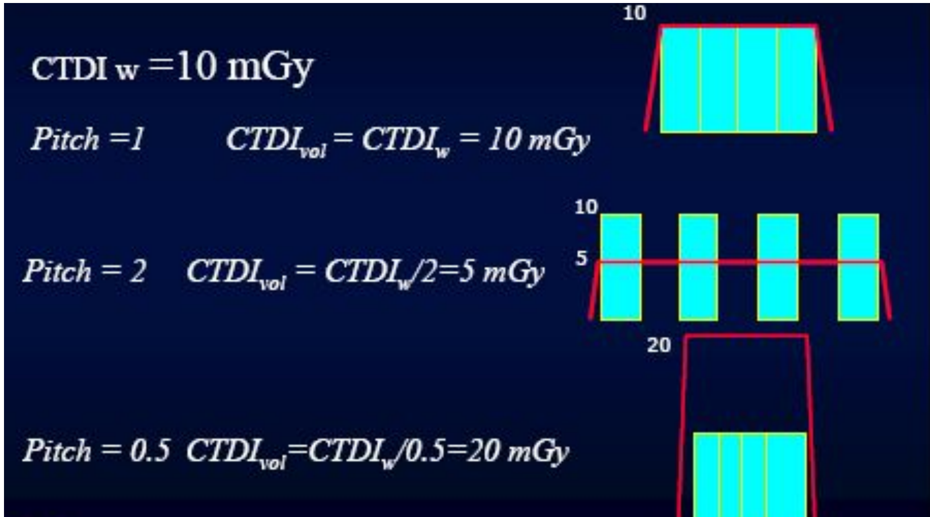
In the Spiral CT during a complete rotation of the Xray tube –detectors assembly we have a movement of the bed along the Z axis;

$$Pitch = \frac{\text{bed displaceme nt}}{\text{slice thickness}}$$



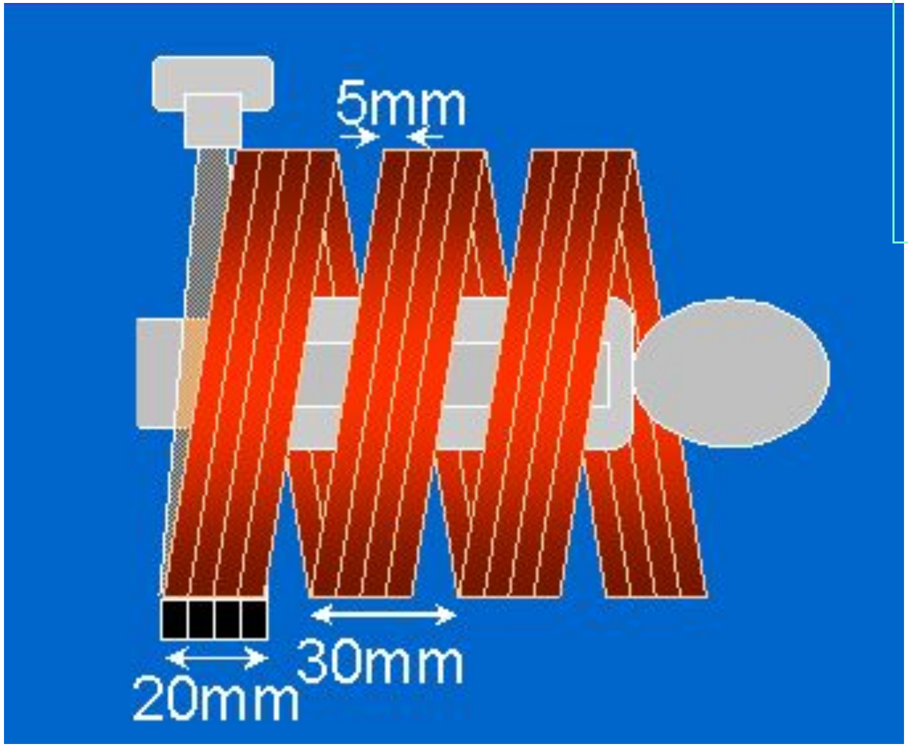
Dividing the $_{n}CTDI_{w}$ by the pitch we obtain:

$CTDI_{vol}$



$CTDI_{Vol}$ in MDCT

MDCT



$$Pitch = \frac{\text{bed displacement}}{\text{primary collimation}}$$

Primary collimation =

n° acquired slices * slice Thickness

p=30/20 =1.5

$CTDI_{vol}$

- Measured at acceptance and after major changes in CT scanner (Tube replacement)
- Used to establish dose reference levels
  - Not to be used in QC
  - CTDIvol (and DLP) displayed on console

Dosimetric Indexes in CT: Factors P_B and P_H

- The relation between *CTDI*w and *CTDI*air depends on the scanner type used for the examination and on the dosimetry phantom considered.
- For the purpose of dose estimation, the ratio of both quantities is defined for the standard head (H) and body (B) CT dosimetry phantom

$$P_H = \frac{CTDI_{w,H}}{CTDI_{air}} \quad and \quad P_B = \frac{CTDI_{w,B}}{CTDI_{air}},$$

Dosimetric Indexes in CT: Factors PB and PH

Table 1 Summary of characteristic performance parameters[a] for four single-slice and six multi-slice CT systems used for dose calculation in this study

Manufacturer	Scanner	Abbr.	N	U_{ref} (kV)	h_{ref} (mm)	dz (mm)	Head mode			Body mode		
							$_nCTDI_{w,H}$ (mGy/mAs)	P_H	k_{CT}	$_nCTDI_{w,B}$ (mGy/mAs)	P_B	k_{CT}
General Electric	LX/i	G-1	1	120	10	0	0.152	0.66	0.80	0.072	0.31	0.65
Philips	Tomoscan AV	P-1	1	120	10	0	0.150	0.75	0.90	0.080	0.40	0.80
Siemens	Somatom Plus 4	S-1	1	120	10	0	0.146	0.82	1.00	0.083	0.47	1.00
Toshiba	XVision	T-1	1	120	10	0	0.162	0.63	0.80	0.065	0.30	0.65
General Electric	Lightspeed QX/i	G-4	4	120	5	3.0/4.0[b]	0.182	0.64	0.80	0.094	0.39	0.80
Philips	Mx8000 Quad	P-4	4	120	5	1.7	0.130	0.75	0.90	0.067	0.39	0.80
Siemens	Volume Zoom	S-4	4	120	5	1.7	0.200	0.76	0.90	0.083	0.49	1.00
Toshiba	Aquilion	T-4	4	120	8	3.0	0.189	0.67	0.80	0.107	0.30	0.65
Philips	Mx8000 IDT	P-16	16	120	1.5	3.0	0.130	0.75	0.90	0.067	0.39	0.80
Siemens	Sensation 16	S-16	16	120	1.5	3.0	0.190	0.76	0.90	0.070	0.41	0.80

[a] Definition of scanner parameters: N, number of simultaneously acquired slices; U_{ref}, reference voltage for $_nCTDI_{w,H/B}$; h_{ref}, slice collimation for $_nCTDI_{w,H/B}$; dz, width of penumbra; $_nCTDI_{w,H/B}$, normalized $CTDI_w$ for head or body mode; $P_{B/H}$, phantom factor for head or body mode; k_{CT}, scanner-specific correction factor.

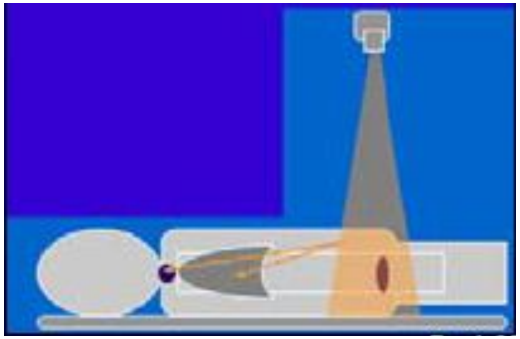
[b] Value depends on focal spot size.

Brix *et al* Eur Radiol 2004

Dose Lenght Product DLP

By doubling the scan lenght, the $CTDI_{vol}$ doubles? NO

The CTDI indexes are dose indicators. As such they refer to the dose in a specific point. They do no take into account the length of the acquisition.



The product of the CTDI times the length of the acquisition is the Dose Length Product :

$$DLP = {}_nCTDI_w \cdot mAs \cdot n \cdot h$$

The DLP can be used to estimate the Effective Dose

It is an index of the global irradiation of the patient.

Effective Dose ED

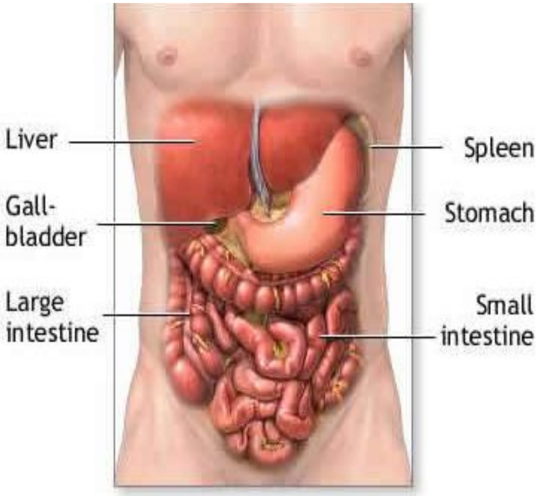
To reflect the combined detriment from stochastic effects due to the equivalent doses in all the organs and tissues of the body, the equivalent dose in each organ and tissue is multiplied by a tissue weighting factor, W_T, and the results are summed over the whole body to give the effective dose E

$$E = \sum_{T} w_{T} \sum_{R} w_{R} D_{T,R} \quad \text{or} \quad E = \sum_{T} w_{T} H_{T}$$

where HT or w_R $D_{T,R}$ is the equivalent dose in a tissue or organ, T, and w_T is the tissue weighting factor. The unit for the effective dose is the same as for absorbed dose, J kg^{-1}, and its special name is Sievert (Sv).

Effective Dose ED

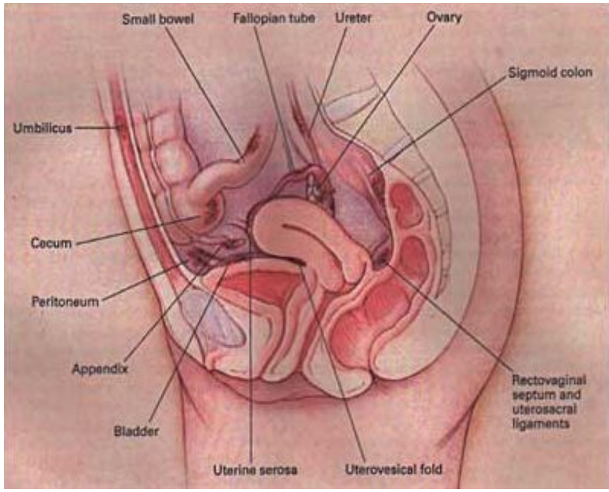
ABDOMEN



ABDOMEN PELVIS

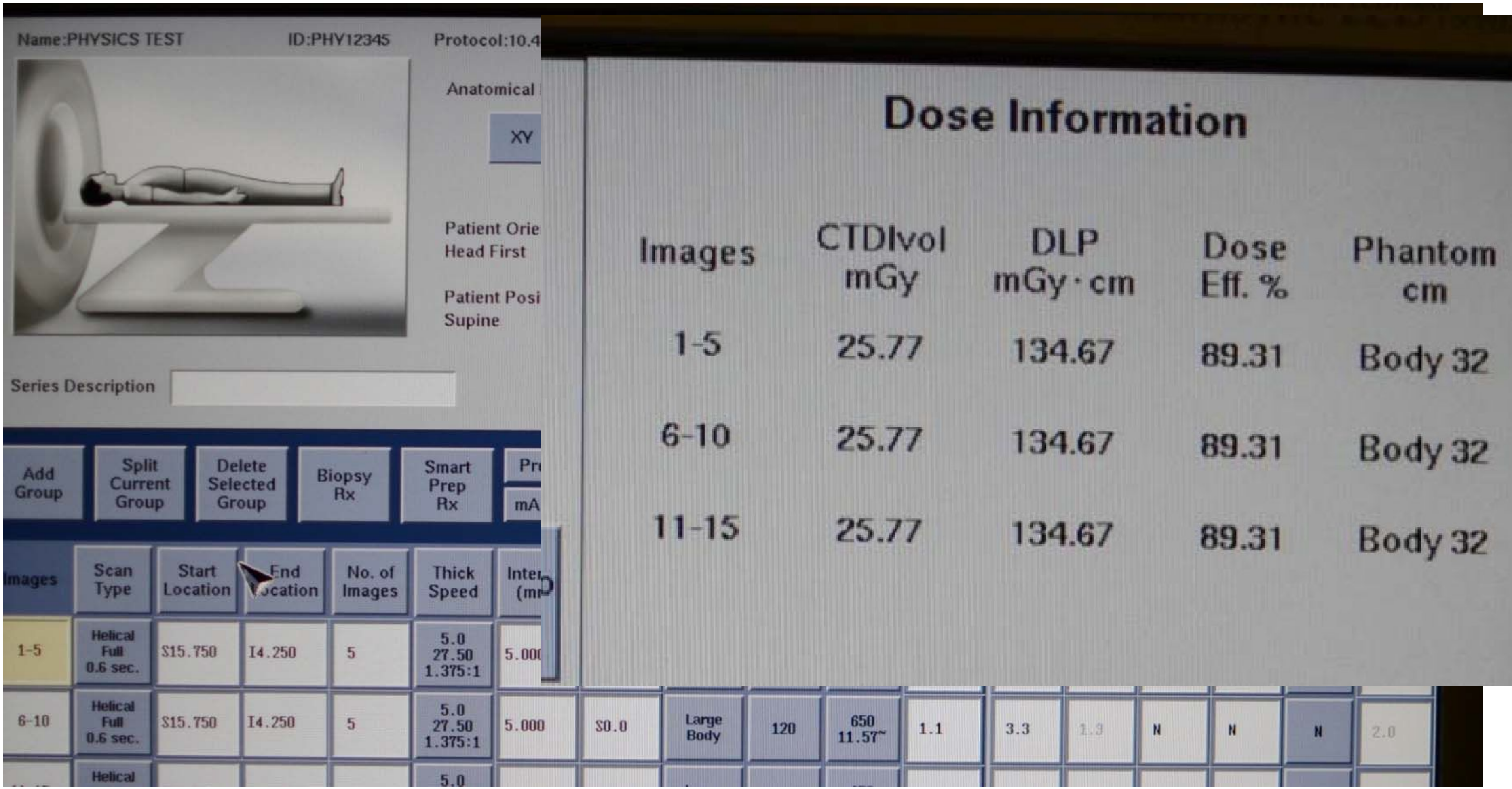
Organs	W_T	H_T	$W_T H_T$
Gonads	0,08	31,385	2,511
Bone Marrow	0,12	12,329	1,479
Colon	0,12	23,233	2,788
Lung	0,12	7,359	0,883
Stomach	0,12	24,794	2,975
Bladder	0,04	32,403	1,296
Breast	0,12	1,355	0,163
Liver	0,04	22,636	0,905
Oesophagus	0,04	1,063	0,043
Thyroid	0,04	0,097	0,004
Skin	0,01	8,826	0,088
Bone Surface	0,01	16,392	0,164
Remainder 2	0,12	12,136	1,456
Effective Dose (mSv)			14,8

PELVIS



Tissue weighting factors (W_T) derived from whole population

What the scanner shows



GE Scanner

ED_{DLP} Conversion Factors

E = DLP x k

k values region specific

Guidelines EUR16262EN

Region of body	Normalized Effective Dose E_{DLP} (mSv mGy^{-1} cm^{-1})
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Accession Number: 698346

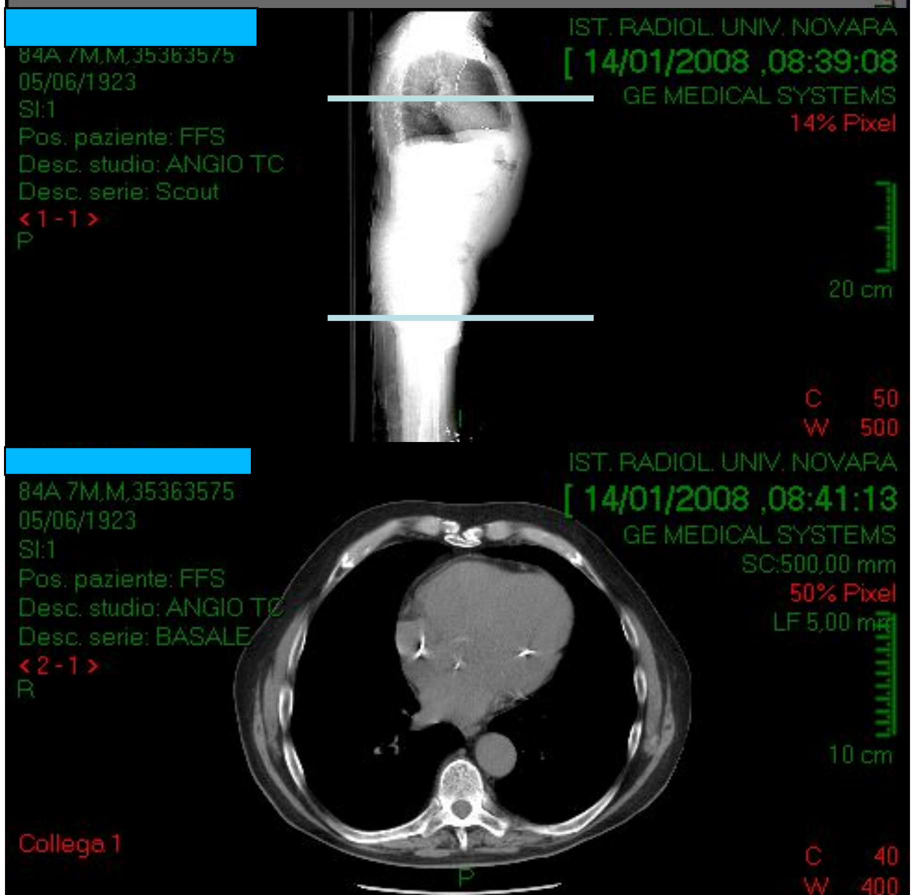
LightSpeed VCT

Desc. studio: ANGIO TC

Desc. serie: Rapporto dose

Report Dose

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	I198.250-I663.250	19.47	995.06	Body 32
200	Axial	I234.000-I234.000	33.07	16.52	Body 32
3	Helical	I207.000-I630.125	29.36	1378.43	Body 32
3	Helical	I207.000-I632.000	25.72	1212.13	Body 32
		Total Exam DLP:		3602.14	



E_{DLP} (mSv mGy^{-1} cm^{-1}) = 0.017-0.019

E (mSv)= 0.017 x 995.06 = 16.9

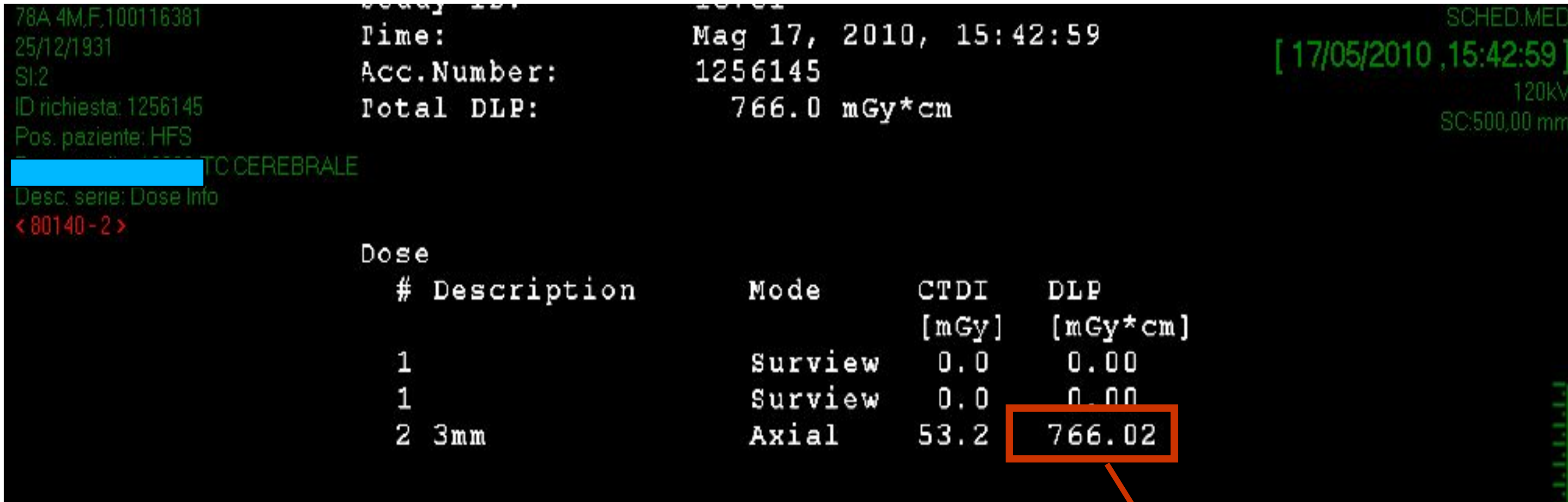
E (mSv)= 0.017 x 1378.43 = 23.4

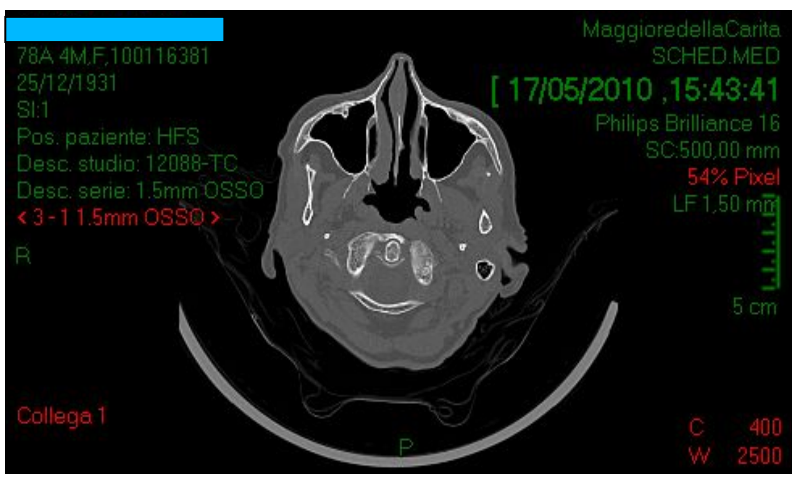
E (mSv)= 0.019 x 1212.33 = 23.0

E_{Tot} (mSv)= 63.3

CT Abdomen- Pelvis Multiphase

CT Head

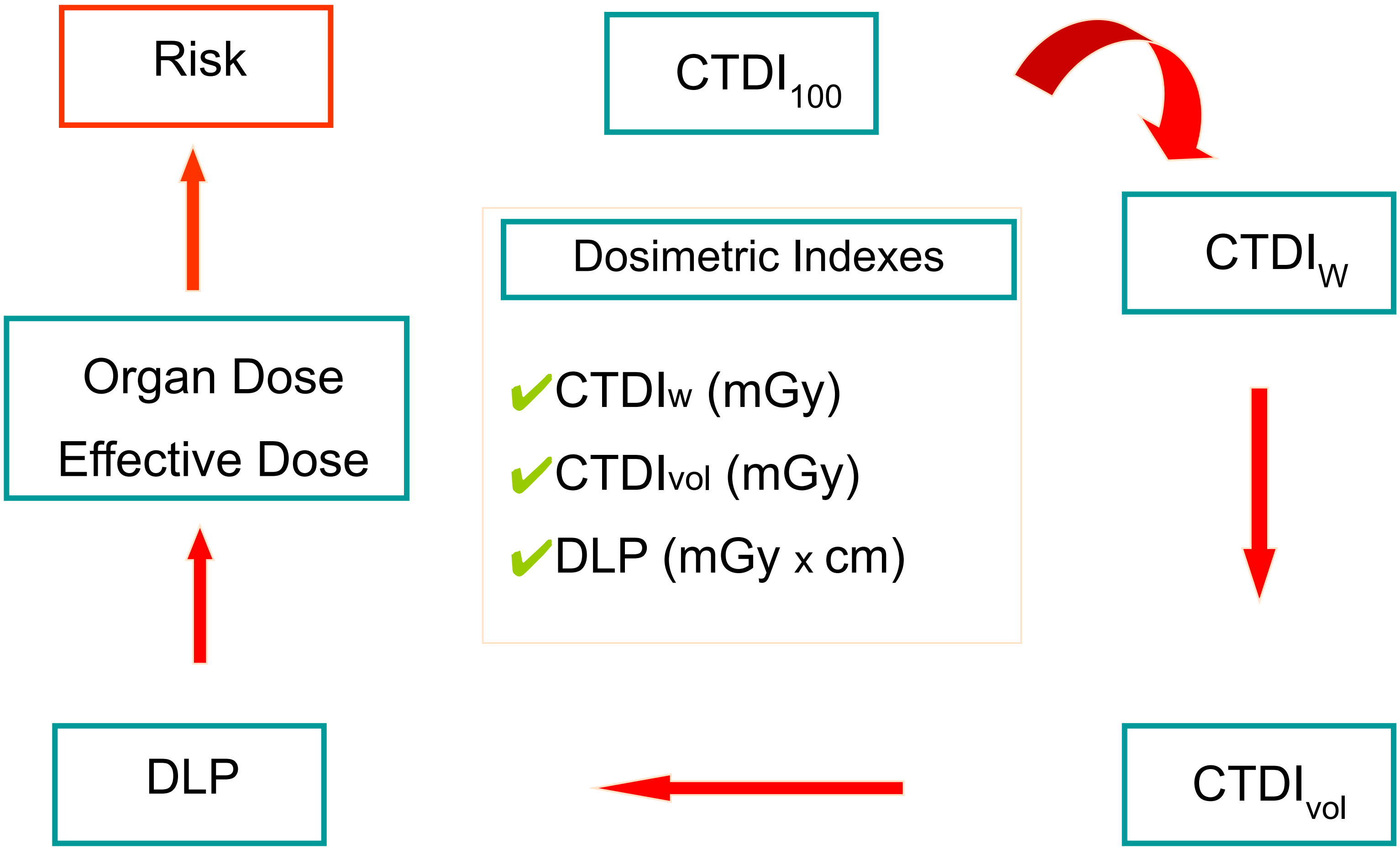




E_{DLP} (mSv mGy^{-1} cm^{-1}) = 0.0023

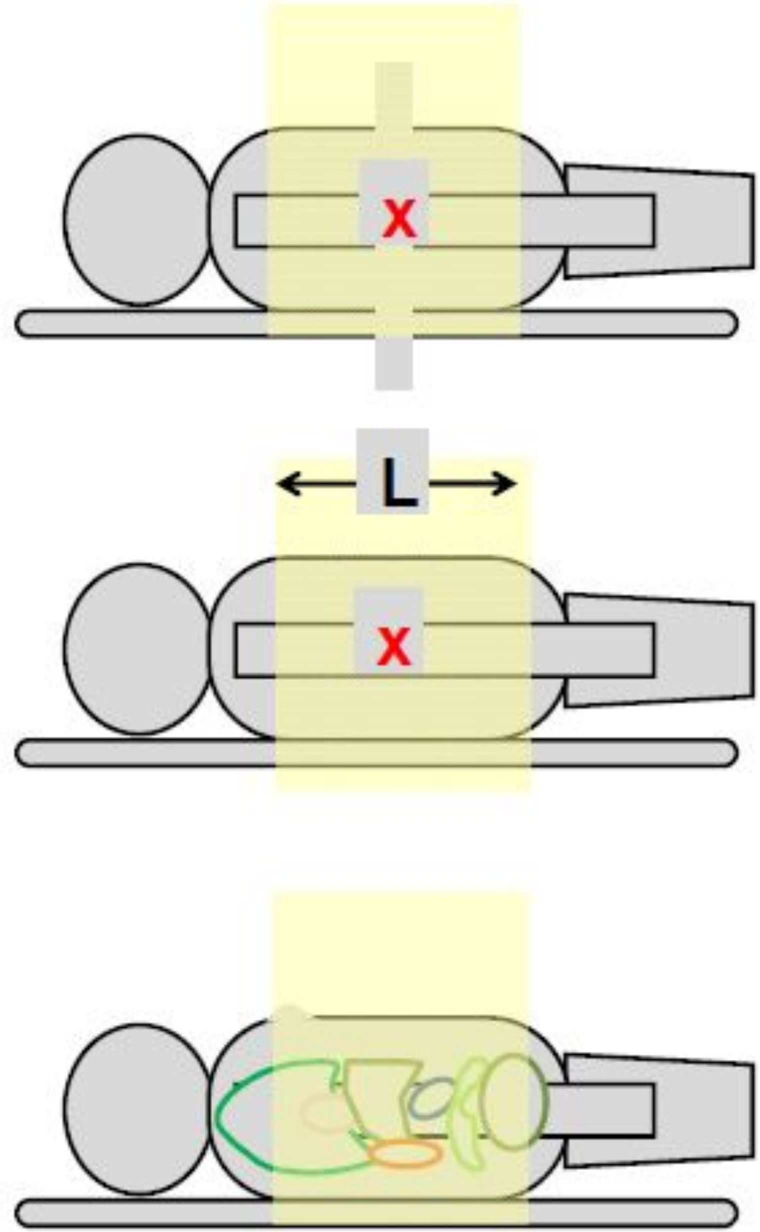
E (mSv)= 0.0023 x 766.02 = 1.76

Relationship between Dosimetric Indexes in CT



Conclusions ?

- CTDIvol (mGy)
  - ~ represents local absorbed dose
- DLP = CTDIvol x L (mGy.cm)
  - represents total absorbed dose
  - ~ represents relative risk
- Effective dose (mSv)
  - Sensitivity of organs accounted for
  - ED = DLP x k
  - k values region specific



CTDI is not patient dose

– Good for QC
– A good indicator of relative dose between protocols, scanners and standard size patients

- Patients are not 16 or 32 cm cylinders of Perspex
- The integration length (≡ scan length) is not 100 mm
- Patients come in different sizes

Patients come in different sizes

- Patients come in different sizes
- But we quote CTDIvol to the same size phantoms

10 mGy

For same scan parameters

>>> 10 mGy

~10 mGy

<< 10 mGy

Size Specific Dose Estimate (SSDE)

AAPM Report No. 204

AAPM

Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, developed in collaboration with the International Commission on Radiation Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging

ICRU

image gently℠

REVIEWS AND COMMENTARY ■ EDITORIAL

Radiology

Size-specific Dose Estimation for CT: How Should It Be Used and What Does It Mean?[1]

James A. Brink, MD
Richard L. Morin, PhD

Owing to rising concerns about ionizing radiation from medical imaging, the National Council … a metric of radiation output, not of patient dose. The exposure to radiation is the same whether measured in a block

December 2012 Radiology, 265, 666-668.

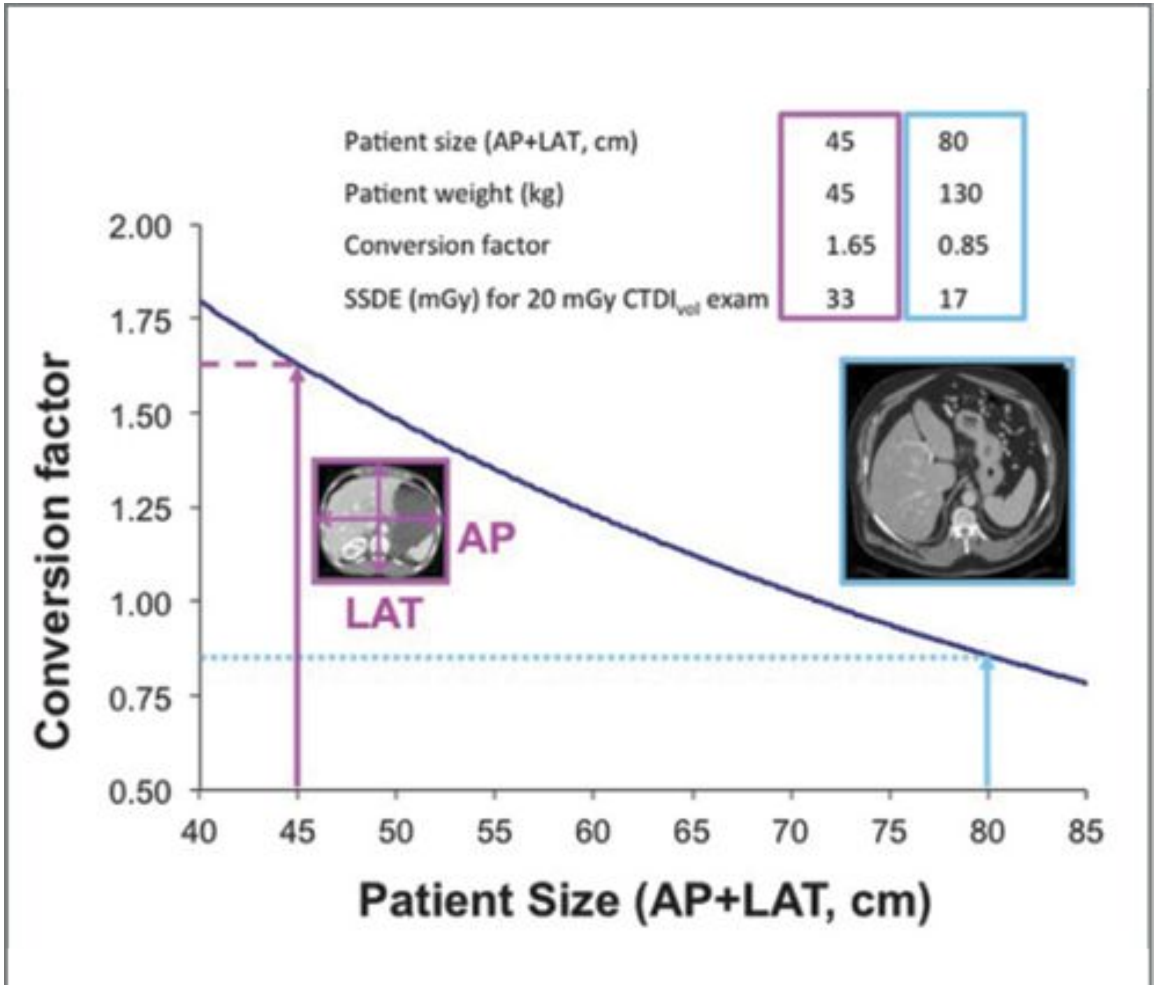
Size Specific Dose Estimate (SSDE)

- This value, given in mGy, is an adjusted CTDI value based on the patient's size
- Uses Effective diameters

$$Eff\ Diameter = \sqrt{APxLAT}$$

- Small Bodies → Larger Doses
- Large Bodies → Smaller Doses

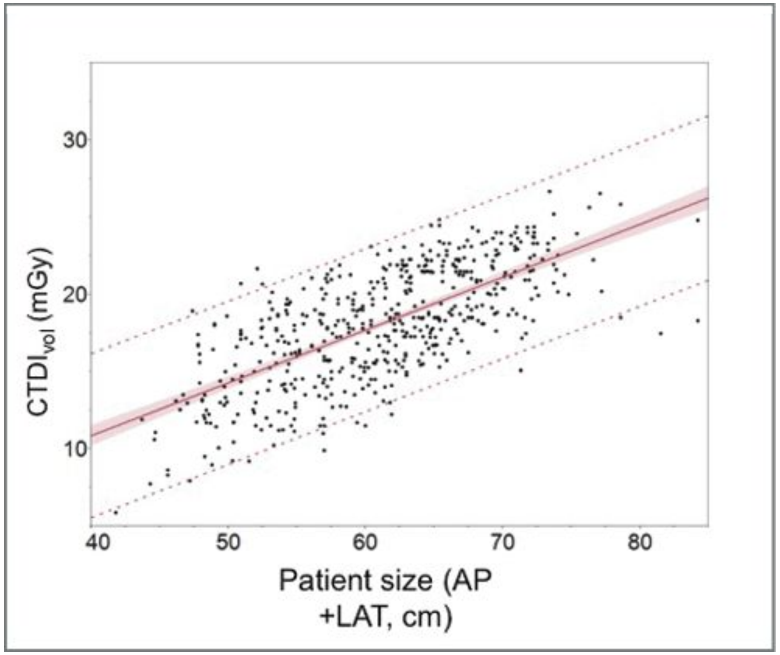
Size Specific Dose Estimate (SSDE)

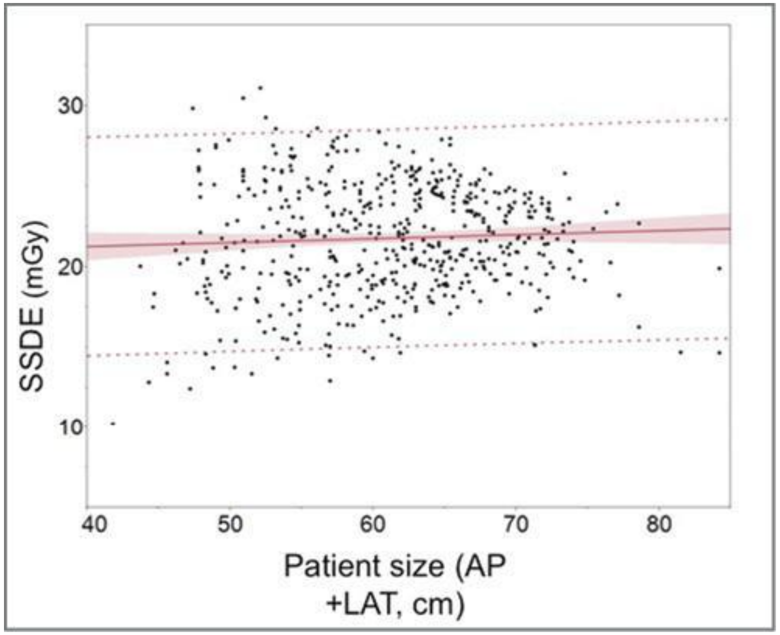


Demonstration of the higher patient dose (represented by size-specific dose estimate (SSDE) delivered to a smaller patient relative to a large patient, for the same scanner output (represented by CTDIvol). Here the patient size is represented by the sum of the anteriopostier (AP) and lateral (LAT) patient dimensions in the center of the scan range. In practice, the scanner output would be lower for the smaller patient and the difference in dose (SSDE) would be minimal.

www.rsna.org

Size Specific Dose Estimate (SSDE)





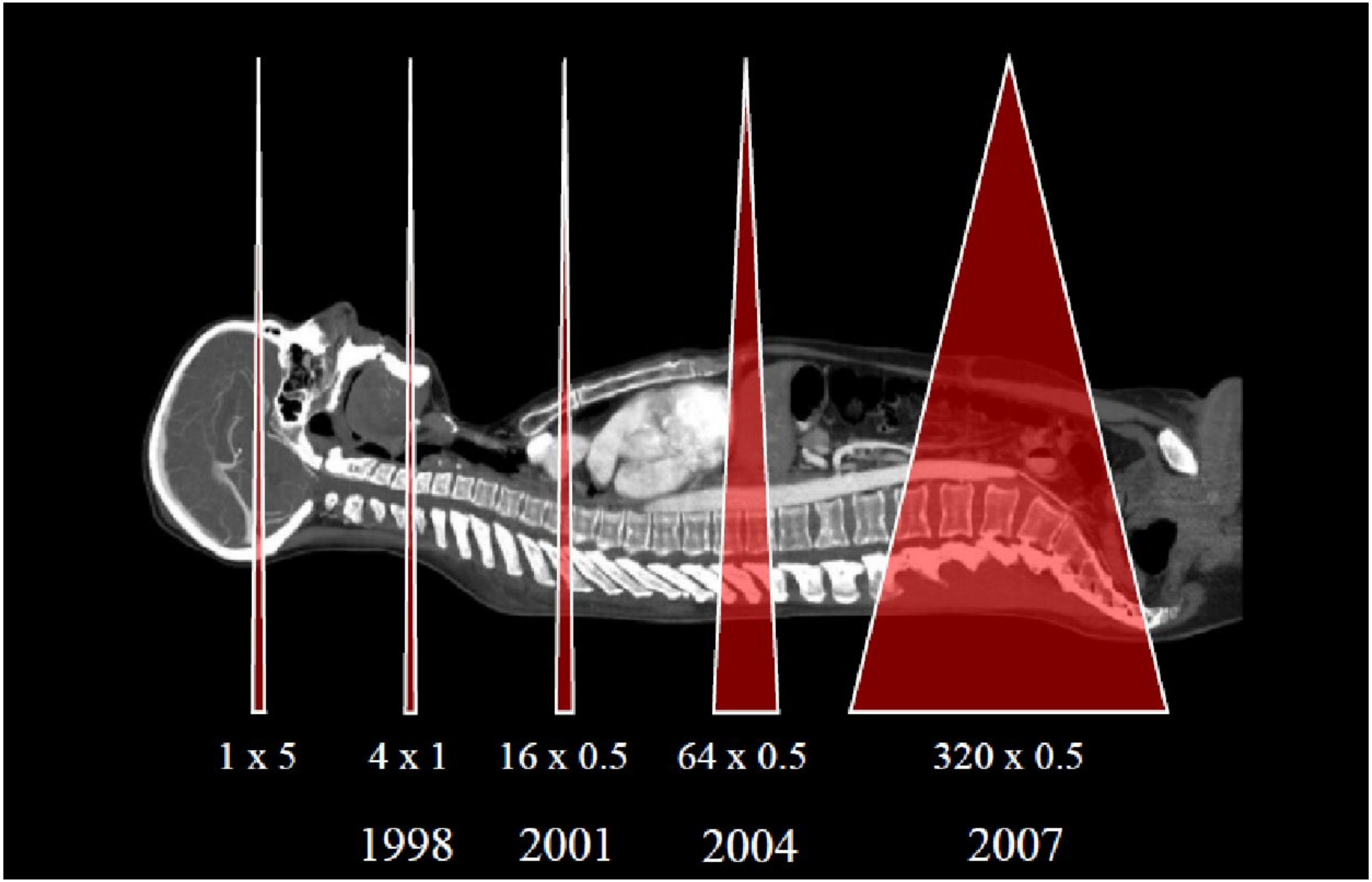
From left: in 545 adult patients undergoing abdominal CT, the scanner output (CTDIvol) increased proportional to the sum of the anterioposterior (AP) and lateral (LAT) dimensions, measured in the center of the scan range.

After conversion to patient dose (SSDE), there is no statistically significant relationship between patient size and dose, demonstrating that the use of higher scanner output values (CTDIvol) in larger patients (to obtain adequate image quality) does not necessarily translate to increased patient dose in larger patients.

www.rsna.org

CTDI is not patient dose

The integration length (≡ scan length) is not 100 mm



IAEA Human Health Report N.5

IEC: Wide Beam $CTDI_{vol}$

- **CTDIvol** :nominal beam widths (NxT) < 40 mm .... no change

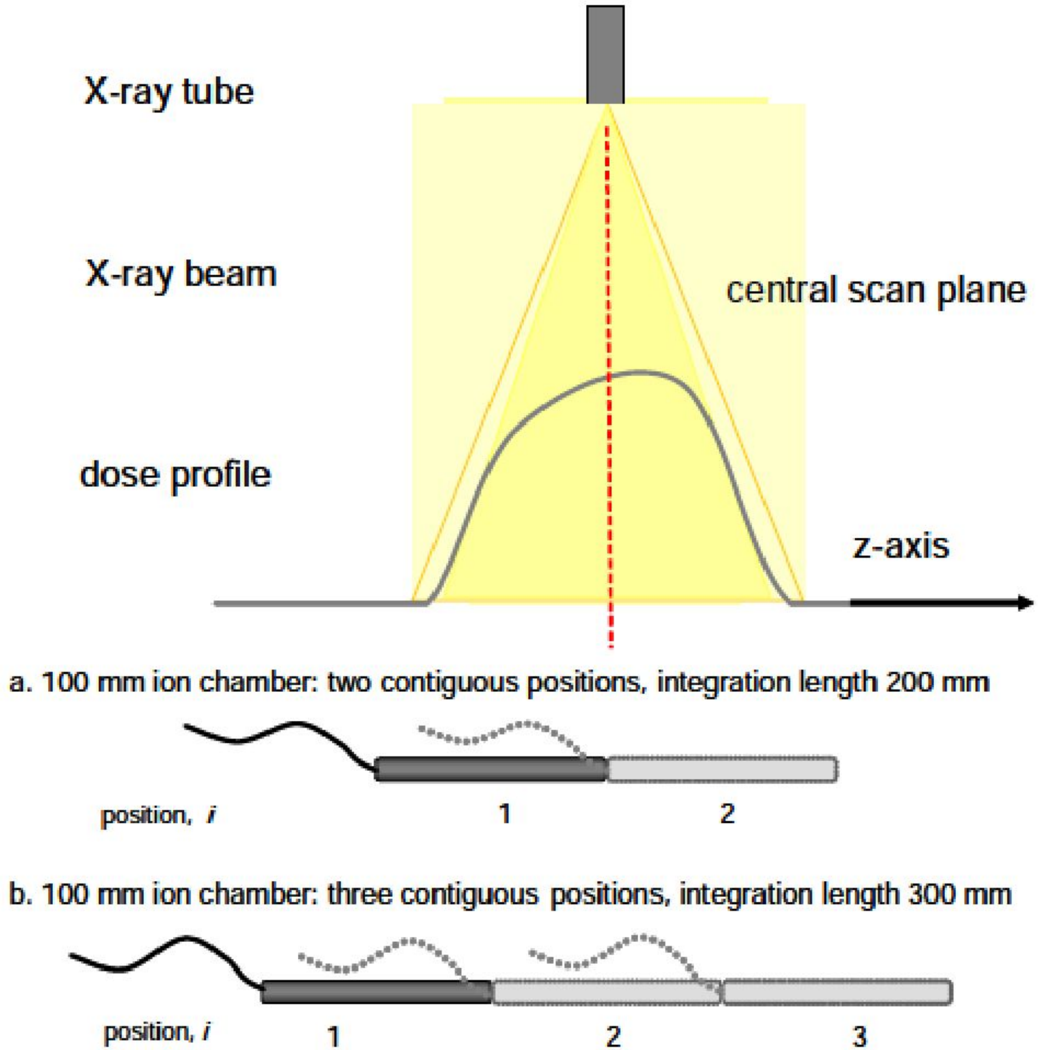
- **CTDIvol** :nominal beam widths (NxT) greater than 40 mm
  – Measure for an ~ 20 mm beam, correct with $CTDI_{air}$ ratios

$$CTDI_{vol}\text{: beam width (NxT) mm} = CTDI_{vol}\text{: beam width} \sim 20\text{ mm} \times \left[\frac{CTDI_{air}\text{: beam (N xT) mm}}{CTDI_{air}\text{: beam} \sim 20\text{ mm}} \right]$$

IAEA Human Health Report N.5

Wide Beam $CTDI_{free\text{-}in\text{-}air}$

beam width of 160 mm



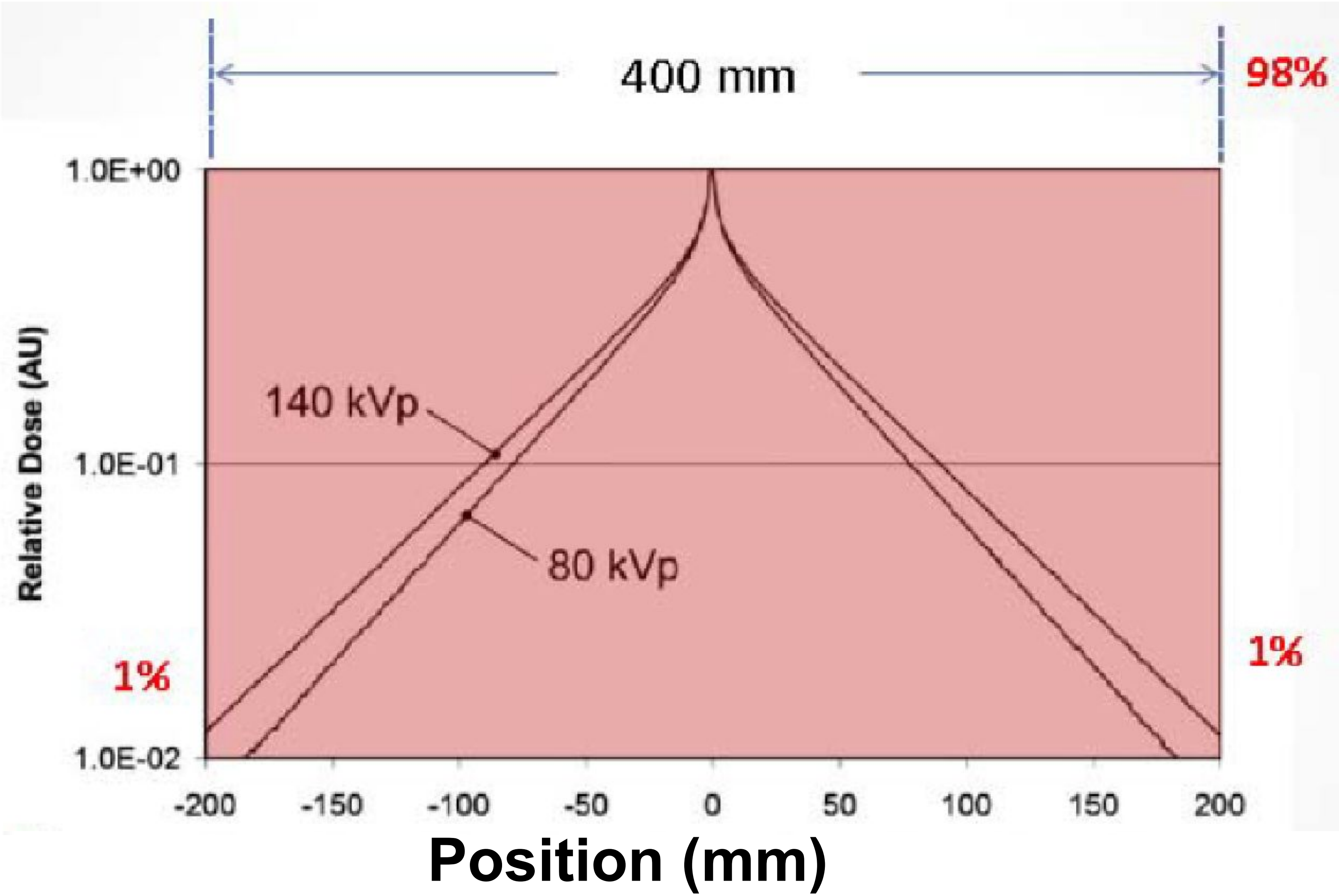
100 mm ion chamber

step increments equal to the ion chamber length

The 200 mm integration length is sufficient according to the minimum requirement of IEC, however the 300 mm integration length can also be used

CTDI is not patient dose

The scan length is > 100 mm



JM Boone Dose spread function in computed tomography. A Montecarlo Study. Med Phys 36, 2009

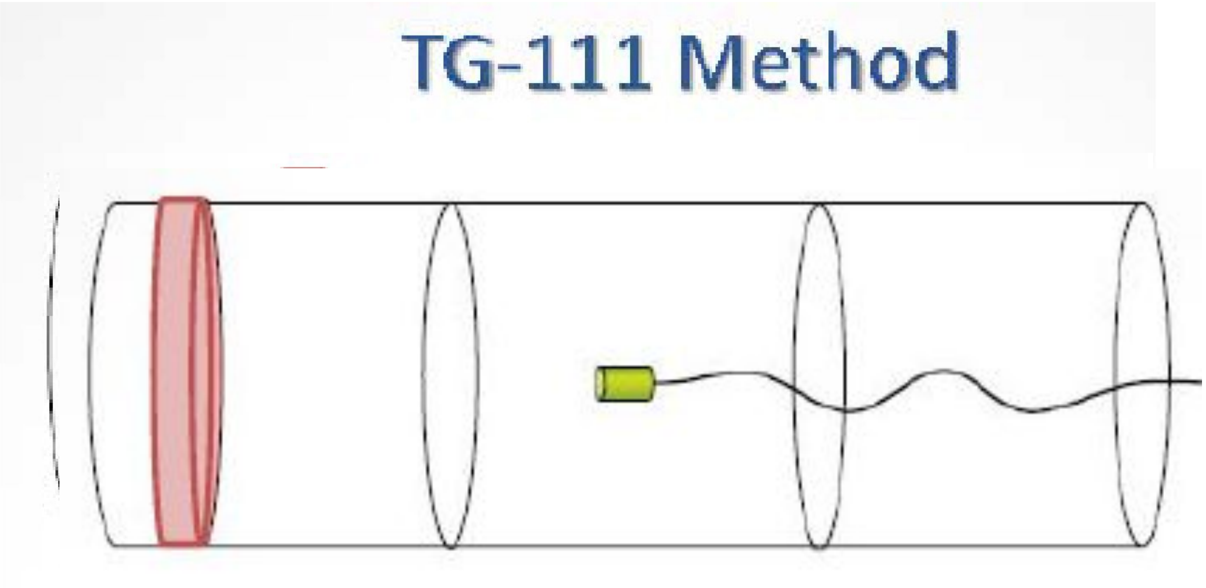
AAPM TG111

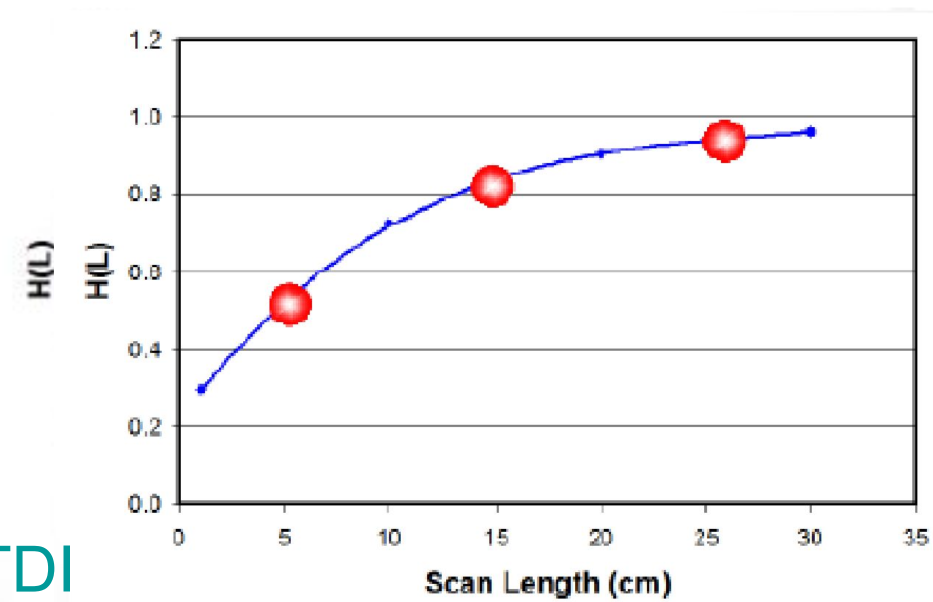
AAPM REPORT NO. 111

Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography

A New Measurement Paradigm Based on a Unified Theory for Axial, Helical, Fan-Beam, and Cone-Beam Scanning With or Without Longitudinal Translation of the Patient Table

AAPM TG111





CTDI infinity – equilibrium CTDI

DRLs of CT procedures dedicated for treatment planning in radiation oncology

National reference levels of CT procedures dedicated for treatment planning in radiation oncology

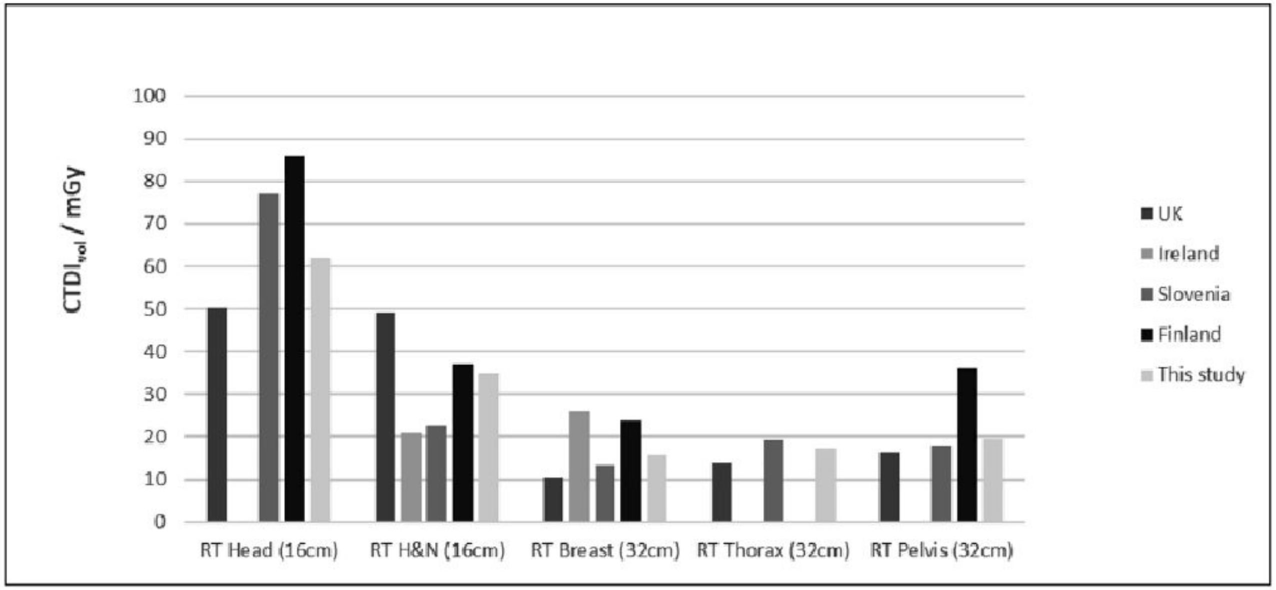
Ana Božanić [a,b,*], Doris Šegota [a], Dea Dundara Debeljuh [a,b,c], Manda Švabić Kolacio [a], Đeni Smilović Radojčić [a,b], Katarina Ružić [d], Mirjana Budanec [e], Mladen Kasabašić [f], Darijo Hrepić [g], Petra Valković Zujić [h,i], Marco Brambilla [j], Mannudeep K. Kalra [k,l], Slaven Jurković [a,b]

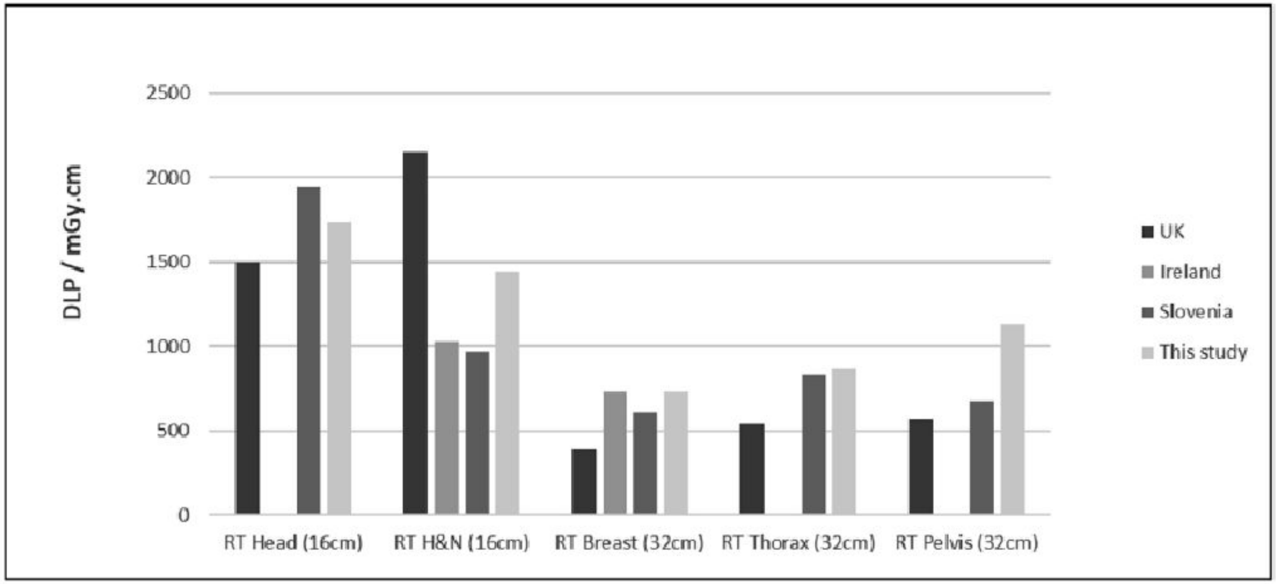
Proposed national RPRL and achievable national levels for radiation oncology CT acquisitions of the investigated anatomical regions.

Protocol	Proposed national RPRL		Achievable level	
	$CTDI_{vol}$/mGy	DLP/mGy.cm	$CTDI_{vol}$/mGy	DLP/mGy.cm
RT Head (16 cm)	62	1738	60	1569
RT H&N (16 cm)	35	1444	32	1422
RT Breast (32 cm)	16	731	8	361
RT Thorax (32 cm)	17	865	9	697
RT Pelvis (32 cm)	20	1133	17	802

Bozanic et al Phys Med 2022

DRLs of CT procedures dedicated for treatment planning in radiation oncology





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Can CT protocols used for RT TPS be adjusted to optimize image quality and patient dose?

CT images used in RT must serve two key purposes:

1. Accurately identify the position of the tumour and OARs
2. Provide a map of the ED for the various tissues to be used in the TPS dose calculation

Most radiotherapy centres now have access to dedicated CT scanners. Therefore, the opportunity exists to optimize scan protocol.

On radiotherapy CT scanners a “one size fits all” approach is often taken with minimal variation in scan parameters

Can CT protocols used for RT TPS be adjusted to optimize image quality and patient dose?

Disadvantages

Inaccuracies and variability in the outlining process done manually

The use of auto contouring systems might be compromised

Technological developments such as:
- metal artefact reduction
- dual energy imaging
- iterative reconstruction
- TCM
- Automatic KV selection

are not used

Concern

Varying scan parameters will change HU values in the images and subsequently introduce inaccuracies to the dosimetric information produced in the TPS.

Problem

Which is the level of HU variation which can be tolerated for different CT imaging techniques, without adversely affecting the dose distribution in the planning process**?**

Tolerance of HU in guidance documents

Tissue type	References	RED value	Defined RED or HU tolerance	Corresponding HU[a]
Lung	ESTRO, SGSMP[34,35]	0.2	±0.05 (±25%)	±50
	IPEM[32]	0.2	±0.004 (±2%)	±4
	IPEM[32]	0.4	±0.008 (±2%)	±8
	IAEA[23,30,31]	0.21	±0.02 (±10%) or 20 HU	±20
	AAPM[46]	0.2	±50 HU	–
Soft tissue	ESTRO, SGSMP[34,35]	1.0	±0.05 (±5%)	±50
	IPEM[32]	1.0	±0.01 (±1%)	±10
	IAEA[23,30,31]	1.06	±0.02 (±2%) or 20 HU	±20
	AAPM[46]	1.0	±30 HU	±30
Bone	ESTRO, SGSMP[34,35]	1.5	±0.1 (±7%)	±170
	IPEM[34]	1.3	±0.03 (±2%)	±50
	IPEM[34]	1.8	±0.04 (±2%)	±70
	IAEA[23,30,31]	1.6	±0.02 (±1%) or 20 HU	±34
	AAPM[46]	1.3	±50 HU	–

AAPM, American Association of Physicists in Medicine; ESTRO, European Society for Radiotherapy and Oncology; HU, Hounsfield unit; IAEA, International Atomic Energy Agency; IPEM, Institute of Physics and Engineering in Medicine; RED, relative electron density; SGSMP, Swiss Society for Radiobiology and Medical Physics.

[a]HU tolerance calculated using Thomas[24] equations.

Davies AT et al Br J Radiol;90:20160406

Scan parameters and level of Hounsfield unit (HU) change in published papers

CT scan parameter	Impact on HU and scanner manufacturers covered by review
Tube current	No change unless very low current used—GE, Toshiba (Toshiba Medical, Zoetermeer, Netherlands)[42,52,53,57]
Kilovoltage	Significant level of HU change—Philips, Toshiba, GE, Siemens (Philips, Amsterdam, Netherlands)[2,42,52,53,57]
Acquisition FOV	Depends on CT scanner make/model and which FOV is selected—GE, Toshiba (GE Healthcare, Milwaukee)[53,57,58]
Reconstruction FOV	Standard FOVs—no information in articles reviewed
	Extended FOVs—significant change across FOV—Philips, GE[59,60]
Slice thickness	Minimal change—Toshiba[56]
X-ray tube rotation time	Minimal change—Toshiba[56]
Spiral *vs* sequential	Minimal change—Toshiba[56]
Reconstruction algorithms	Depends on CT scanner make/model and which algorithm is selected—Siemens, Toshiba (Siemens Healthcare, Erlangen, Germany)[38,56]

FOV, field of view.

Davies AT et al Br J Radiol;90:20160406

Summary of HU tolerances to achieve a 1% dose change limit

± 20 HU for soft tissue IAEA

± 50 HU for lung and bone AAPM

Note: effects of changes must be considered for all tissue types (air, bone, soft tissue) together when present in the clinical plan.

1. a given change of HU or RED will result in a larger change in dose for a greater thickness of tissue than for reduced tissue thickness;
2. a single-field treatment plan will deliver a greater dose change for a specific HU change than a multiple field plan;
3. the use of lower energy treatment beam results in a higher dose change for a given HU change than the use of higher energy treatment beam;

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Advantages of defined tolerance for HU variation during optimization

- When adjusting CT scan protocols, it is helpful to know quickly whether changes to scan protocols are likely to be detrimental to the dosimetric aspects of the planning
- Scan.
- HUs can be easily measured with a phantom on the scanner, thereby allowing early exclusion of inappropriate adjustment to scan parameters.
- Both image quality and HU changes could be assessed with a multipurpose phantom before undertaking a more detailed check to assess the level of dose change in the TPS with an anthropomorphic phantom.
- Use phantoms which approximately match the size and shape of patients when measuring HUs

Davies AT et al Br J Radiol;90:20160406

Conclusions

Scan protocol settings affect image quality. The radiation dose delivered from CT imaging must also be considered and justified.

- The impact of scan parameters in radiotherapy CT is not well detailed in the literature, also considering the number of scanners and the variety of settings within CT protocols
- Publications tend to look at a limited set of scan parameters and only give detailed information on variability when it is considered significant.
- No publications were found which fully assessed the performance of a radiotherapy CT scanner based on variation in both image quality parameters and HU or RED.

Davies AT et al 2017 Br J Radiol;90:20160406