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

Matthew Dunn¹
&
Emma Inness¹

¹Nottingham University Hospitals, England

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Outline

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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, e.g. helical scanning, cone beam CT
- Ability to scan increasingly larger patient lengths
- How big is the CTDI\textsubscript{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
- $\text{CTDI}_{\infty}$ is more representative of dose for large $L$
- The central axis dose gains in relative importance for increasing $L$
Multi-slice Average Dose (MSAD)

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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.

![Graph showing relative dose with MSAD label and z-axis with 1 cm mark.](image)
Dose that scanning of slice 1 gives to all slices = dose that slice 1 gets from scanning of all slices [Shope, 1981].
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].
CTDI\textsubscript{100} → average dose at the centre (z = 0) resulting from a series of contiguous scans over a 100 mm scan length

\[ CTDI_{100} = \frac{1}{nT} \int_{-50\text{mm}}^{+50\text{mm}} D(z) \, dz \]
The Problem and possible solutions

Problem:

- *The 100 mm chamber is too short!*
- CTDI<sub>100</sub> 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

\[ CTDI_w = \frac{1}{3} CTDI_c + \frac{2}{3} CTDI_p \]

- 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)
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
The pencil chamber is too short:
- non-negligible tails beyond z = ±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\%
Phantom measurements

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

- Approach to equilibrium is approximately independent of $T$
- $\text{CTDI}_{100}$ is only a fraction of $\text{CTDI}_{\infty}$ for all $T$
CTDI$_{100}$ is not typically measured in a realistic phantom!

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

\[
140 \text{CTDI}_{100} = 12.01 \text{ mGy} \\
600 \text{CTDI}_{100} = 13.24 \text{ mGy} \\
600 \text{CTDI}_\infty = 22.6 \text{ mGy}
\]

So we have:

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

Similarly, on the periphery:

- \(600 \text{CTDI}_\infty = 1.18 \times 140 \text{CTDI}_{100}\)
For a GE 16 slice scanner operating at 120 kV, 200 mAs:

- $\text{CTDI}_{100}$ underestimates $\text{CTDI}_\infty$ by 47% on the central axis.
- $\text{CTDI}_{100}$ underestimates $\text{CTDI}_\infty$ by 15% on the peripheral axis.
Further work

- Ideal material for a phantom
  - Water-based phantom
  - Anthropomorphic 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
- Small ion chamber method is valid for CT dosimetry
- A longer phantom is needed in order to achieve scatter equilibrium
- $\text{CTDI}_{100}$ underestimates dose for any scan length $>100$ mm
- Any overestimate of dose by $\text{CTDI}_\infty$ is less than its underestimate by $\text{CTDI}_{100}$ for $L \geq 250$ mm
- Central axis dose gains in relative importance as $L$ increases
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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
Top tips for avoiding “errors”

Our mistakes:

• \( \text{CTDI}_{100} \) 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

- Dixon, R. L., and J. M. Boone, Cone beam CT dosimetry: A unified and self-consistent approach including all scan modalities- With or without phantom motion, Medical Physics, 37(6), 2703-2718, 2010.
- Dixon, R. L., and A. C. Ballard, Experimental validation of a versatile system of CT dosimetry using a conventional ion chamber: Beyond CTDI100, Medical Physics, 34(8), 3399-3413, 2007.