PRACTICAL DOSIMETRY OF CONE-BEAM GEOMETRY CT SCANNERS

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Conflict Statements

Conflicts of Interest: NONE

Conflicts with Facts: Hopefully none, if you see one speak up!

What you really need to do: Look at these references!

IAEA Human Health Reports No. 5, Status of Computed Tomography Dosimetry for Wide Cone Beam Scanners (International Atomic Energy Agency, Vienna, 2011)

AAPM Report No. 111, Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography (American Association of Physicists in Medicine, College Park, 2010)

AAPM Report No. 200, Task Group No. 200 - CT Dosimetry Phantoms and the implementation of AAPM Report Number 111 (Work in Progress, but nearing finish line)

Current IEC Standard 60601-2-44 Edition 3.2

What are the goals of CT dosimetry?

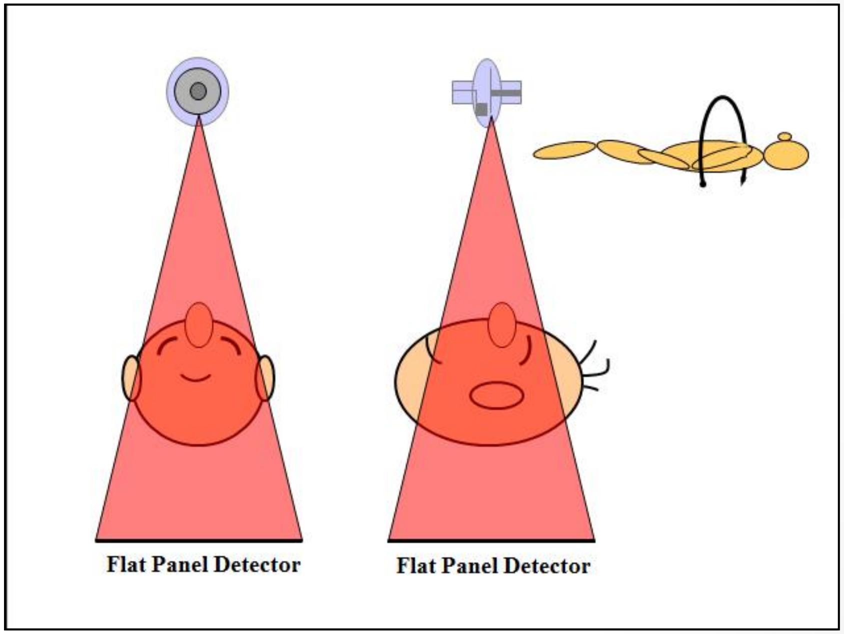
Acceptance Testing: does scanner meet the vendors specifications and are the displayed dose metrics (CTDI, DLP) accurate

Continuing Quality Assurance: is x-ray output stable and reproducible, is output correct for desired image quality, do the dose metrics continue to reflect the actual radiation output

Clinical Needs: Estimation of patient doses and optimization of clinical scan protocols

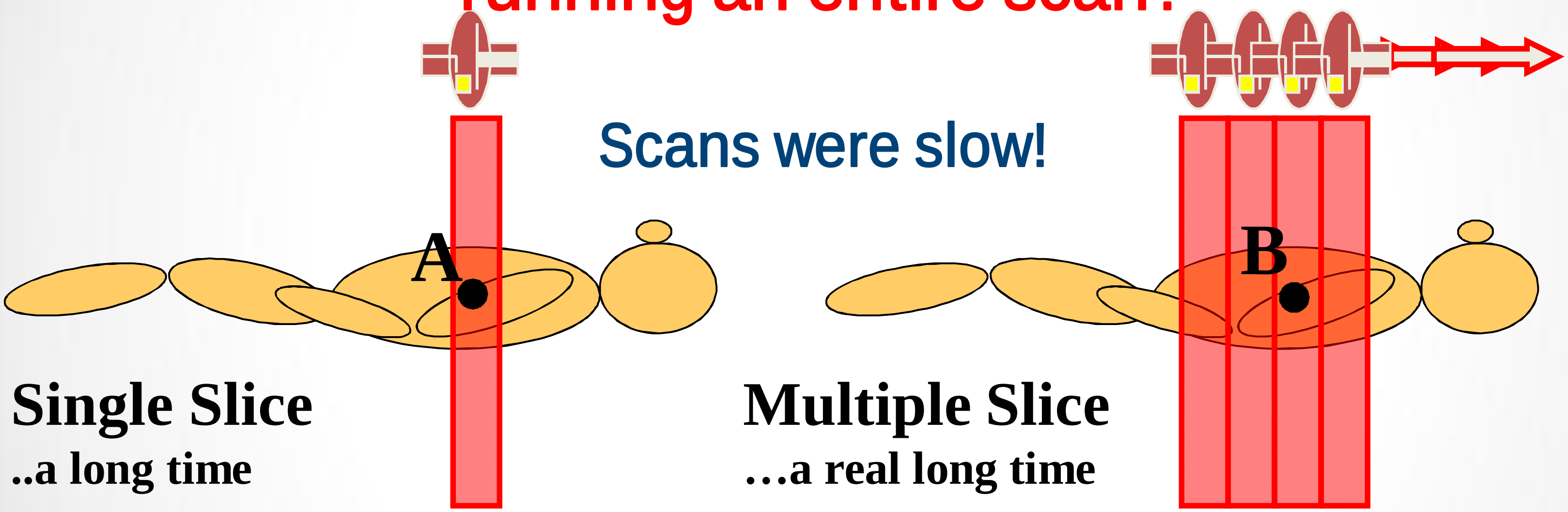
What is cone beam CT (CBCT) for the purposes of this talk?

Conventional CT is "fan beam" geometry; CBCT occurs when the axial dimension of the radiation beam becomes "large" in extended axial view MDCT or in rotational angiographic acquisitions



The Problem at the Birth of CT

Can we estimate the dose at some point without running an entire scan?



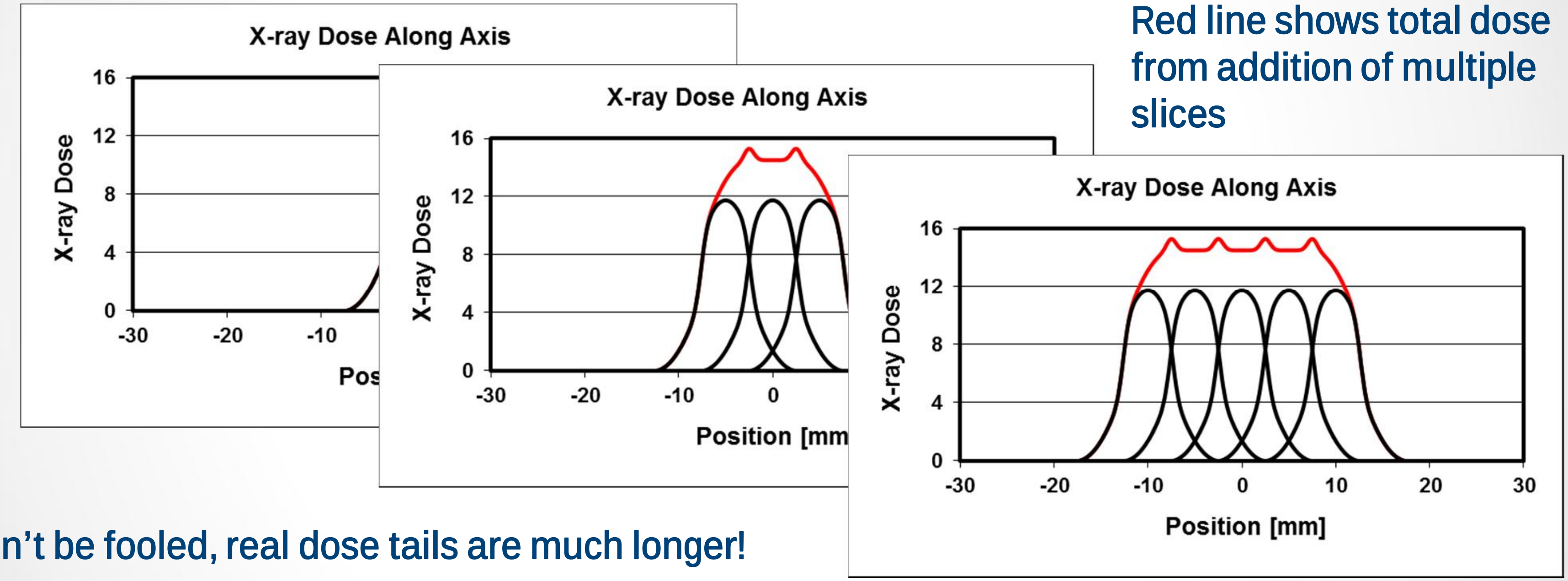
Scans were slow!

Single Slice
..a long time

Multiple Slice
…a real long time

For multiple slices, scatter from adjacent slices increases the dose at point B

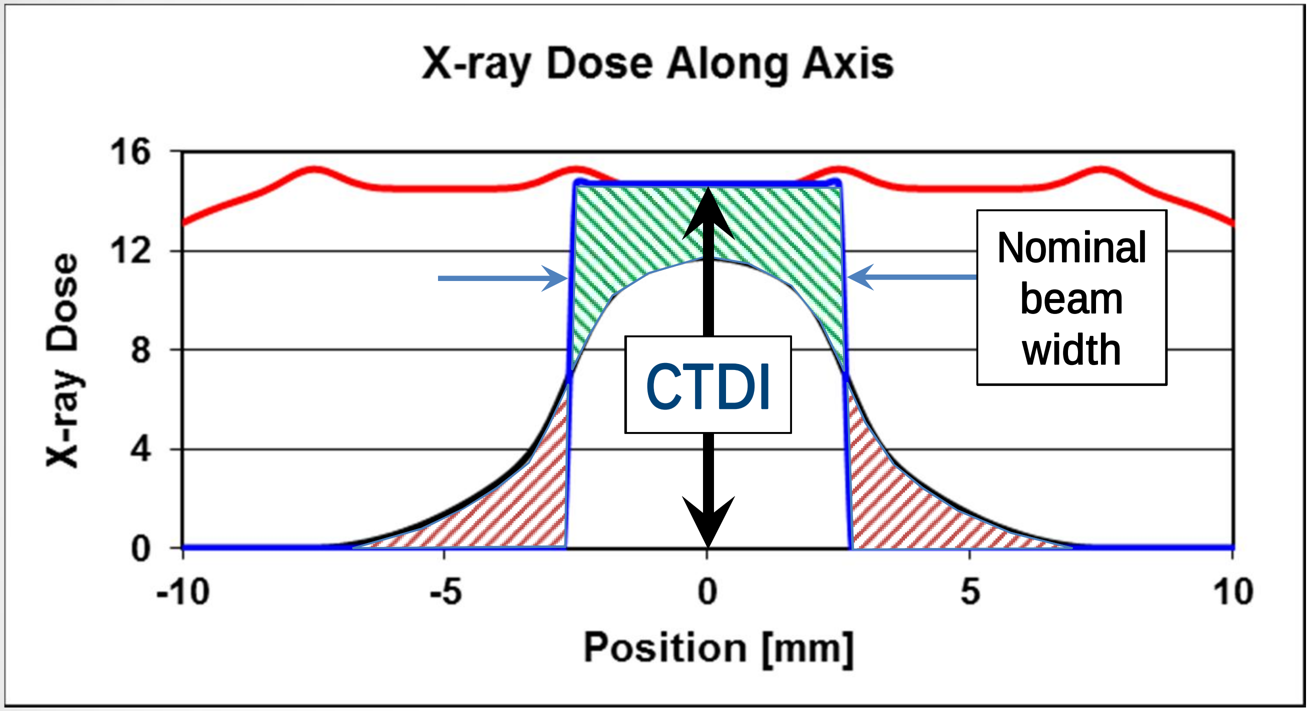
Making it all add up-looking at the dose profile D(z) (f(z) in some schemes)



Red line shows total dose from addition of multiple slices

Don’t be fooled, real dose tails are much longer!

Basis of the CTDI



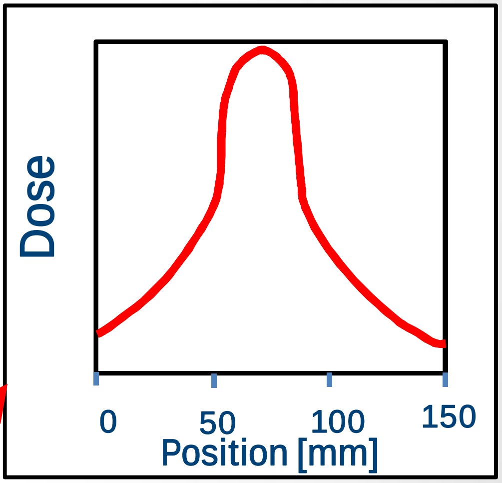
If dose integrated across total beam width assigned to nominal beam width, associated dose (rectangle height) would be CTDI

Important properties of CTDI

Accuracy requires a detector/phantom longer than total beam width (primary plus scatter).

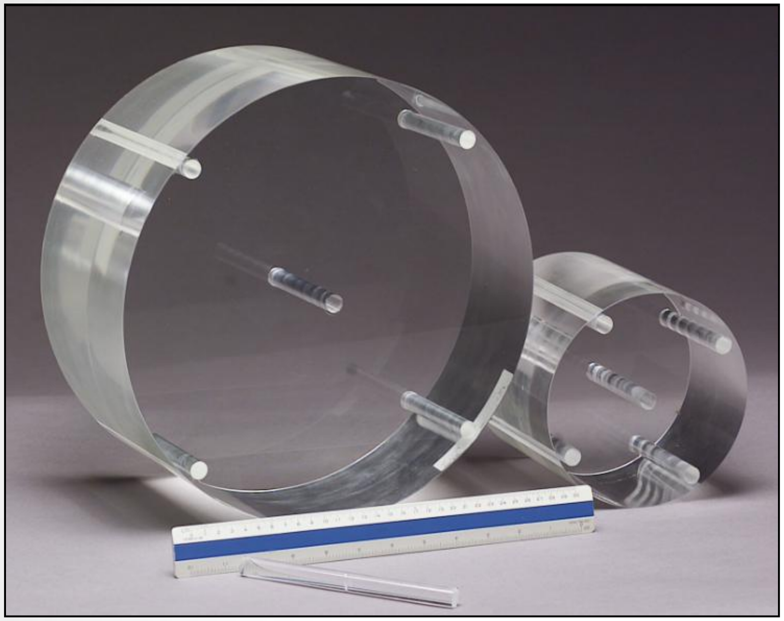
CTDI overestimates dose for single axial acquisition (CTDI > f(0))

Dose to a phantom, not a patient



For a more realistic beam profile, see IAEA Rep #5

Tools of the Trade



PMMA phantoms, ϕ=16, 32 cm; length = 15 cm

1. 10 cm pencil chamber (conventional CTDI)
2. 0.6 cm^3 Farmer chamber (TG-111)
3. 0.125 cm^3 chamber

Flavors of CTDI – I (The original article)

$\boldsymbol{CTDI_{FDA}}$: $$\boldsymbol{CTDI_{FDA} = \frac{1}{T}\int_{-7T}^{7T} D(z)\, dz}$$

"Original" CTDI, measured with stack of TLDs and reported as dose to plexiglass

Flavors of CTDI -- II

1 becomes active length L[mm]

$CTDI_{100}$:

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

My chamber of active length L reads out in R or AK! What to do?

CTDI measured with 100 mm pencil ion chamber and allowing for multi row detectors, nominal beam width N rows with image thickness T; reported as dose to air

Flavors of CTDI -- III

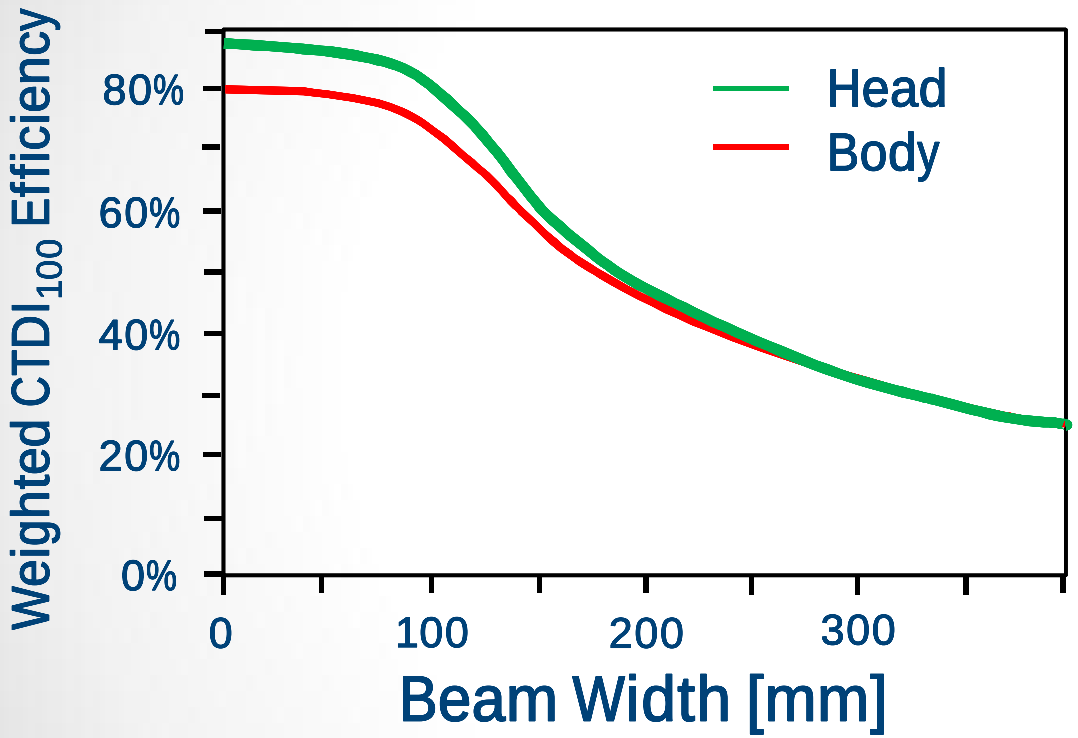
$$CTDI_W = \frac{1}{3} \times CTDI_{center} + \frac{2}{3} \times CTDI_{peripheral}$$

Averaged CTDI value over the phantom cross-section

$$CTDI_{vol} = \frac{CTDI_W}{p}$$

CTDI associated with a helical scan of pitch p

About that accuracy business



CTDI efficiency compares $CTDI_{100,150}$ to $CTDI_{\infty}$ (phantom and chamber)

We miss some of the dose, even at narrow widths, because of the tails, but we all do it the same!

Following IAEA Report No.5 and JM Boone, MedPhys 34(4)2007

A first attempt for cone beam dosimetry: CTDI.e, $\overline{D}_{100}$ and IEC 60601-2-44(2009)

Pragmatic modified $CTDI_{100}$, developed for dosimetry of a wide beam (160 mm) CT scanner (Toshiba, Aquilion ONE) by comparison to measurements made with 350 mm phantom, 300 mm pencil ion chamber (Geleijns *et al.*, Phys. Med. Biol. 54 (2009) 3141–3159)

Conventional $CTDI_{100}$ fails, beam is wider than chamber/phantom

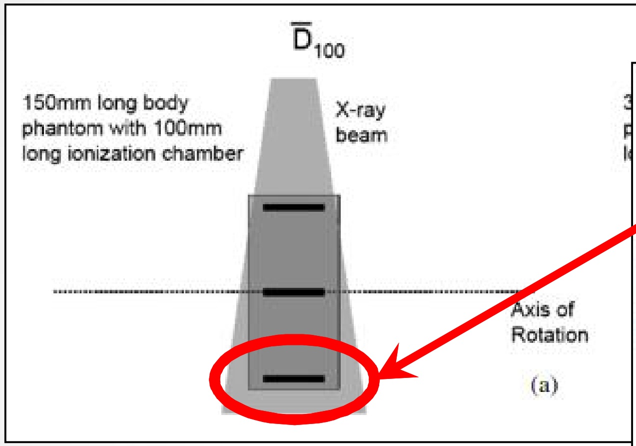
CTDI.e, $\overline{\mathrm{D}}_{100}$ and IEC 60601-2-44(2009)

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

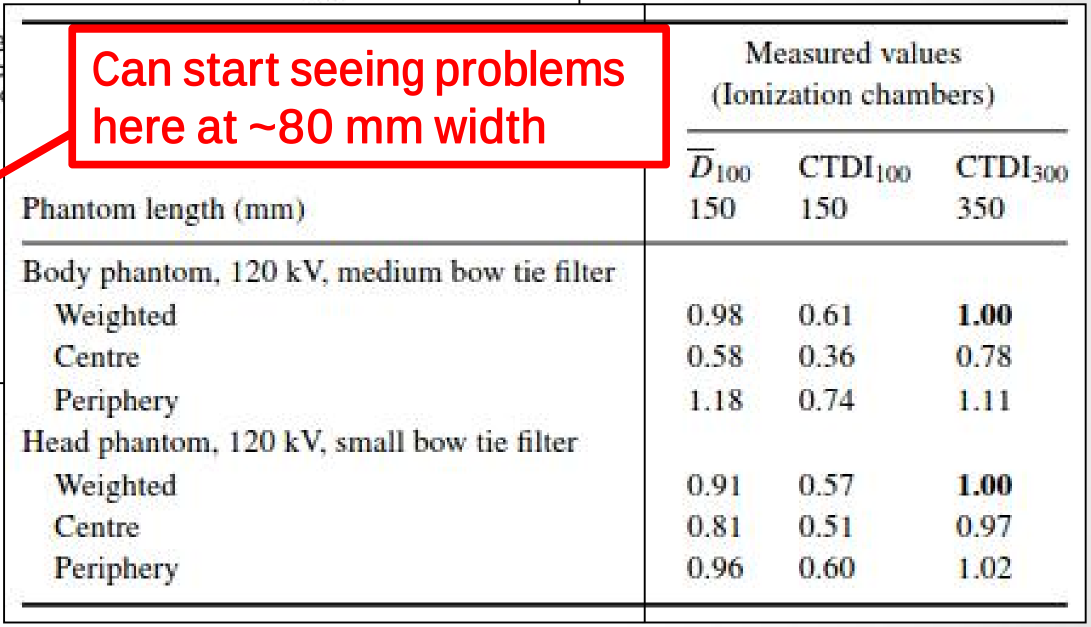
If nominal beam width ($N \times T$) less than length of pencil chamber, calculate CTDI_{100} normally by dividing integrated dose profile by nominal beam width

If nominal beam width ($N \times T$) greater than length of pencil chamber, divide integrated dose profile by the length of the chamber, not nominal beam width

CTDI.e, $\bar{D}_{100}$ and IEC 60601-2-44(2009)



Can start seeing problems here at ~80 mm width



	Measured values (Ionization chambers)		
	$\bar{D}_{100}$	CTDI$_{100}$	CTDI$_{300}$
Phantom length (mm)	150	150	350
Body phantom, 120 kV, medium bow tie filter			
Weighted	0.98	0.61	**1.00**
Centre	0.58	0.36	0.78
Periphery	1.18	0.74	1.11
Head phantom, 120 kV, small bow tie filter			
Weighted	0.91	0.57	**1.00**
Centre	0.81	0.51	0.97
Periphery	0.96	0.60	1.02

Geleijns *et al*., Phys. Med. Biol. 54 (2009) 3141–3159

CTDI values low because we divide by N x T, which is bigger than chamber!

CTDI.e, $\overline{D}_{100}$ and IEC 60601-2-44(2009)

Results using D_{100} agree with the (300 mm chamber)/(350 mm phantom) within about 10% or better

BOTTOM LINE: Make measurements as for conventional CTDI, but if beam is wider than 100 mm (length of ion chamber), calculate CTDI using 100 mm instead of N x T.

SHORTCOMINGS: Measurement still knows nothing about beam outside phantom, reflects only direct beam, scatter interacting in 15 cm phantom and 100 mm ion chamber

Current IEC Standard (60601-2-44(2016))

To address D_{100}, shortcomings, current IEC includes information for beam *outside* length of the 15 cm phantom.

Two-tiered approach

a) beams 40 mm and less obtain $CTDI_{100}$ in time honored way.

b) beams greater than 40 mm, scale a reference CTDI (based on in-air measurements)

Justification outlined in IAEA Report No.5

Current IEC Standard (60601-2-44(2016))

40 mm width
or less:

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

Business as usual

Current IEC Standard (60601-2-44(2016))

> 40 mm width:

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

How do I do this if the width is greater than 100 mm?

Reference CTDI obtained conventionally using widest beam width available on scanner that is 20mm or less; scale by ratio of two CTDI$_{\text{free air}}$ measurements to get CTDI for wide beam

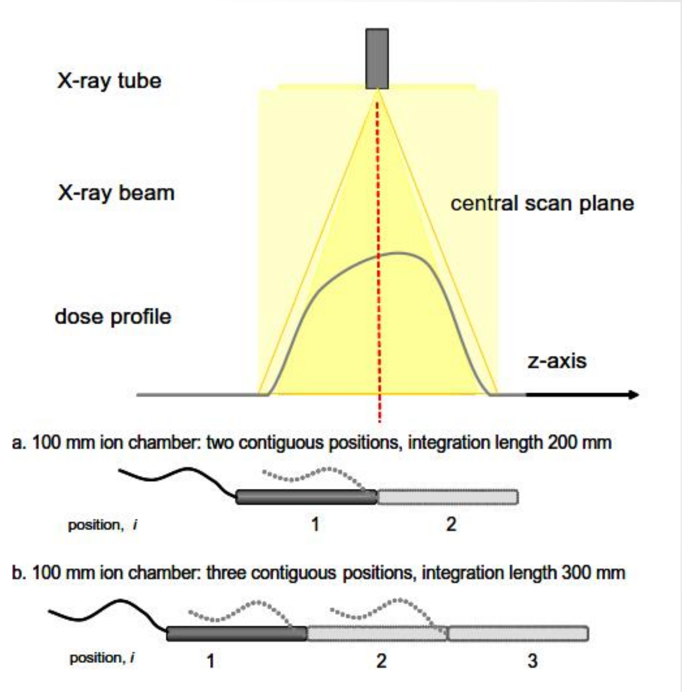
Current IEC Standard (60601-2-44(2016))

> 40 mm width:

Standard 100 mm chamber translated to make in air measurement for wide beams

The number of placements is given by

$$Y = trunc\left(\frac{beam\ width}{chamber\ length}\right) + 1$$



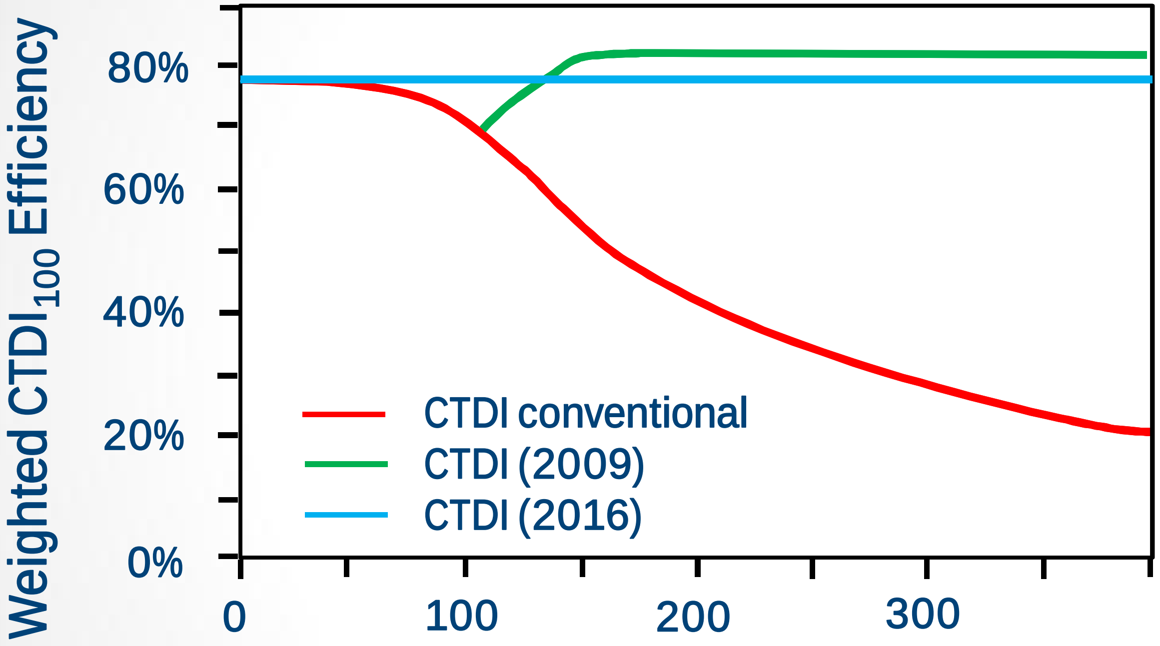
IAEA Human Health Reports No. 5, Status of Computed Tomography Dosimetry for Wide Cone Beam Scanners

Current IEC Standard (60601-2-44(2016))

Notes:

1) Keep patient support out of beam; use small, low density support device, keep end of support at least half beam width away from edge of beam.
2) Note final IEC version separates techniques at 40 mm beam width; the IAEA suggested 60 mm beam width.
3) IAEA Report No. 5 has illustrations and advice!

How do these approaches compare?

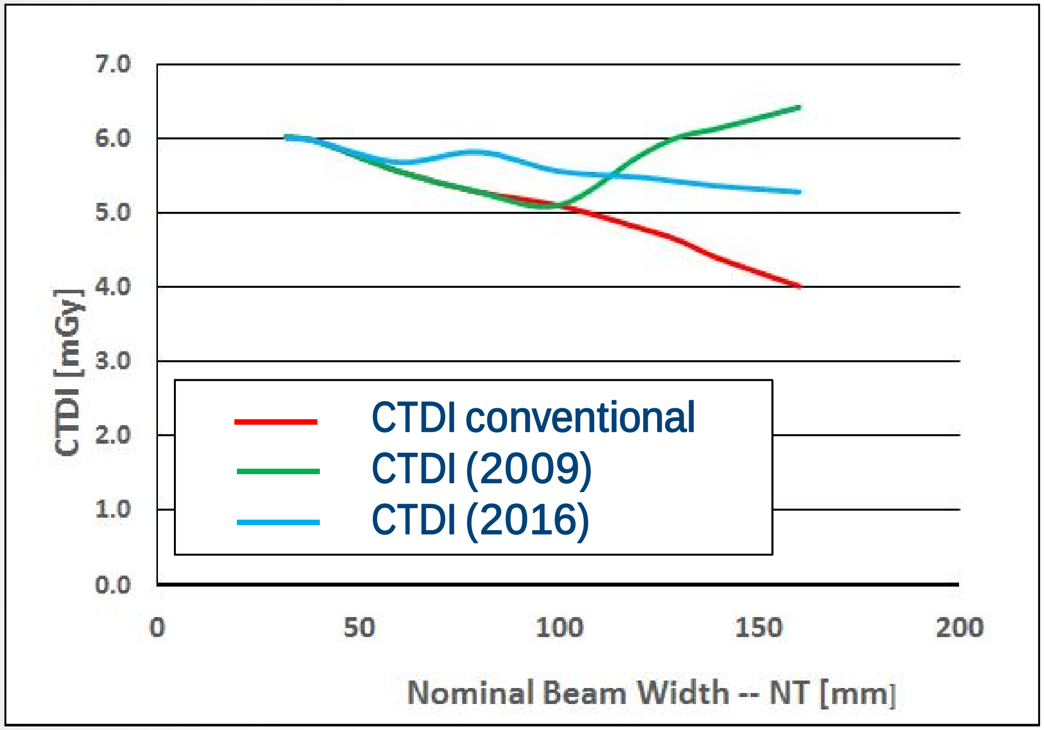


Body (32 cm dia.) phantom

10 cm chamber

After IAEA Rept #5

And some supporting data



Body (32 cm dia.) phantom

10 cm chamber

Private Communication

Something Entirely Different: TG-111, or These are not your fathers' scanners

AAPM Report No. 111, Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography

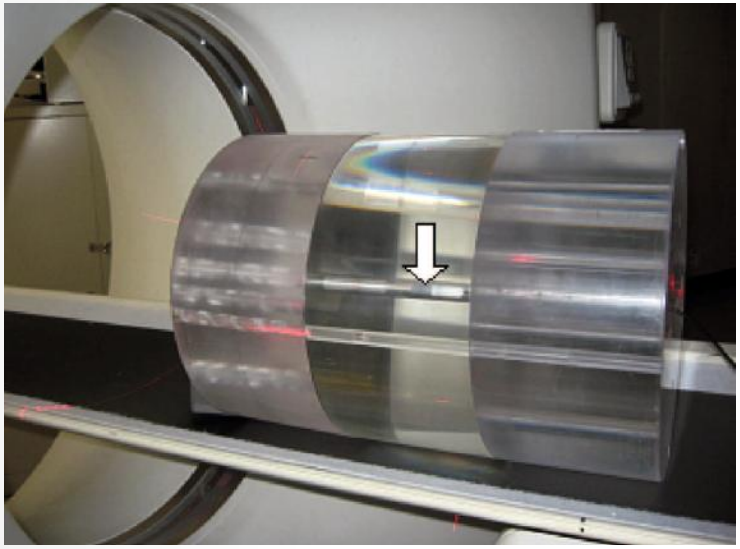
TG-111

- Created in recognition that
  - Phantoms too short
  - CTDI based on axial measurements; not all clinical scans well approximated by axials
  - Scanners are fast, there is no reason not to acquire data at a point from full scans

Results can be used to estimate doses in axial, helical and cone beam modes

TG-111 Paradigm

- Use a short (point) ion chamber and long (maybe 40-45 cm) phantom.



AAPM Report No. 111

TG-111 Paradigm

- Make helical scans of increasing length to estimate the D_{eq} (z=0) (asymptotic cumulative dose for long scans) for a selected set of parameters (kVp, f.s., mAs, n, T, beamwidth)
- Calculate the equilibrium dose pitch product $\hat{D}_{eq}$ (depends on D_{eq} and beamwidth, pitch, and n x T)
- From $\hat{D}_{eq}$ and free-in-air measurements, doses for other scan configurations can be calculated

TG-111 Paradigm

It sounds complicated and we won’t really know how to use it until a second TG, TG-200, defines the phantom and specifies how to make these measurements in practice. (maybe Q4 2017)

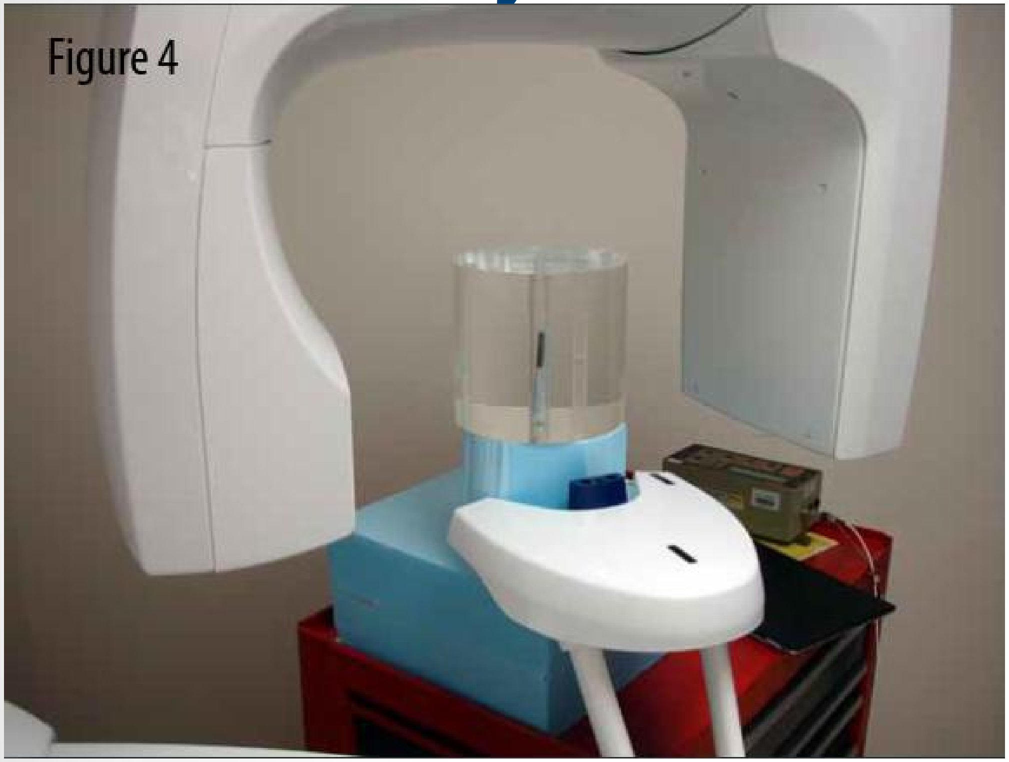
BUT

TG-111 Paradigm

“In a scanning mode involving fan-beam or cone-beam irradiation without translation of the patient table, the clinically relevant in-phantom dose descriptor is f(0), not D_{eq}”

We have gotten back to sticking a small chamber into the phantom and taking a single rotation scan to determine the dose to the phantom! This is where we began.

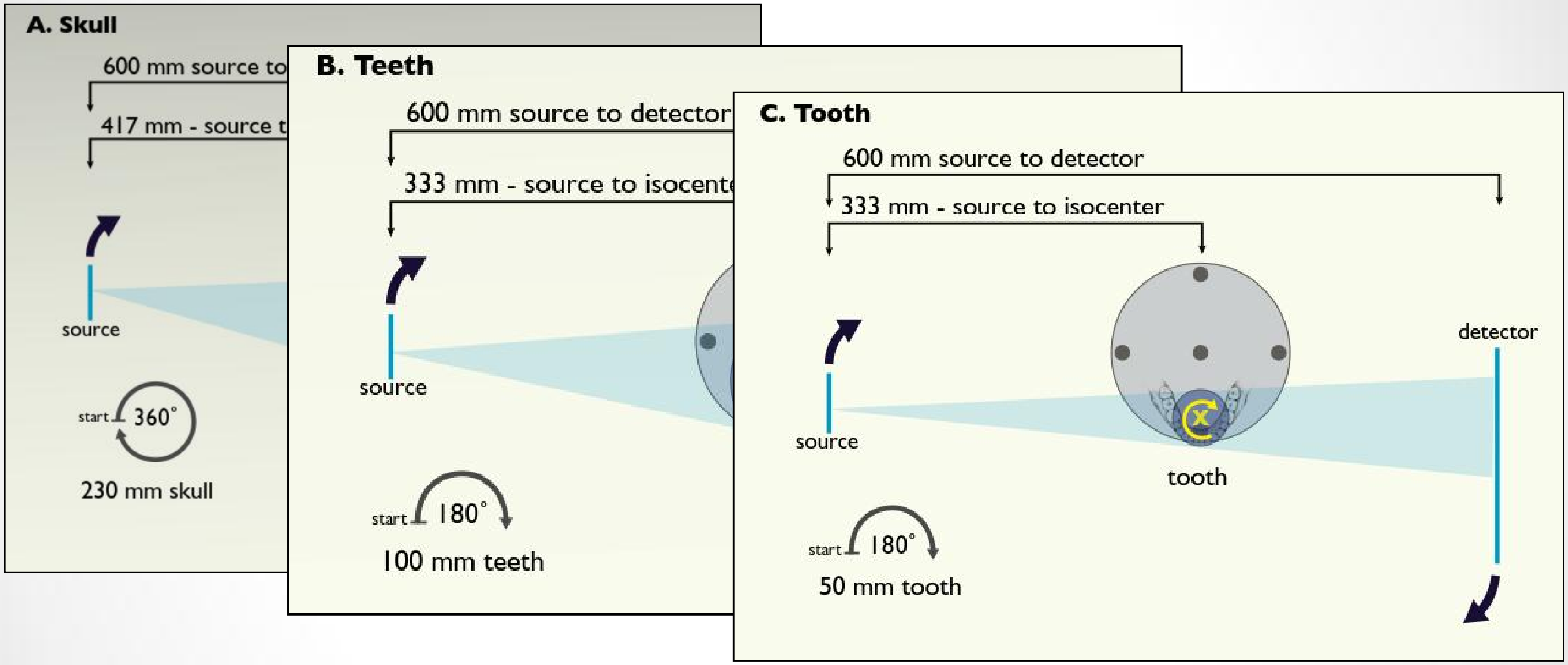
Case Study: Planmeca Promax 3D



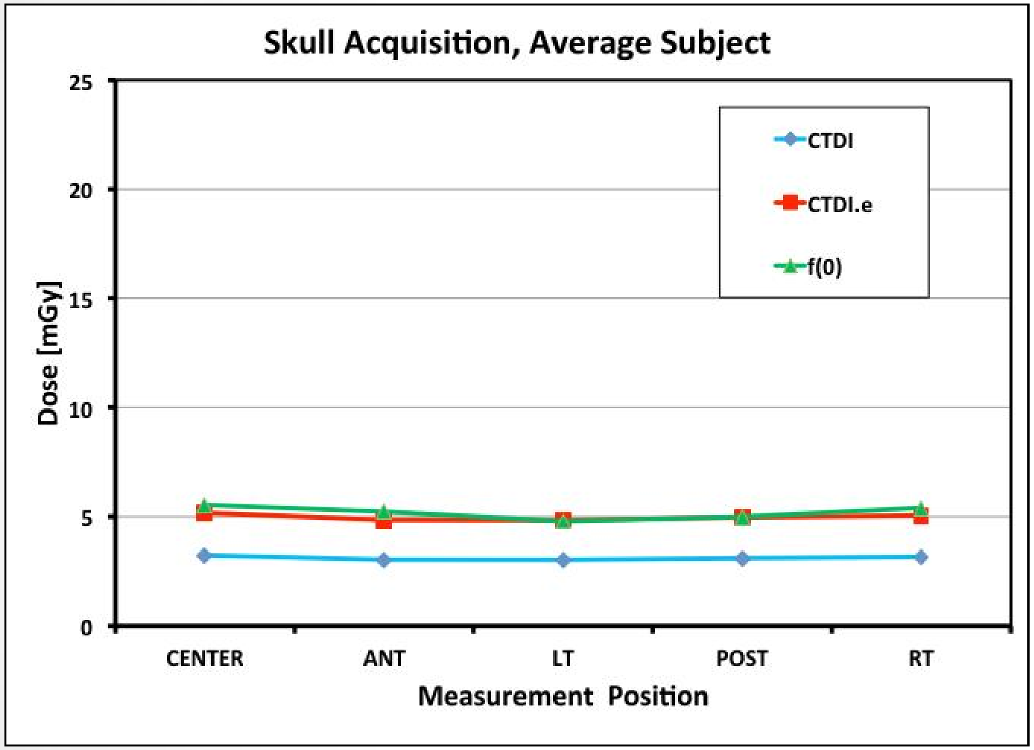
CTDI and CTDI.e acquired with conventional pencil chamber. f(0) obtained with 0.1 cm^3 chamber (shown).

Skull, Teeth, and Tooth protocols studied.

Case Study: CT Modes



Case Study: Results



Skull acquisition has 160 mm acquisition in z direction.

CTDI.e and f(0) are quite close,

As expected, CTDI under reports dose.

CT Dose – The Beginning and End

A long time ago,
in a medical
physics universe
far, far away

New CT scanners appeared.

Medical physicists pondered
how to measure CT doses.

Scans were SLOW and limited.

Time was precious.

Thus was the origin of