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CTDI and Patient Dose: A European Perspective

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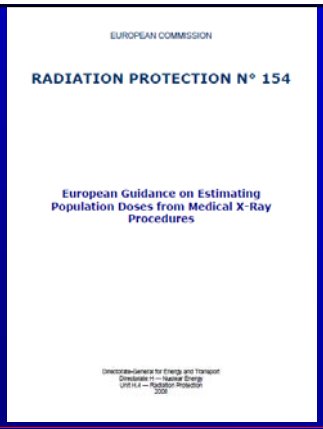
Disclosures

- WAK is a consultant to Siemens Healthcare, Erlangen, Germany.
- WAK is founder, shareholder and CEO of CT Imaging GmbH, Erlangen, Germany.

CTDI and patient dose: Why these topics again?

- We have heard a bit about CTDI and "trouble" related to it; a final word is still missing.
- We have heard a lot about patient dose in CT in general and about uncertainties in its assessment.
- Discussions are much less intense in Europe than in the US, possibly due to information early on.


EUROPEAN COMMISSION

RADIATION PROTECTION N° 154

European Guidance on Estimating Population Doses from Medical X-Ray Procedures

Directorate-General for Energy and Transport
Directorate H — Nuclear Energy
Unit H.4 — Radiation Protection
2008

Funded by the European Commission (EC)

Organized by the Health Physics Authority (HPA)

EC Radiation Protection Report N° 154, 2008

Patient Dose Assessment in Europe

Table 13: Mean effective doses for the 'Top 20 Exams' in the ten DOSE DATAMED countries

Exam type	Mean E per examination (mSv)										
	LU -	BE 00-05	DE 92-05	NO 85-95	CH 1998	FR 01-03	SE 1995	DK 1995	NL 2002	UK 90-01	Max Min
13. CT head	2.6	2.3	2.6	1.8	2.2	1.8*	2.0	1.9	1.2	2.0	**2.2**
14. CT neck	2.5	-	2.5	3.4	3.1	2.5*	-	1.3	-	2.4	**2.6**
15. CT chest	10.0	4.1	7.6	11.5	8.8	5.5*	-	11.0	5.5	7.8	**2.8**
16. CT spine	9.0	-	2.9	4.3	9.1	4.0*	-	5.7	3.1	4.2	**3.1**
17. CT abdomen	15.0	11.3	18.6	12.6	8.4	5.8*	-	14.0	10.6	9.8	**3.2**
18. CT pelvis	-	-	10.6	9.3	7.0	-	-	8.3	7.4	9.8	**1.5**
19. CT trunk	7.0	-	24.1				10	15.0		10.4	**3.1**
All CT	7.4	7.7	8.1	6.1	6.0	3.5*	6.0	5.9	5.3	5.4	**2.3**

Natural background radiation in the US: 3 mSv/y. (range: 1-15 mSv/y.)

EC Radiation Protection Report N° 154, 2008

"Disclaimer"

While AAPM is an accepted authority representing Medical Physics in the US + CN, there is no European equivalent and therefore no unique European perspective.

What I am going to present is hopefully a sound analysis, but not an official statement, and certainly not intended as a confrontation Europe vs. US!

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- Foreword
- CTDI
  Status & Proposals
- Patient dose estimates
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The Computed Tomography Dose Index (CTDI)

CTDI is a measure of a CT scanner's exposure output. It is not meant as a measure of patient dose.

Literature on CTDI

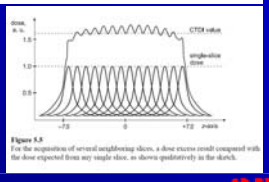
- AAPM Report 96 (2007)
- AAPM Report 111 (2010)
- IAEA Report 5 (2011)
- IEC 60601-2-44 (2009, 2010, 2011)
- Kalender (2000, 2005, 2010)
- …

Initial CTDI definition

- The CTDI concept was originally proposed by FDA and aims at estimating typical dose levels reached in CT examinations of volumes.

$$CTDI_{FDA} = \frac{1}{T} \cdot \int_{-7T}^{+7T} D(z)dz \qquad (5.2)$$

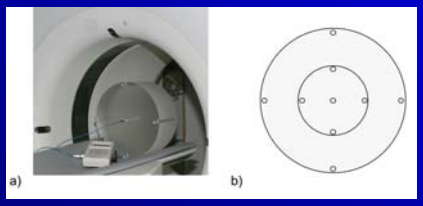
T – slice thickness
D(z) – dose along the z-axis



Shope et al. Med Phys 1981; 8:488-495

Phantoms for CTDI measurements

- CTDI can be measured in phantoms or in air. Perspex phantoms 15 cm in length with diameters of 16 cm ("head") and 32 cm ("body") are the standard.



Established CTDI concepts (since 2000)

- See AAPM Report 96 (2008), IAEA (2011) or else

N - # slices
T - slice thickness
x: position
c = center
p = periphery
in air

p - pitch factor for spiral scans

$$CTDI_{100,x} = \frac{1}{N \cdot T} \cdot \int_{-50mm}^{+50mm} D(z)dz$$

$$CTDI_{100,air} = \frac{1}{N \cdot T} \cdot \int_{-50mm}^{+50mm} D(z)dz$$

$$CTDI_{Vol} = (1/3 \cdot CTDI_{100,c} + 2/3 \cdot CTDI_{100,p})/p$$

- Valid and mandatory worldwide for acceptance and constancy testing in clinical routine!
- Robust and easy to perform, including spiral scans!

Open issues regarding CTDI concepts

- Tests of tube current modulation (TCM) and automatic exposure control (AEC) implementations (since about 2000)
- Validity for CT scanners with wide collimation, typ. > 64 detector rows or > 40 mm (since about 2005)
- Applicability to "cone-beam CT" including C-arm CT and small dedicated scanners (since about 2008)

CTDI for TCM and AEC implementations

- There are no phantoms or procedures defined yet for testing TCM and AEC implementations.
- Standards for testing and scanner comparisons would be desirable.

Continuous Phantom Incremental Phantom

Kolditz, Saltybaeva, Bohle, Kalender. RSNA 2012

CTDI for scanners with wide collimation

- $CTDI_{100}$ with an integration length of 100 mm underestimates dose for $N \times T > 100$ mm.
- The situation was first analyzed and described by Mori et al. in 2005 and by Boone in 2007.

Med Phys 2005; 32(4): 1061-69

Enlarged longitudinal dose profiles in cone-beam CT and the need for modified dosimetry

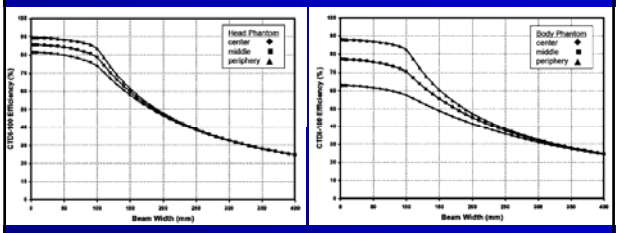
Shinichiro Mori, Masahiro Endo,[a] Kanae Nishizawa, and Takanori Tsunoo
National Institute of Radiological Sciences, Chiba 263-8555, Japan

Med Phys 2007; 34(4): 1364-71

The trouble with $CTDI_{100}$

John M. Boone[a]
Departments of Radiology and Biomedical Engineering, University of California Davis Medical Center, Ellison Building, 4860 Y Street, Suite 3100, Sacramento, California 95817

CTDI for scanners with wide collimation



It is generally accepted today that $CTDI_{100}$ works for $N \times T$ up to 40 mm; a solution is needed for $N \times T > 40$ mm.

Boone J. Med Phys 2007; 34(4): 1364-71

CTDI for scanners with wide collimation

I. Solution proposed by AAPM Report 111

- offers a thorough analysis of CT dosimetry
- proposes measurements of D(z) using phantoms of close to 50 cm

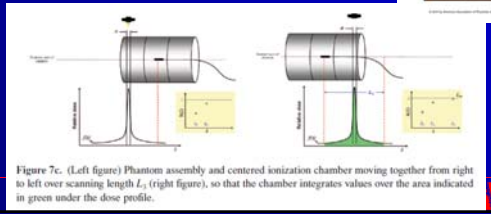


Figure 7c. (Left figure) Phantom assembly and centered ionization chamber moving together from right to left over scanning length L_2 (right figure), so that the chamber integrates values over the area indicated in green under the dose profile.

CTDI for scanners with wide collimation

I. Solution proposed by AAPM Report 111

- demands heavy phantoms;
- proposes a 3 cm ionization chamber which appears long for D(z) profile measurements;
- does not give clear or practical instructions for medical physicists involved in scanner testing; e.g.

> For the purpose of measurements of equilibrium dose, 30-cm long modules of PE cylinders could be assembled adjacent to each other along the longitudinal axis.

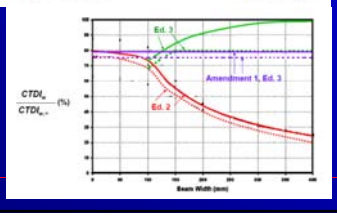
- …

CTDI for scanners with wide collimation

II. Solution proposed by IEC 60604-2-44 (2011)

- Measure $CTDI_{100}$, e.g., for $N \times T = 64 \times 0.625$ mm ("ref") and correct by CTDI measurements in air.

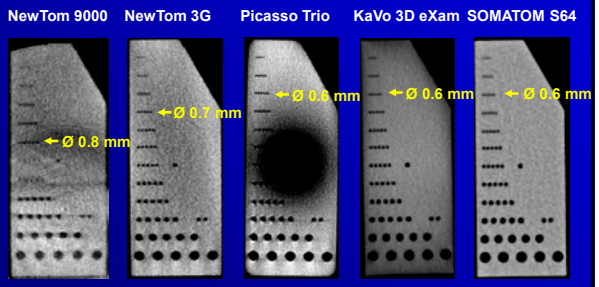
$$CTDI_{100} = \frac{1}{(N \cdot T)_{ref}} \cdot \int_{-50mm}^{+50mm} D_{ref}(z)dz \cdot \frac{CTDI_{free\ in\ air,\ N \cdot T}}{CTDI_{free\ in\ air,\ ref}}$$



CTDI for cone-beam CT scanners

- Many 1000s of these are installed by now, but not necessarily covered by CT regulations.
- Use the appropriate CTDI phantom!
- Apply the IEC approach if $N \times T > 40$ mm!

Spatial resolution and dose



Dose ($CTDI_w$ in mGy) (C = mean, W = 750)

Kyriakou, Kolditz, Langner, Krause, Kalender. RöFo 2010; 183:144-153

20

Conclusions on CTDI concepts

- The established concept amended by IEC for wide-collimation scanners appears acceptable.
- There is no need for new and heavy phantoms, only for long ionization chambers (30 cm) when operating with wide collimation.
- Dedicated CBCT and FDCT scanners can be covered with the same concept as clinical CT.
- We may forget the use of CTDI phantom measurements for patient dose assessment.

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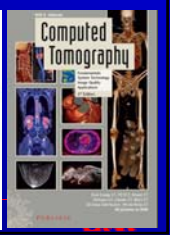
Literature on concepts for patient dose estimation

- EC Report N° 154 (2008)
- AAPM Report 204 (2010)
- Kalender (2000, 2005, 2010)
- …



Common approaches to assessing patient dose in clinical CT today

1. CTDI and DLP values
   are of interest for comparison purposes, but they do not represent patient dose.
   They are the basis for fixing DRLs (Diagnostic Reference Levels).

Diagnostic Reference Level
(demanded for the EU by law in 1997)

Table 5.2 Some reference dose levels valid for the European Union and the USA*

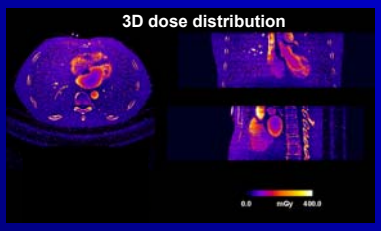
	EC [EC, 1999]		UK [DH, 2007]		Germany [BfS, 2010]		USA [ACR, 2008]
	$CTDI_w$	DLP	$CTDI_{vol}$	DLP	$CTDI_w$	DLP	$CTDI_{vol}$
Head	60	1050	65	930	60	1050	75
Chest	30	650	13	580	22	650	-
Abdom.	35	780	14	470	24	1500	25
Pelvis	35	570	14	560	28	750	-

* Kalender WA. Computed Tomography. 3nd ed. Publicis, Erlangen 2011

Common approaches to assessing patient dose in clinical CT today

1. CTDI and DLP values are of interest for comparison purposes, but they do not represent patient dose.
2. DLP-to-E conversion (initiated by the European Community)

Estimating effective dose E by DLP
(MC calculations based on $CTDI_{air}$)



If dose distribution is known
➡ Organ dose and eff. Dose E

Scan parameters (CTDI, DLP) are known
➡ k = E/DLP

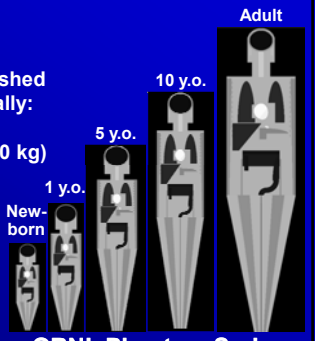
In general: Effective Dose E = k×DLP

Kalender W.A. Computed Tomography. 3rd ed. Publicis, Erlangen 2011

Dose calculations based on phantoms

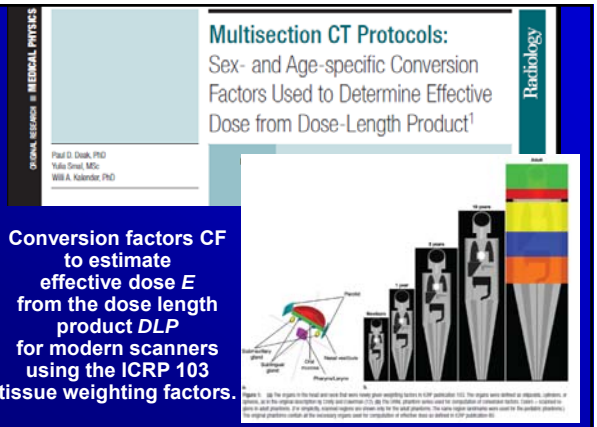
Advantages

- Phantoms are well established and approved internationally: "Adult" corresponds to ICRP`s "standard man" (70 kg)
- Clearly defined anatomy of the complete body including all organs
- ICRP may follow up with family of voxel phantoms.



ORNL Phantom Series

Cristy M. Oakridge National Laboratory 1980. Rep. ORNL/NUREG/TM-367

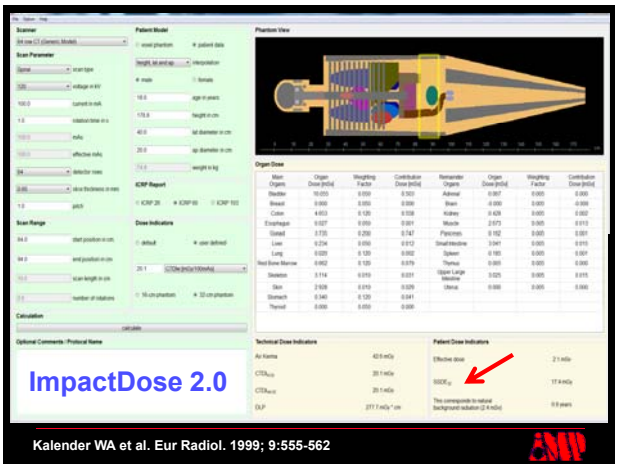


Conversion factors CF to estimate effective dose *E* from the dose length product *DLP* for modern scanners using the ICRP 103 tissue weighting factors.

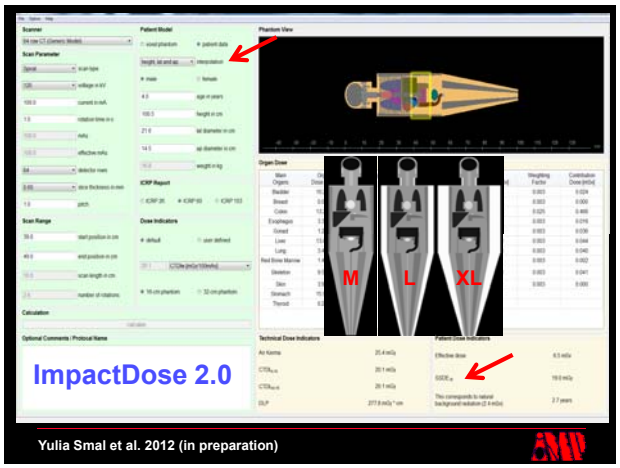
Deak P, Smal Y, Kalender W.A. Radiology 2010; 257:158-166

Common approaches to assessing patient dose in clinical CT today

1. CTDI and DLP values are of interest for comparison purposes, but they do not represent patient dose.
2. DLP-to-E conversion is neither patient- nor scanner-specific and does not provide organ dose values.
3. Programs based on pre-tabulated data, e.g. ImpactDose (D), ImPACT CT Patient dose calculator (UK), CT-Expo (D), …



Kalender WA et al. Eur Radiol. 1999; 9:555-562



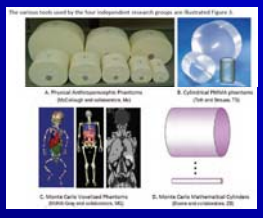
Yulia Smal et al. 2012 (in preparation)

Common approaches to assessing patient dose in clinical CT today

1. CTDI and DLP values are of interest for comparison purposes, but they do not represent patient dose.
2. DLP-to-E conversion is neither patient- nor scanner-specific and does not provide organ dose values.
3. Programs based on pre-tabulated data are mostly not patient size-specific and not scanner-specific.
4. SSDE according to AAPM Report 204.

Size-specific dose estimates (SSDE)

- are based on measurements and MC calculations for four sets of phantoms

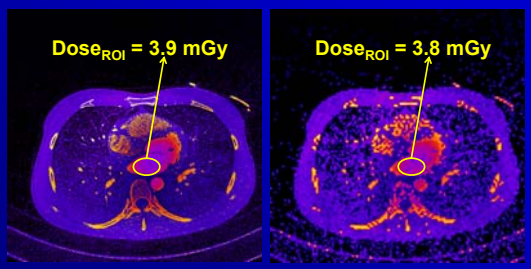


- estimate a patient-specific CTDI
- do not provide organ or patient dose

Tasks to be solved for providing patient-specific dose estimates

1. Total scatter has to be accounted for; i.e.: we need a complete body representation.
2. Dose to organs has to be assessed; i.e.: organs have to be identified & segmented.
3. Organ and effective dose values should be estimated for the patient, scanner and scan protocol in question.
4. Results should be available without long wait times and in a comprehensible format.

Fast MC solutions are available



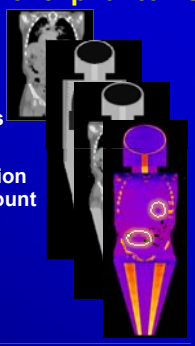
Time$_{cal}$ = 10 min Time$_{cal}$ = 10 s

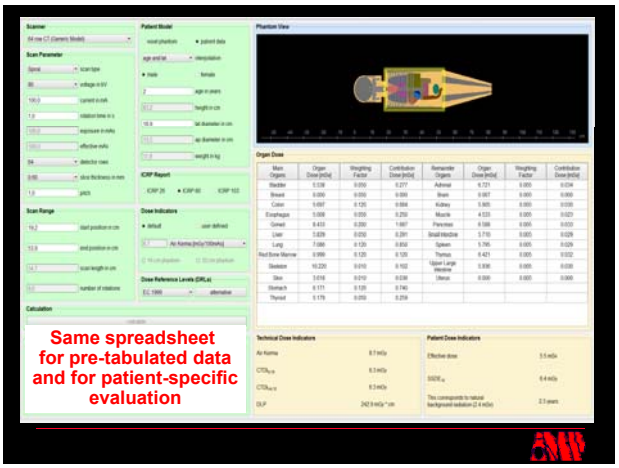
Calculations are accelerated by using GPU clusters * and by reducing resolution.

* Chen, Kolditz, Beister, Bohle, Kalender. Med Phys 2012;39:2985-2996

Steps in generating and using patient-specific whole-body voxel phantoms

1. Use the acquired patient CT data
2. Choose the "best-fitting" phantom from ORNL series or other sources
3. Insert the CT data
4. Perform whole-body dose calculation taking TCM, AEC & filters into account
5. Overlay organ contours & check
6. Determine organ dose values and effective dose *E*





Same spreadsheet for pre-tabulated data and for patient-specific evaluation

Validation by phantom measurements

Phantoms	CT	Dose	ΔD
Newborn			7.2 %
5 y. old			9.0 %
Adult			5.3 %

ΔD:
mean difference between MC calc. and TLD measurements for 94 TLD chips.

Saltybaeva, Kolditz, Bohle, Smal, Kalender. (in preparation)

Conclusions on patient-specific dose estimates (PSDE)

- Patient-, scanner- and protocol-specific dose estimates can be provided online to within 10 % accuracy.
- Manufacturer cooperation is required w.r.t. relevant information, e.g. data on filtration and AEC curves incl. start position and angle.
- It can be a great approach for research, but is not necessary in routine practice.

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Summary & Conclusions

- Scanner dosimetry can be handled adequately using the established CTDI concepts amended by CTDI in air measurements for collimations >40 mm.
- Approaches to patient-, scanner- and protocol-specific dose estimates (PSDE) have to be investigated further and need support by manufacturers regarding necessary scanner data.
- We need international cooperation on this!

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Personal Remarks

- Dose in CT must not be seen as a problem!

Sub-mSv CT is a reality already for cardiac and pediatric CT!

Table 8.2 Potentials for dose reduction to be exploited in the 2010s *

	%	factor
X-ray spectra	20	0.8
X-ray detectors	30	0.7
Dose management	30	0.7
X-ray beam collimation	20	0.8
Image reconstruction	40	0.6
Total	80	0.2


Radiology

Achieving Routine Submillisievert CT Scanning: Report from the Summit on Management of Radiation Dose in CT

* Kalender W.A. Computed Tomography. 3rd ed. Publicis, Erlangen 2011

What about risk and risk communication?

- CT dose values are mostly in the range of natural background radiation and well known. The risk is not known and certainly very low. The benefits are well known and high.

  Hendee WR, O'Connor MK. Radiology 2012;264:312-321.
  "Radiation Risks of Medical Imaging: Separating Fact from Fantasy".

- Stress AHARA!
  The benefit-to-risk ratio has to be "As High As Reasonably Achievable"!

  Kalender WA. "Computed Tomography". 3rd ed. Publicis, Erlangen 2012
  … on the final page.

Personal Hope

- We need international cooperation on many topics in medical physics; dose issues are certainly central. E.g., SSDE and PSDE concepts might be merged.
- Europe needs an organization like AAPM. However, a European Society of Physicists in Medicine (ESPM) is still a dream and probably far away.