Practical investigations into using a small ion chamber and realistic phantom length for CT dosimetry

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Outline

The Purpose of the Project

Purpose

- CTDI used as an index for QC, and scanner-to-scanner comparisons
- Also used for patient doses
- Since CTDI was introduced, there have been revolutionary advances in CT, eg. helical scanning, cone beam CT
- Ability to scan increasingly larger patient lengths
- How big is the $CTDI_{100}$ shortfall as indicator for patient doses?
- Investigate a new methodology for determining patient doses from CT exams
- Method was proposed *Dixon*, 2003; uses a small ion chamber and realistic phantom length

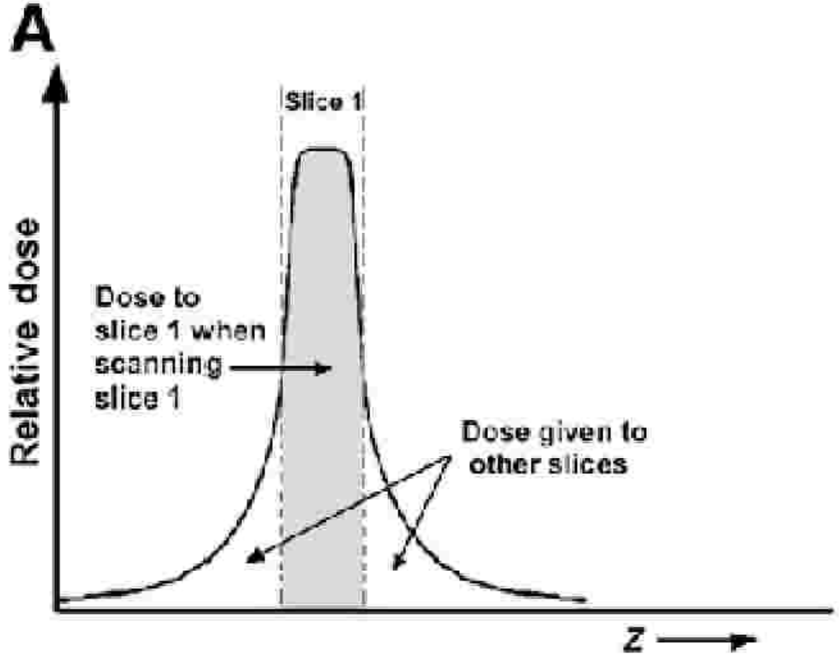
The Ultimate goal

Hypothesis

- The standard dosimetry phantoms are insufficient in length
- The 100 mm pencil chamber is too short
- $CTDI_{\infty}$ is more representative of dose for large L
- The central axis dose gains in relative importance for increasing L

Multi-slice Average Dose (MSAD)

- Single dose profile contains primary and scatter regions



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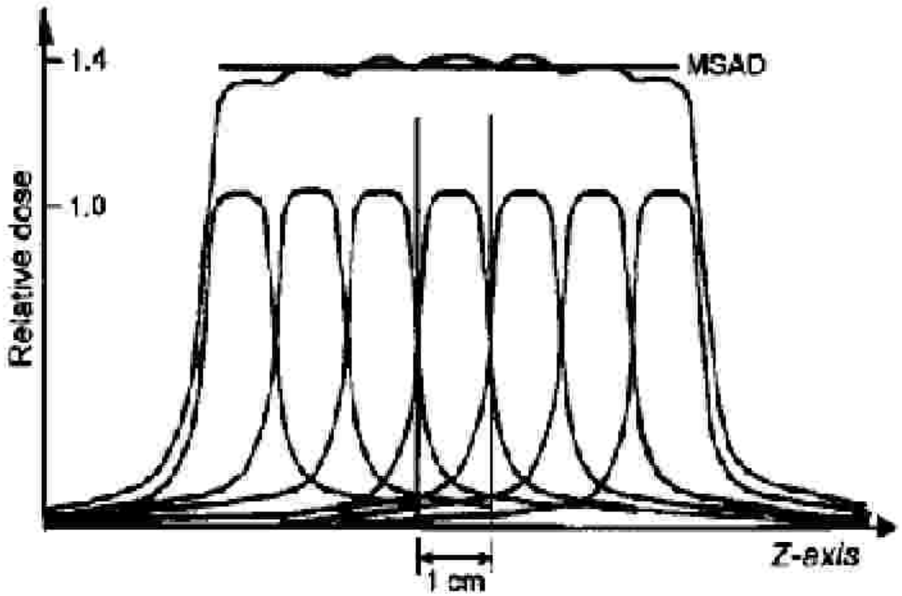

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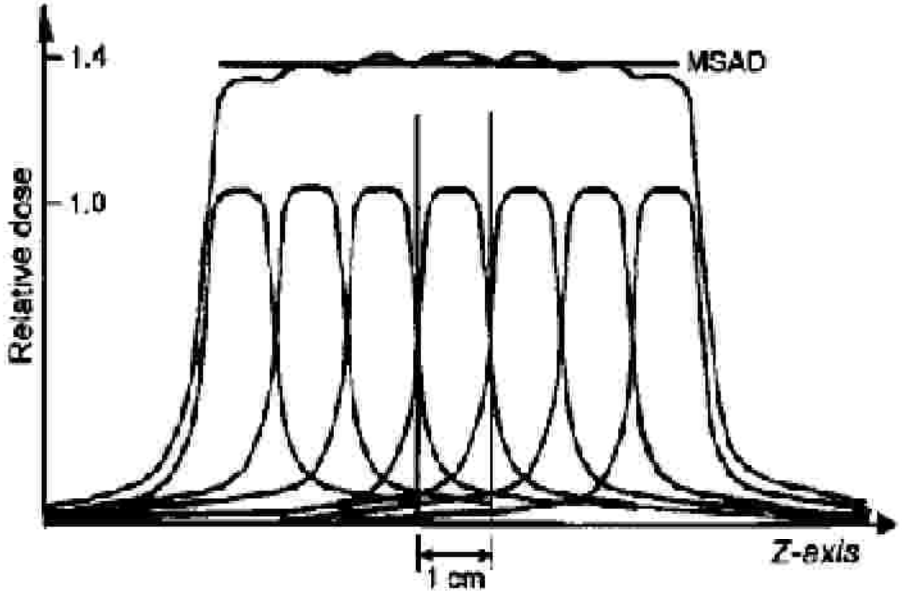

Multi-slice Average Dose (MSAD)

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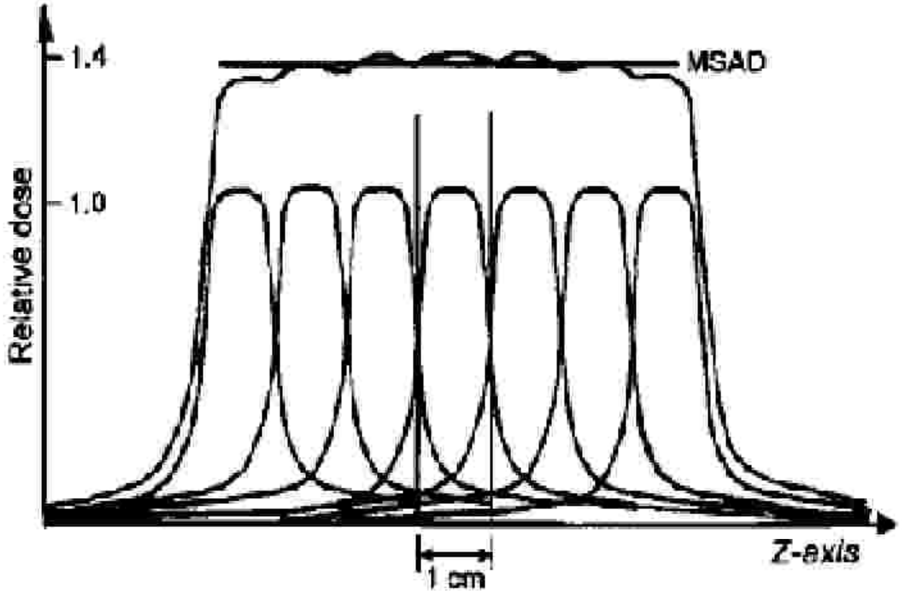
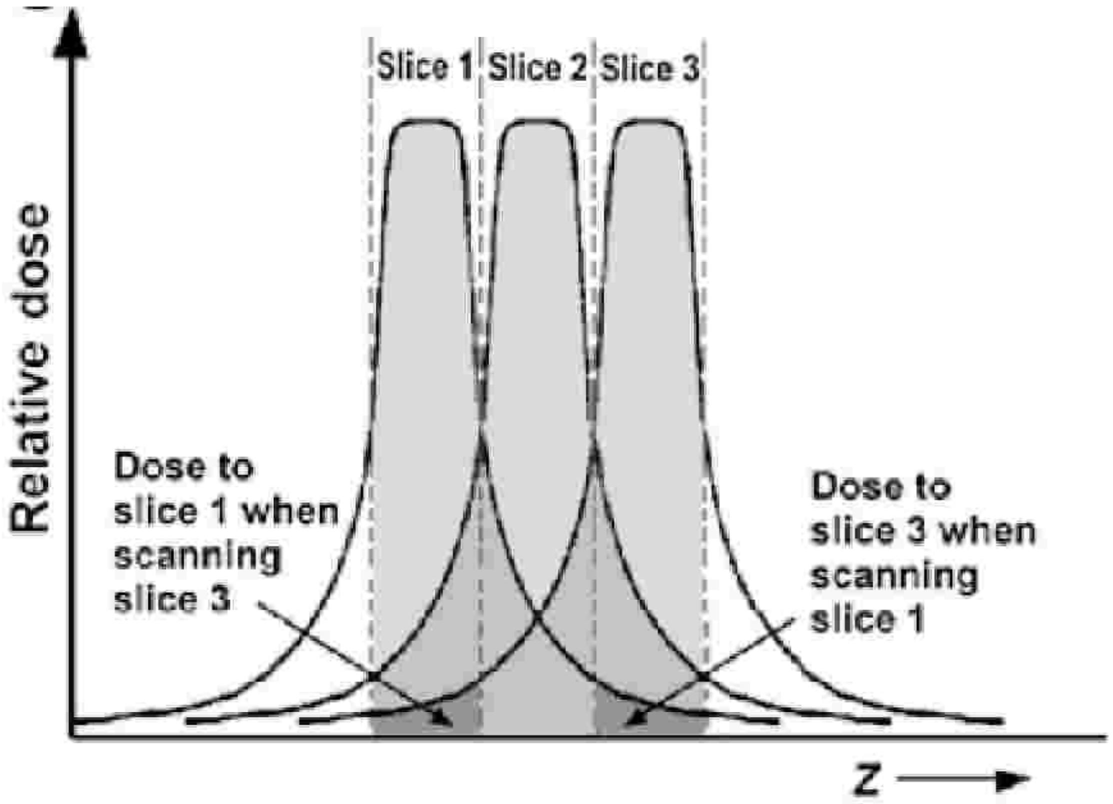
- Slices receive scattered radiation when adjacent slices are scanned
- MSAD was the first CT-specific dose descriptor and accounts for the effects of multiple scans
- MSAD- Average of the cumulative dose resulting from a series of contiguous slices



CT Dose Index (CTDI)



Dose that scanning of slice 1 gives to all slices = dose that slice 1 gets from scanning of all slices [*Shope*, 1981].

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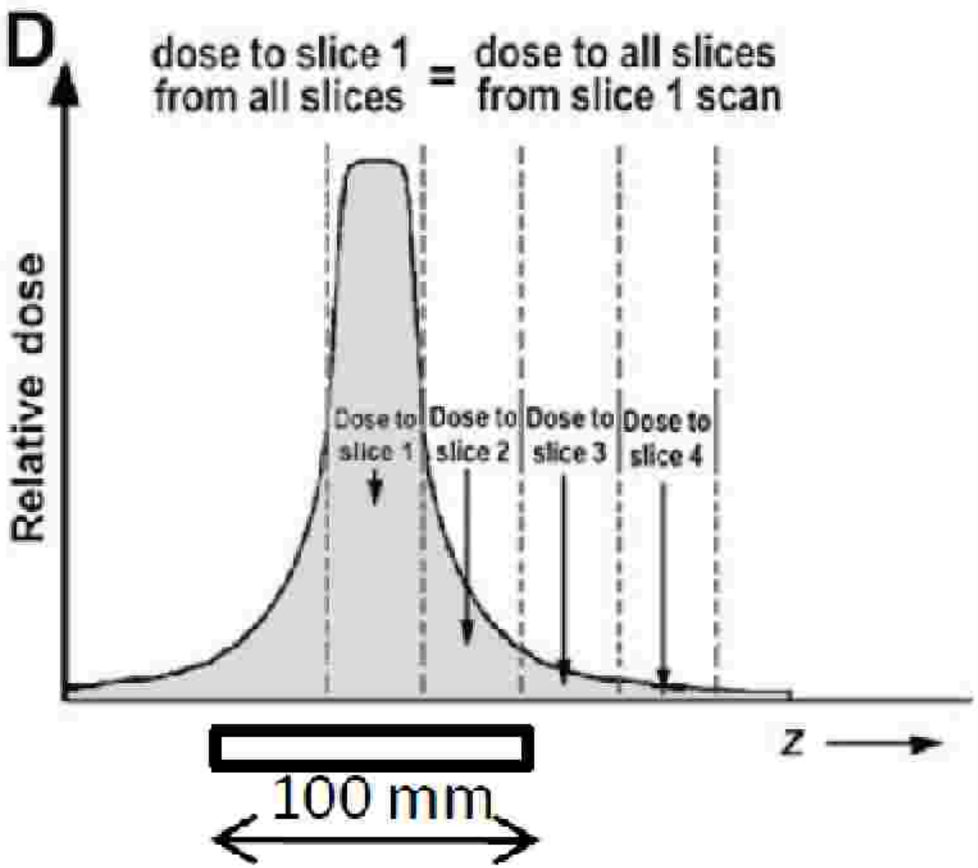

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CTDI_{100}

$$\mathrm{CTDI}_{100} = \frac{1}{nT}\int_{-50\mathrm{mm}}^{+50\mathrm{mm}} D(z)\,dz$$

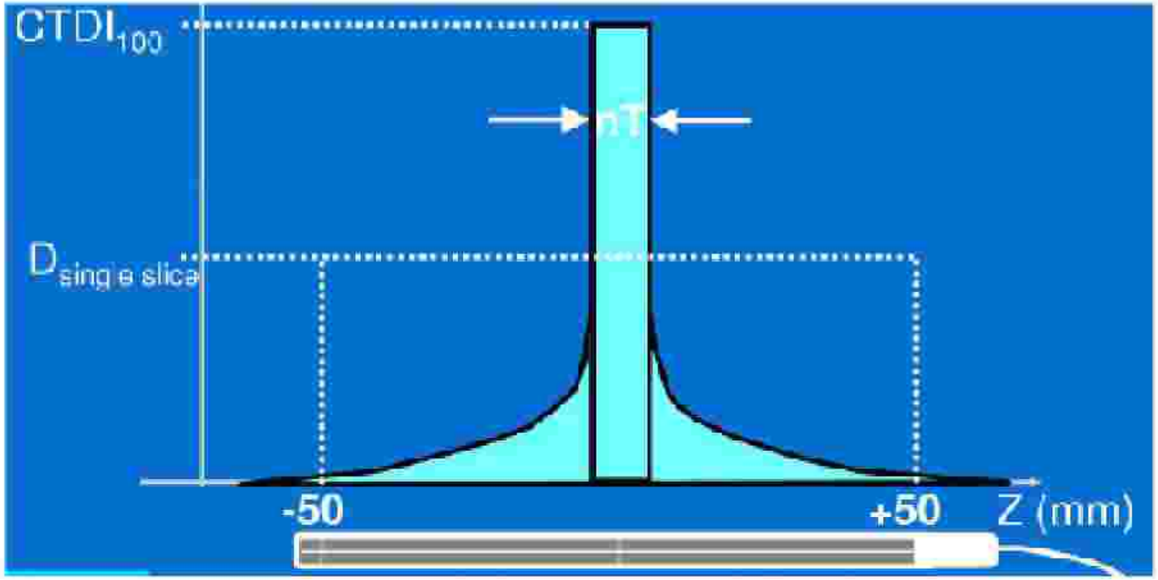


Figure from: *Maria Lewis*, ImPACT, 2006

CTDI_{100} → average dose at the centre ($z = 0$) resulting from a series of contiguous scans over a 100 mm scan length

The Problem and possible solutions

Problem:

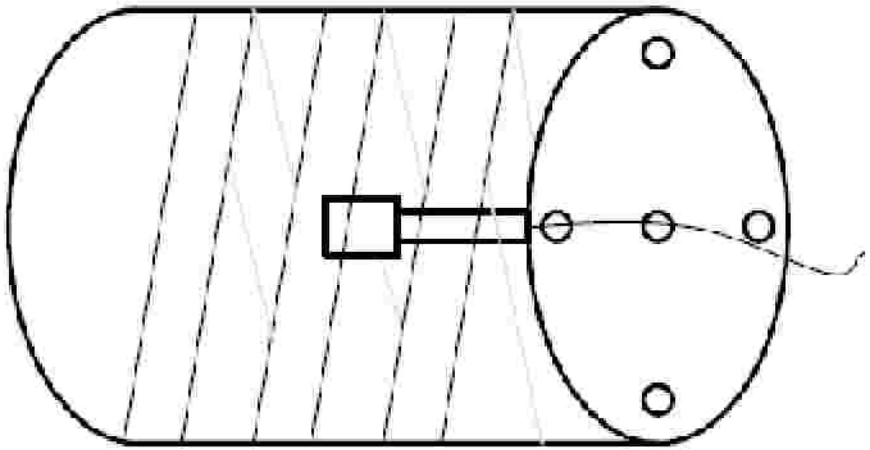
- *The 100 mm chamber is too short!*
- $CTDI_{100}$ underestimates the dose for any scan length > 100 mm.

Solutions:

- Increase the length of the pencil chamber
- Use a small ion chamber that can act as a 'virtual pencil chamber' of any length

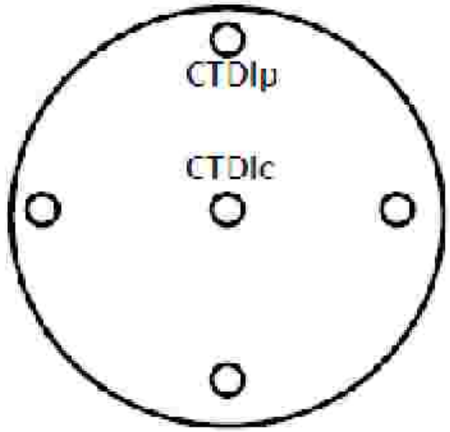
The small ion chamber method

- Ion chamber is fixed at z=0
- Phantom and chamber are translated through the beam plane
- If accumulated dose is multiplied by the acquisition pitch we get $CTDI_L$
- Accumulated dose at z=0 is measured directly
- Advantage: the scan length is always identical to the integration length L of the single rotation dose profile



Another form of dose measurement

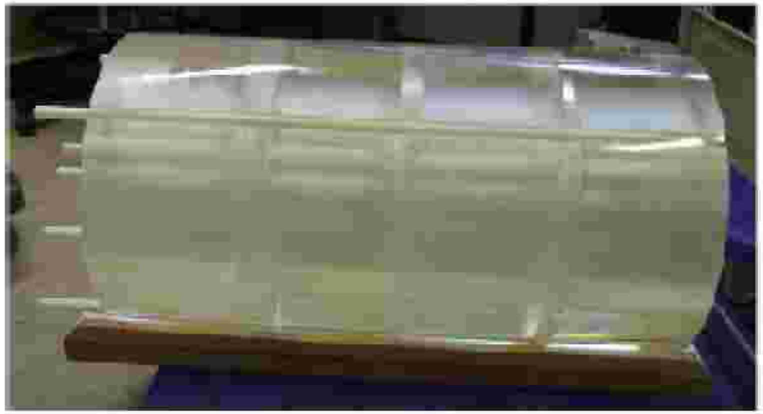
$$CTDI_w = \frac{1}{3}\mathrm{CTDI}_c + \frac{2}{3}\mathrm{CTDI}_p$$



- Accounts for the fact that CTDI varies with depth
- Provides a weighted average of the center and peripheral contributions to dose
- The weighting factors are derived by assuming that dose in a plane depends linearly on *r*

Equipment

- General Electric (GE) Lightspeed-16 slice scanner
- 140 mm and 600 mm PMMA body phantoms
- 100 mm pencil chamber and small ion chamber (23 mm)



The Dosimetry system

Cross comparison

Scan parameters:

- Chambers were positioned at the isocentre
- 120 kV, 200 mAs, helical scan, slice thickness of 10 mm, scan length beyond chamber length

For free-in-air measurements the chambers agreed to within 1%

Small ion chamber and long phantom

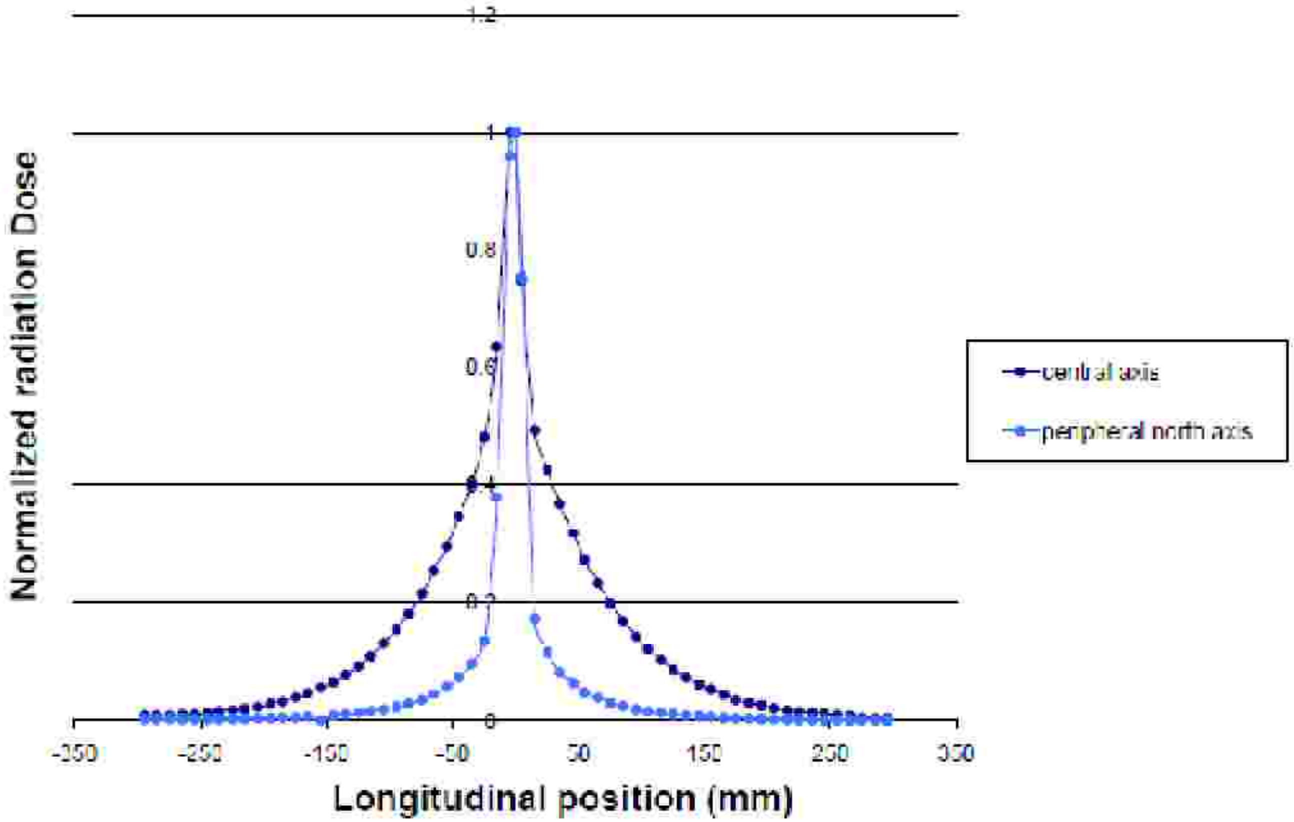
Chamber method comparison

- Methods were compared in a 600 mm phantom for L =100 mm, beamwidths of 5, 10 and 20 mm, on both central and peripheral axes
- Methods agreed to within 1.2% across beamwidths
- Agreed with *Dixon* [2007] who found a 1% difference
- Crucial was scanning off the section joints

The need for a longer phantom

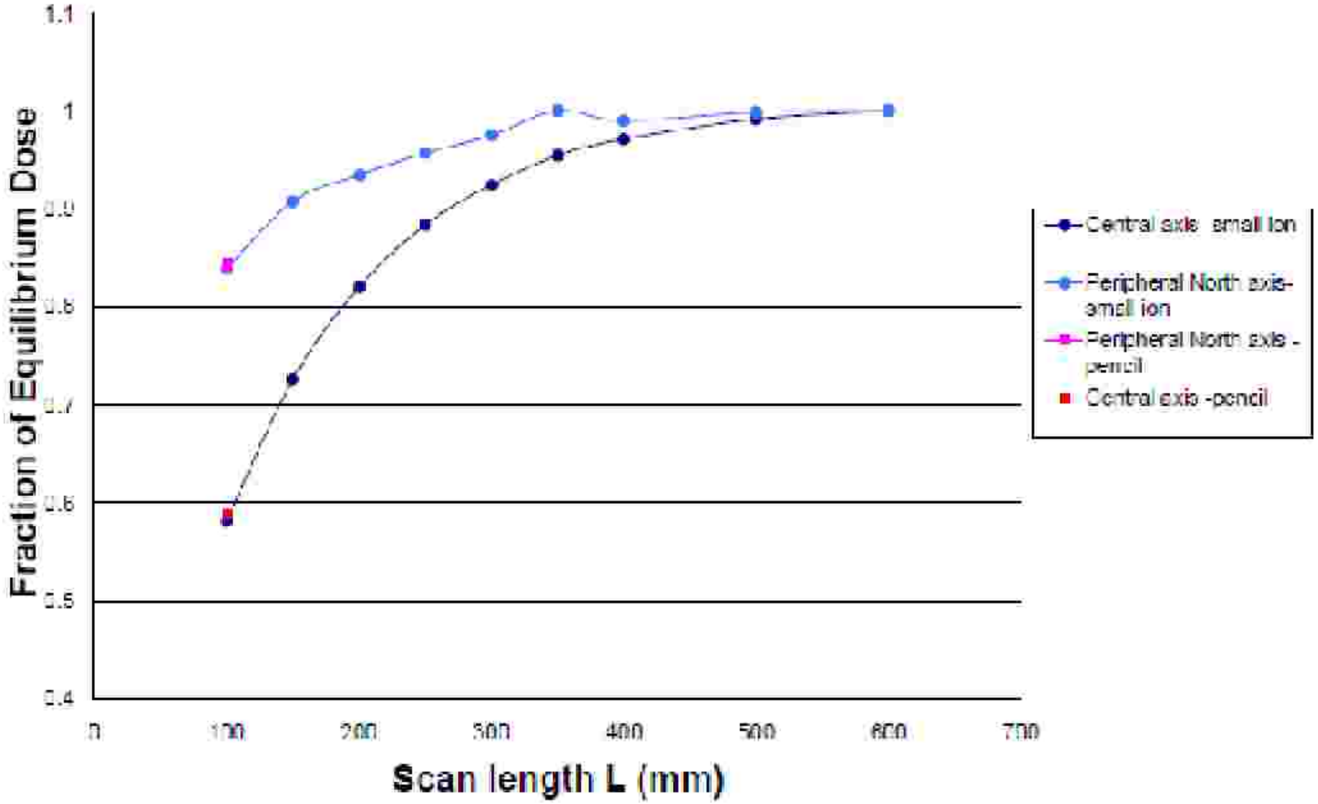
- Standard dosimetry phantoms: 14 or 15 cm long
- $CTDI_{100}$ was measured using the small chamber in both the standard & 600 mm phantoms
- Doses increased by 6% and 4.8% on the central and peripheral axes, respectively

Single scan dose profiles



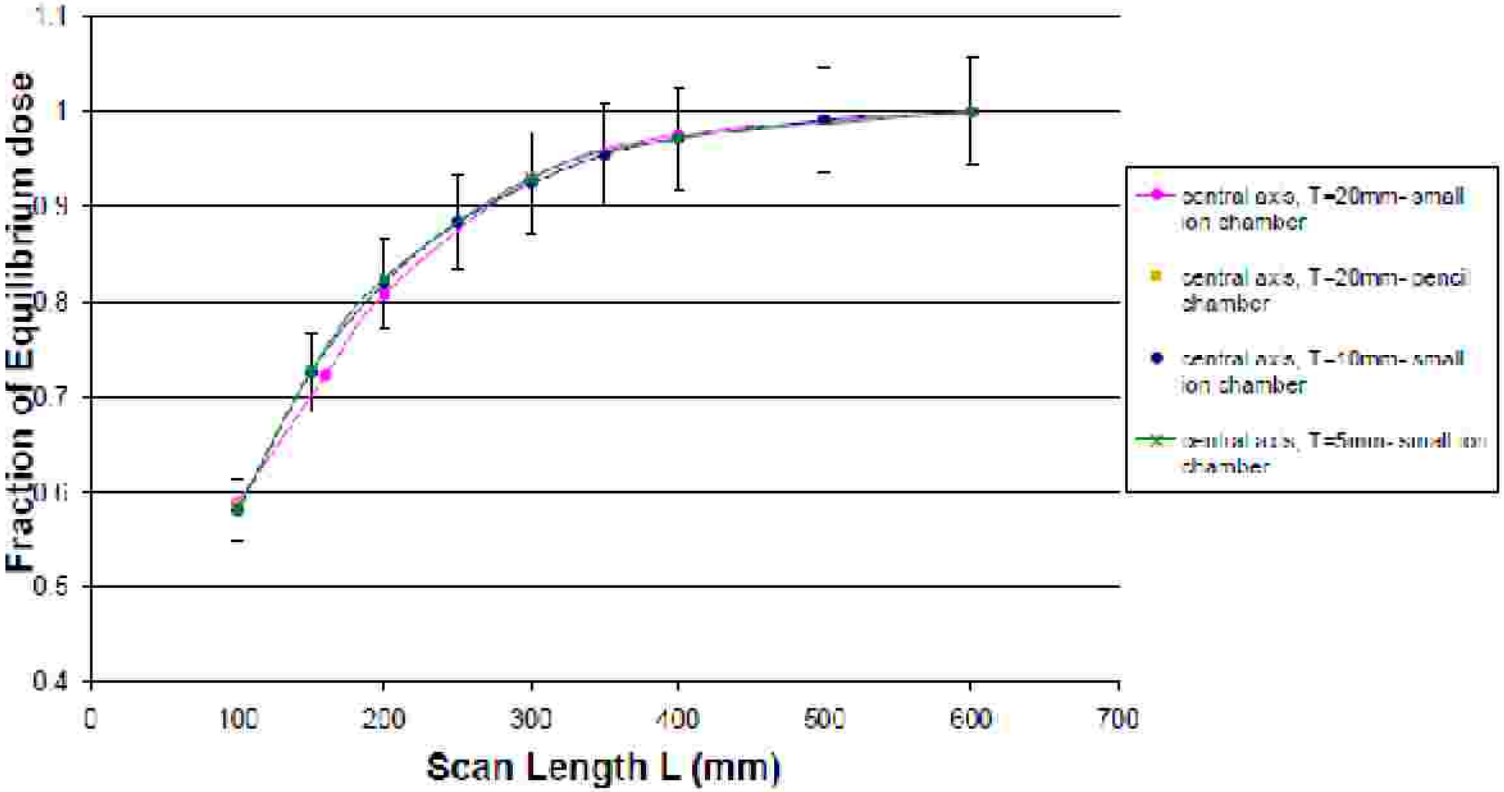
- The pencil chamber is too short:
  - non-negligible tails beyond $z = \pm 50$ mm
- Chamber reading is an average of the dose over its volume

Fraction of Equilibrium with scan length- For T=10 mm



- For $L \geq 250$ mm, the accumulated dose is $\geq 88\%$ and $\geq 96\%$ on the central and peripheral axes, respectively
- Pencil and ion chambers agree to within 0.8%

Fraction of Equilibrium with scan length- For different beamwidths, T



- Approach to equilibrium is approximately independent of T
- $CTDI_{100}$ is only a fraction of $CTDI_{\infty}$ for all T

Total shortfall of $CTDI_{100}$

$CTDI_{100}$ is not typically measured in a realistic phantom!

For beamwidth=10mm, 120 kV, 200 mAs we have on the central axis:

$$\begin{aligned} {}_{140}CTDI_{100} &= 12.01\ m\mathrm{Gy} \\ {}_{600}CTDI_{100} &= 13.24\ m\mathrm{Gy} \\ {}_{600}CTDI_{\infty} &= 22.6\ m\mathrm{Gy} \end{aligned}$$

So we have:

- A 10% increase in dose when moving to a larger phantom
- ${}_{600}\mathrm{CTDI}_{\infty} = 1.88 \times {}_{140}\mathrm{CTDI}_{100}$

Similarly, on the periphery:

- ${}_{600}\mathrm{CTDI}_{\infty} = 1.18 \times {}_{140}\mathrm{CTDI}_{100}$

Summary of Total $CTDI_{100}$ shortfall

For a GE 16 slice scanner operating at 120 kV, 200 mAs:

- $CTDI_{100}$ underestimates $CTDI_{\infty}$ by 47% on the central axis
- $CTDI_{100}$ underestimates $CTDI_{\infty}$ by 15% on the peripheral axis

Further work

- Ideal material for a phantom
  - Water-based phantom
  - Antropomorphic phantom
  - Monte carlo modelling
- Realistic diameter for a phantom
  - Patient studies for the actual standard sized patient
- Use a point source dosimeter
- Compare the results across scanners

Summary

- Small ion chamber method is valid for CT dosimetry
- A longer phantom is needed in order to achieve scatter equilibrium
- $CTDI_{100}$ underestimates dose for any scan length >100 mm
- Any overestimate of dose by $CTDI_{\infty}$ is less than its underestimate by $CTDI_{100}$ for $L \geq 250$ mm
- Central axis dose gains in relative importance as L increases

Further work

AAPM report 111

Recommends :

- At type testing scanners are assessed for D_{eq} using large phantom of unknown size shape and material – but not for QA.
- Energy imparted E_{tot} is used instead of DLP
- The planar average equilibrium dose D_{eq} replaces $CTDI_{vol}$
- Dose radially modelled on quadratic function or measured rather than Linear. 1/3 and 2/3 becomes ½ and ½.
- Small ion chamber used

Further work

Top tips for avoiding “errors”

Our mistakes :

- $CTDI_{100}$ is not equal to scanning 100mm chamber with 100mm scan length.
- Don’t put your chamber in the gaps of the phantom – air is not good absorber of X-rays
- Small chambers need high signal - 0.6cc volume.
- May need to shield electrometer from scatter or use long cable (RF induction)
- Don’t need longer than 60cm phantom – we measured it just because people would probably ask.

References

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