Diagnostic Exposure Tracking in the Medical Record

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Relevant disclosures
None

Learning objectives
Understand various dose metrics produced by imaging modalities
Illustrate how effective dose can be estimated
Discuss limitations of effective dose calculations; wide range of dose indices from different systems, and limitations of total effective cumulative dose

Risks of ionizing radiation... In the media
- Everyone has access to dose information
  - Internet availability everywhere
  - Often the risks are embellished, while the benefits are ignored.....

29,000 deaths from CT scans performed in U.S. in 2007
1 in 270 risk of cancer death from a 40 YO women having cardiac CT

- And it’s more than CT...

What are the issues?
- Risks of ionizing radiation
  - Deterministic effects
    - Radiation “sunburn”
    - Epilation
    - More severe response
  - Stochastic effects
    - Induction of cancer
    - Genetic effects
**Imaging modalities with available dose metrics**

- CT
- Interventional Radiology and Cardiology
- Fluoroscopy
- Radiography and mammography

Not included (yet)
- Nuclear Medicine
- Radiotherapy

**Radiation Dose Structured Report (RDSR)**

DICOM object information:

- All modalities:
  - kV, mA, collimation, filters, etc.
  - Patient/Order/Study details
- CT
  - DLP, CTDI_vol, Effective Dose (optional)
- Projection X-Ray
  - DAP, Dose@RP, geometry, fluoro dose, fluoro time
- Mammography
  - AGD, Entrance Exposure@RP, Compression, HVL

**Dose Reporting in Diagnostic Radiology**

- Digital Radiography
  - Exposure Index… Manufacturer-specific
  - Does not indicate patient dose
  - More information needed (DAP, Reference point dose, kV – mAs – geometry)

- A new Exposure Index standard has been implemented for consistency across manufacturers

\[
DI = 10 \times \log_{10} \left( \frac{EI}{EI_f(b,v)} \right)
\]

IEC 62494-1: Exposure Index of Digital Radiography Systems

**Dose Reporting in Interventional Radiology**

- Reference Dose Air Kerma measurements
- Dose – Area – Product Measurements
- Reference Dose levels per procedure
- DICOM RDSR and individual sequence reporting
- **NEEDED:** Dose mapping tools to identify peak dose and potential “sentinel event reporting”
Dose Reporting in CT

• Scanner dose measurement indicators \textit{CTD}_{vol} \& DLP
• How to get the CT provided data?
  • Dose report and Optical Character Recognition
  • DICOM Structured Radiation Dose Report
  • Open-source and commercial “dose gathering” products

DICOM RDSR for CT

Dose QA Tracking (D-QAT)
**DOAT report page in RIS**

**Meeting the requirements of SB1237**

- **TODAY**
  - Right lower quadrant pain
- **FINDINGS**
  - Routine CT scan of abdomen and pelvis with 100 cc of iopamir 300 IV contrast

**CT dose information:** CTDIvol (mGy) 11; total DLP (mGy-cm) 475

**FINDINGS**

Liver, spleen, pancreas, gallbladder, adrenal, and kidneys all appear normal. All appear normal. Stained right parietal wall showing no...surrounding inflammation changes. Broad expanses...fibrotic...infection. No suspicious lymphadenopathy per site criteria. Small fre...No free air.

**Possible scenario**

**Dose by Date**

**Dose by Patient**

**Dose by procedure**

(from Clinical Microsystems)

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**Dose Reporting...... WHAT?**

- What to do with the dose data?
  - Participate in dose registry, compare with peers
  - Accumulate dose for inclusion in patient record

- But, there are lots of ways to go wrong......
  - Mismatch of body size to CT dose phantom size
  - Inappropriate accumulation of dose indices
  - Inaccurate conversion factors to “Effective Dose”

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**Current CT dose reporting methods**

- **Computed Tomography Dose Index, CTDIvol (mGy)**
  - Provides dose comparison for scan protocols or scanners
  - Useful for obtaining “benchmark” data
  - Not good for estimating patient dose

- **CTDIvol conversion factors** are needed because of differences in
  - Dose calibration phantom size
  - Patient size, composition, and shape
**Current CT dose reporting methods**

- **Dose Length Product (DLP):** $\text{CTDI}_{\text{vol}} \times \text{scan length}$
  - volume dose delivered to the patient (mGy-cm)
  - in limited scan range, DLP is less useful (e.g., density-time studies such as brain perfusion) and values can be low relative to amount of radiation delivered to patient

- **Effective Dose:** a crude measure of whole body dose
  - Estimated from DLP (mSv)
  - Conversion factors are generated from Monte Carlo transport methods in standardized phantoms
  - Not intended for individual patient dose metrics

**Patient-specific effective dose?**

- It is inaccurate and misleading to associate an estimate of ED with any specific patient
- ED is only defined in terms of generic adult male and female phantom models
- ED should not be placed in any patient’s image data or medical record

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**Table 1:** Standardized parameters per diagnostic imaging modality with patient size (millimetres) and phantom size (centimetres) considered. MRT and CT images were evaluated at 120 kVp. Conversion factors are provided as dose-area product (mGy-cm) to mSv. All other conversion factors were based on the AAPM Task Group 204 report.

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<thead>
<tr>
<th>Modality</th>
<th>Female</th>
<th>Male</th>
<th>Adult</th>
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<tbody>
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<td>Mammography</td>
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<td>Nuclear Medicine</td>
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**Measurement, Reporting, and Management of Radiation Dose in CT**

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<th>Measurement</th>
<th>Female</th>
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<th>Adult</th>
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<tbody>
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<td>Effective Dose</td>
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<td>Surface dose</td>
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<td>Patient dose</td>
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<td>Reference photon energy</td>
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<td>Reference energy</td>
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<td>Reference tissue density</td>
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**Relative dose**

- $\text{CTDI}_{\text{vol}}$
- Effective diameter

Compliments of John Boone

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**Family of physical phantoms**
- Cynthia McCollough, Mayo Clinic
- Tom Toth & Keith Strauss

**Standard phantoms**
- Mike McNitt-Gray, UCLA

**Monte Carlo phantoms (1 – 50 cm)**
- John M. Boone, UC Davis

**Anthropomorphic Monte Carlo phantoms**
- Mike McNitt-Gray, UCLA

Compliments of John Boone
Dose estimate conversion factors for body size

Determine effective diameter

Normalize scanner output to CTDI\textsubscript{vol}

Normalized output
Example Case of SSDE Calculations

- Pediatric patient scanned initially with a Siemens scanner in outpatient clinic
- CareDose 4D used
- $\text{CTD}_{\text{vol}} = 4.78 \text{ mGy}$
- Effective diameter $= 25 \text{ cm}$

32 cm PMMA Dose Reference Phantom

Example Case of SSDE Calculations

- Post-surgery, patient scanned in-patient GE scanner
- Smart mA used
- $\text{CTD}_{\text{vol}} = 17.7 \text{ mGy}$

16 cm PMMA Dose Reference Phantom

TG-204 Size conversion factors for CTD$\text{vol}$
Uncorrected data from scanners:

17.7 mGy / 4.78 mGy = \textit{3.7} \times \text{difference in CTD}_{\text{vol}}

TG-204 SSDE Corrections:

17.7 mGy (16 cm PMMA reference) \times \textbf{0.71} = 12.5 mGy

4.8 mGy (32 cm PMMA reference) \times \textbf{1.47} = 7.1 mGy

12.5 / 7.1 = \textit{1.7} \times \text{difference in CTD}_{\text{vol}}

Even with correction, why was there a difference between scanners?

\textbf{Size-specific CTD}_{\text{vol}}

\textit{Comparison after size-specific conversion:}

\begin{align*}
\text{CTD}_{\text{vol}}: & \quad 12.5 / 7.1 = \textbf{1.7X} \text{ higher dose} \\
\text{abdomen:} & \quad 7.9 / 7.1 = \textbf{1.1X} \text{ higher dose}
\end{align*}

\textit{with Nuss bar attenuators}

\textit{without attenuators}

\begin{itemize}
  \item Should dose modulation be used in situations with highly attenuating materials? Maybe yes, maybe no – depends on the needs of the radiologist and referring physician
\end{itemize}

\textbf{CT digital radiograph localizer}

\textbf{It’s actually more complicated …...}
With current state-of-the-art dose indicators

- Cannot add CTDI\textsubscript{vol} or DLP, unless same scan of body part is repeated
- CTDI\textsubscript{vol} and therefore DLP can be under or overestimated, depending on patient habitus
- Conversion to Effective Dose (in mSv) is currently the method to normalize “dose” but is also fraught with significant limitations
- Is risk cumulative? Should previous exams have an impact on choosing the best current exam?

Next Steps

- Active task groups in the AAPM are tackling issues related to CT dose measurements

So, what should be used for patient risk?

- Using Monte Carlo photon transport on organ-segmented CT scan data of patients
- Estimation of specific individual’s organ doses
- Accumulating organ dose for each instance
- Applying age- and sex-specific risk coefficients
- This is a large undertaking, and will take time for implementation

Monte Carlo modeling can be the basis for patient CT dosimetry

- Compliments of John Boone
Summary

• Need RIS and/or EMR support for IHE Radiation Exposure Monitoring, including DICOM RDSR
• But, can’t just present these numbers in the RIS or EMR without context of other variables—patient habitus, weight, height, BMI, etc.
• Conversion factors should be applied
• More investigation is needed to describe organ dose and associated risks

Summary

• It is tempting, but incorrect to use simplified approaches (e.g., effective dose) for determining patient dose and associated risk from CT and other studies using ionizing radiation
• Estimation of organ dose and use of age- and gender-specific risk coefficients are necessary to determine individual risk
• Investigations using Monte Carlo photon transport within CT scan data, identification / segmentation of organs, and tabulating organ doses are a start to individual, customized dose measurements

Summary

• So, what do we do in the meantime?
  • Insist on DICOM RDSR
  • Implement IHE REM
  • Continue to collect CTDivol and DLP values
    • In State of California, this information is required in radiologists report by July 2012
    • Continue to calculate effective dose so that “cumulative” dose can be determined
    • Be aware of more than just CT doses, in particular doses in Interventional Radiology and Cardiology

FINALLY…….

Un-informed and over-simplified uses of dose indicators might have unintended negative consequences for patient care

Let the physicist (and other users) beware ……