What is the situation in Europe w.r.t. recording and reporting dose?

- CTDI concepts are well established and are not questioned.
- Dose reporting is generally based on CTDI_{100} [mGy] and DLP [mGy·cm].
- Assessment of patient dose primarily aims at effective dose.
- Discussions of dose issues are much less intense in Europe than in the US.

Essential position:
Scanner output (CTDI) and effective dose (E) are separate issues!

CTDI and Patient Dose: A European Perspective

- CTDI Status & Proposals
- Patient dose estimates Status & Proposals
- Summary & Conclusions

CTDI is a technical measure of a CT scanner’s radiation output, not a measure of patient dose.
Established CTDI concepts (since 2000)

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

\[
\text{CTDI}_{100} = \frac{1}{N \cdot T} \int_{-5mm}^{5mm} D(z) dz
\]

\[
\text{CTDI}_{100, p} = \frac{1}{N \cdot T} \int_{-5mm}^{5mm} D(z) dz
\]

\[
\text{CTDI}_{\text{vol}} = \left( \frac{1}{3} \cdot \text{CTDI}_{100, c} + 2/3 \cdot \text{CTDI}_{100, p} \right)^{1/3}
\]

- CTDI\text{vol}[mGy] is established for apparatus acceptance and constancy testing.
- CTDI\text{vol}[mGy] accounts for patient scan protocols, i.e., for mAs and spiral pitch.

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) with longer phantom setups.

CTDI for scanners with wide collimation

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

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

Conclusions on CTDI concepts

- The established concept amended by IEC for wide-collimation scanners appears acceptable.
- There is no need for new phantoms, but only for long ionization chambers (30 cm) in case of operation with wider collimation.
- Dedicated CBCT and FDCT scanners can be covered with similar concepts.
CTDI and Patient Dose: A European Perspective

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Literature on concepts for patient dose estimation
- AAPM Report 204 (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 official basis for fixing DRLs (Diagnostic Reference Levels) in Europe.

Dose-length product \( DLP = CTDI_{vol} \times R \) [mGy·cm]

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Head</th>
<th>Chest</th>
<th>Abdom.</th>
<th>Pelvis</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC [FC, 1999]</td>
<td>60</td>
<td>30</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>UK [DRL, 2007]</td>
<td>1050</td>
<td>65</td>
<td>780</td>
<td>570</td>
</tr>
<tr>
<td>Germany [HSG, 2010]</td>
<td>65</td>
<td>13</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>USA [ACR, 2008]</td>
<td>930</td>
<td>580</td>
<td>470</td>
<td>560</td>
</tr>
</tbody>
</table>

Continuous updating of DRLs

E.g., in Germany the old 2003 DLP values for adults (red) were replaced by new values in 2010 (blue).

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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 in the 1990s)

   The general approach:
   \[
   \text{Effective Dose } E = k \times \text{DLP}
   \]

   If dose distribution is known
   - Organ dose and eff. Dose E
   Scan parameters (CTDI, DLP) are known
   - \( k = E / \text{DLP} \)

   Monte Carlo (MC) calculations based on CTDI

   ORNL Phantom Series

   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 organs (ICRP 66)
   - ICRP has followed up with human voxel phantoms.


   Conversion factors \( k \) 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

   MC dose calculations based on phantoms


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   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), …

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 as a function of patient diameters,
  - do not provide organ or patient dose directly.

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 dose values should be estimated for the patient, scanner and scan protocol in question.
4. Results should be available fast and in a comprehensible format.

Fast MC solutions are available

\[
\text{Dose}_{\text{ROI}} = 3.9 \text{ mGy} \quad \text{Time}_{\text{cal}} = 10 \text{ min} \quad \text{Dose}_{\text{ROI}} = 3.8 \text{ mGy} \quad \text{Time}_{\text{cal}} = 10 \text{ s}
\]
Calculations are accelerated by using GPU clusters and by reducing resolution.

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 $E$

W. Kalender, N. Saltybaeva et al. EJMP 2014 (in print)
Validation by phantom measurements

$\Delta D$: average difference between MC calculations and TLD measurements for up to 94 TLD chips

- Patient-, scanner- and protocol-specific organ dose estimates can be provided with high accuracy, here better than 10%.
- Manufacturer cooperation is required w.r.t. relevant information, e.g. data on filtration and AEC curves incl. start position and angle.
- Use is limited to rare cases and research, e.g. optimization efforts.

Conclusions on patient- and organ-specific dose estimates

- Scanner dosimetry can be handled using the established CTDI concepts, amended by CTDI in air measurements in case of collimations $>40$ mm and provides CTDI and DLP as DRL values.
- Patient dose estimates are based on in-air measurements, not on CTDI phantoms. Patient- and organ-specific dose estimates (POSDE) can be provided with high accuracy using MC modeling.
- Manufacturer cooperation is mandatory!

Summary

- Patient-, scanner- and protocol-specific organ dose estimates can be provided with high accuracy, here better than 10%.
- Manufacturer cooperation is required w.r.t. relevant information, e.g. data on filtration and AEC curves incl. start position and angle.
- Use is limited to rare cases and research, e.g. optimization efforts.

Thank you for your attention!