CT Dose Estimation

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CT Dose Estimation

Introduction

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Dose Length Product

Effective Dose

Dose Reporting

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Radiation Overdoses Point Up Dangers of CT Scans
Written by Humboldt Online Editor on 16 October 2009

New York Times
Raven Knickerbocker, then an X-ray technologist at Mad River Community Hospital in Arcata, Calif., activated a CT scan 151 times on the same area of the head of a 2-year-old Jacoby Roth, investigators concluded.

California hospital fined $25,000 for pediatric CT radiation overdose
By Cynthia E. Keen
AuntMinnie.com staff writer
March 24, 2009

Parents sue California hospital over pediatric CT radiation overdose
By Cynthia E. Keen
AuntMinnie.com staff writer
November 20, 2008

A rural California hospital is being sued by parents of a child who underwent a CT exam during an emergency department visit for a neck injury. The parents allege that their 23-month-old boy received radiation burns and has permanent chromosomal damage due to excessive radiation exposure from the CT scan, which took over an hour to perform.
Introduction
The radiation from CT has caught the eye of the public

FDA Public Health Notification: Reducing Radiation Risk from Computed Tomography for Pediatric and Small Adult Patients

FDA: Medical devices can shock in CT scans

CT scans in children linked to cancer

By Steve Sternberg, USA TODAY

Each year, about 1.6 million children in the USA get CT scans to their abdomen — and about 1,500 of those will die later in life of radiation cancer, according to research out today.

What’s more, CT or computed tomography scans given to kids are not calibrated for adults, so children absorb two to six times the radiation, produce clear images, a second study shows. These doses are higher than the sorts of doses that people at Three Mile Island were given, Brenner of Columbia University says. "Most people got a tenth of the dose of a CT."

Radiation-induced temporary hair loss as a radiation damage only occurring in patients who had the combination of MDCT and DSA


Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries

BEIR VII: Health Risks from Exposure to Low Levels of Ionizing Radiation

Amy Berrington de González, Sarah Darby

Hospital radiation overdoses probed

"It's pretty mystifying to me."

David Brenner, director of the Center for Radiological Research at Columbia University Medical Center, asks how the radiation doses could have gone unreported for 19 months.

The overdoses also could have been caught during periodic calibrations of the machines, when radiation levels are tested directly.

Najnudin Mesinkov, a professor of industrial and systems engineering at the University of Southern California, said the overdoses point to a problem with a backup system that caught mistakes.

As a result of the radiation overdoses, the FDA issued an alert that raised the possibility that CT scanners at other hospitals could be set wrong — with nobody noticing.
Dose reporting required as of July 1, 2012

California SB-1237, SB-58, AB-510

— 3 —

SB 1237

The people of the State of California do enact as follows:

SECTION 1. Section 115111 is added to the Health and Safety Code, to read:

115111. (a) Commencing July 1, 2012, subject to subdivision (e), a person that uses a computed tomography (CT) X-ray system for human use shall record the dose of radiation on every CT study produced during a CT examination.

(b) The facility conducting the study shall electronically send each CT study and protocol page that lists the technical factors and dose of radiation to the electronic picture archiving and communications system.

(c) The displayed dose shall be verified annually by a medical physicist to ensure the displayed doses are within 20 percent of the true measured dose measured in accordance with subdivision (f) unless the facility is accredited.

(d) Subject to subdivision (e), the radiology report of a CT study shall include the dose of radiation by either recording the dose within the patient’s radiology report or attaching the protocol page that includes the dose of radiation to the radiology report.

(e) The requirements of this section shall be limited to CT systems capable of calculating and displaying the dose.

(f) For the purposes of this section, dose of radiation shall be defined as one of the following:

(1) The computed tomography index volume (CTDI vol) and dose length product (DLP), as defined by the International Electrotechnical Commission (IEC) and recognized by the federal Food and Drug Administration (FDA).
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CTDI: 
Computed Tomography Dose Index

A method for describing the doses delivered by transmission x-ray computed tomography

Thomas B. Shope, Robert M. Gagne, and Gordon C. Johnson

Bureau of Radiological Health, Food and Drug Administration, 5600 Fishers Lane, Rockville, Maryland 20857

(Received 23 September 1980; accepted for publication 3 October 1980)

II. SUGGESTED DOSE DESCRIPTOR FOR COMPUTED TOMOGRAPHY

The dose descriptor we propose is the computed tomography dose index (CTDI) denoted as $C$ and defined by

$$C = \frac{1}{T} \int_{-\infty}^{\infty} D_1(z)dz,$$

where it all began...
$$CTDI_L = \frac{1}{nT} \int_{-L/2}^{+L/2} D(z) \, dz$$

$$CTDI_{100} = \frac{1}{nT} \int_{-50\text{mm}}^{+50\text{mm}} D(z) \, dz$$
CTDI: Measurement tools

100 mm long ion chamber

Phantoms
32 cm body PMMA phantom

100 mm pencil chamber

PMMA plug

16 cm head PMMA phantom

also, pediatric body phantom

peripheral hole

center hole
Measuring CTDI\textsubscript{100} in the real world
100 mm pencil chamber and thin CT x-ray beam

100 mm CT x-ray beam and small radiation meter
Weighted CTDI:

\[ CTDI_w = \frac{1}{3} \times CTDI_{100}^{\text{center}} + \frac{2}{3} \times CTDI_{100}^{\text{periphery}} \]
helical CT acquisition
Dose $\approx \frac{1}{\text{pitch}}$

low pitch

high pitch

Helical or Spiral CT Acquisition
Weighted CTDI:

\[ \text{CTDI}_w = \frac{1}{3} \times \text{CTDI}_{100}^{\text{center}} + \frac{2}{3} \times \text{CTDI}_{100}^{\text{periphery}} \]

Volume CTDI:

\[ \text{CTDI}_{\text{vol}} = \frac{\text{CTDI}_w}{\text{pitch}} \]
CTDI$_{vol}$ is a useful parameter because it is required to be displayable on all modern CT scanners due to IEC regulations. It is also stored in the header of the CT images.
CTDI is a good measure of CT x-ray tube radiation output, but is not a stand-alone metric for patient dose

The trouble with CTDI_{100}

John M. Boone
Departments of Radiology and Biomedical Engineering, University of California Davis Medical Center, Ellison Building, 4860 Y Street, Suite 1100, Sacramento, California 95817

(Received 1 September 2005; revised 26 October 2006; accepted for publication 6 November 2006; published 20 March 2007)

CT Dose Index and Patient Dose: They Are Not the Same Thing

Cynthia H. McCollough, PhD
Shuai Leng, PhD
Liifeng Yu, PhD
Dianna D. Cody, PhD
John M. Boone, PhD
Michael F. McNitt-Gray, PhD

etcetera....
CTDI is a good measure of dose to a 32 cm diameter, 1.19 g/cm³ piece of plastic. Most patients will be smaller, and have higher doses. Larger patients will have lower doses (at the same techniques).
Size Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, developed in collaboration with the International Commission on Radiological Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging.
5.40 mGy = CTDIvol (32 cm phantom)

circle of equal area (weighted)

water equivalent diameter
To perform patient size-specific dose estimation, the conversion factor above is multiplied by the value of CTDI_{vol}.

\[ \text{Dose}_{\text{patient}} \approx \text{CTDI}_{\text{vol}} \times f \]
5.40 mGy = CTDI$_{vol}$ (32 cm phantom)

$$SSDE = CTDI_{vol} \times f$$

$$13.0 \text{ mGy} = 5.40 \times 2.4$$
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Which scan has more “dose”?

...to first order, the dose is the same

\[ D = \frac{\Delta \varepsilon}{\Delta m} \]

\[ L \]
Dose Length Product (DLP):

\[ \text{DLP} = \text{CTDI}_{\text{vol}} \times L \quad (\text{mGy} \cdot \text{cm}) \]

DLP is related to the total energy deposited in the patient.
x-ray beam profile along z
\[ D_L(z) = \frac{1}{b} f(z) \otimes \Pi(z/L) = \frac{1}{b} \int_{-L/2}^{L/2} f(z - z') \, dz'. \]
Dose profiles as a function of Scan Length

\[ D_L(z) \]
Equilibrium Dose as a function of Scan Length

\[ D(L) \]

\[ D_{eq} \]
TG-111 Method
TG-111 Method
TG-111 Method
AAP Task Group 200 & ICRU Phantom
ICRU Method: Real Time X-ray Meter
beam profile \[ \times \text{RECT} \]
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Dose Length Product (DLP):

\[ \text{DLP} = \text{CTDI}_{\text{vol}} \times L \quad (\text{mGy} \cdot \text{cm}) \]

DLP is related to the total energy deposited in the patient.
Most modern dosimetry is Monte Carlo based.

person = mathematical model of person
CT geometry is modeled and organ doses are estimated.
### Organ Doses Computed

<table>
<thead>
<tr>
<th>Organ</th>
<th>absorbed dose</th>
<th>$w_t$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>○</td>
<td>0.08</td>
<td>Y</td>
</tr>
<tr>
<td>Bone marrow</td>
<td>○</td>
<td>0.12</td>
<td>Y</td>
</tr>
<tr>
<td>Colon</td>
<td>○</td>
<td>0.12</td>
<td>Y</td>
</tr>
<tr>
<td>Lung</td>
<td>○</td>
<td>0.12</td>
<td>Y</td>
</tr>
<tr>
<td>Stomach</td>
<td>○</td>
<td>0.12</td>
<td>Y</td>
</tr>
<tr>
<td>Bladder</td>
<td>○</td>
<td>0.04</td>
<td>Y</td>
</tr>
<tr>
<td>Breast</td>
<td>○</td>
<td>0.12</td>
<td>Y</td>
</tr>
<tr>
<td>Liver</td>
<td>○</td>
<td>0.04</td>
<td>Y</td>
</tr>
<tr>
<td>Esophagus</td>
<td>○</td>
<td>0.04</td>
<td>Y</td>
</tr>
<tr>
<td>Thyroid</td>
<td>○</td>
<td>0.04</td>
<td>Y</td>
</tr>
<tr>
<td>Skin</td>
<td>○</td>
<td>0.01</td>
<td>Y</td>
</tr>
<tr>
<td>Bone surface</td>
<td>○</td>
<td>0.01</td>
<td>Y</td>
</tr>
<tr>
<td>Brain</td>
<td>○</td>
<td>0.01</td>
<td>Y</td>
</tr>
<tr>
<td>Salivary Glands</td>
<td>○</td>
<td>0.01</td>
<td>Y</td>
</tr>
<tr>
<td>remainder</td>
<td>○</td>
<td>0.12</td>
<td>Y</td>
</tr>
</tbody>
</table>

Effective dose: YY mSv

Tissue weighting factors from ICRP 103
### Other Minor Details

<table>
<thead>
<tr>
<th>Kerma</th>
<th>Absorbed Dose</th>
<th>Equivalent Dose</th>
<th>Effective Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>$D$</td>
<td>$D \times w_t = H$</td>
<td>$H \times w_t = E$</td>
</tr>
<tr>
<td>mGy</td>
<td>mGy</td>
<td>mSv</td>
<td>mSv</td>
</tr>
</tbody>
</table>
### other minor details

**quantities**

<table>
<thead>
<tr>
<th>kerma</th>
<th>absorbed dose</th>
<th>equivalent dose</th>
<th>effective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>$D$</td>
<td>$D \times w_t = H$</td>
<td>$H \times w_t = E$</td>
</tr>
</tbody>
</table>

**units**

- mGy
- mGy
- mSv
- mSv
CTDI_{vol} is the air kerma measured inside the phantom.

<table>
<thead>
<tr>
<th>kerma</th>
<th>absorbed dose</th>
<th>equivalent dose</th>
<th>effective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>$D$</td>
<td>$D \times w_t = H$</td>
<td>$H \times w_t = E$</td>
</tr>
<tr>
<td>mGy</td>
<td>mGy</td>
<td>mSv</td>
<td>mSv</td>
</tr>
</tbody>
</table>
other minor details

Incident kerma leads to absorbed dose estimate through the Monte Carlo process.

\[ K \rightarrow D \rightarrow D \times w_t = H \rightarrow H \times w_t = E \]

<table>
<thead>
<tr>
<th>kerma</th>
<th>absorbed dose</th>
<th>equivalent dose</th>
<th>effective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>mGy</td>
<td>mGy</td>
<td>mSv</td>
<td>mSv</td>
</tr>
</tbody>
</table>
correction for different types of radiation such as $\alpha$, $\beta$, $\gamma$: $w_r$ for x-rays is 1.0

\[
K \quad D \quad D \times w_r = H \quad H \times w_t = E
\]

kerma absorbed dose equivalent dose effective dose

mGy mGy mSv mSv
other minor details

corrects for organ radiosensitivity using tissue weighting factors, $w_t$.

<table>
<thead>
<tr>
<th>kerma</th>
<th>absorbed dose</th>
<th>equivalent dose</th>
<th>effective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>$D$</td>
<td>$D \times w_t = H$</td>
<td>$H \times w_t = E$</td>
</tr>
<tr>
<td>mGy</td>
<td>mGy</td>
<td>mSv</td>
<td>mSv</td>
</tr>
</tbody>
</table>
The short-cut calculation of $E$ (abdomen)

Effective dose (mSv) and dose length product (mGy.cm) for abdomen CT and the clinical indication: rule out abscess.
The conversion factor is $\frac{1}{59.1} = 0.017$ mSv / (mGy.cm)
Included, data from 46 scanners, 21 single slice, 25 multislice
Effective dose calculated with the ImPACT CT Dosimetry calculator
Effective Dose per DLP (AAPM TG-96)

<table>
<thead>
<tr>
<th>Region of Body</th>
<th>k (mSv/[mGy-cm])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>0.0031</td>
</tr>
<tr>
<td>Head</td>
<td>0.0021</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0059</td>
</tr>
<tr>
<td>Chest</td>
<td>0.014</td>
</tr>
<tr>
<td>Abdomen / pelvis</td>
<td>0.015</td>
</tr>
<tr>
<td>trunk</td>
<td>0.015</td>
</tr>
</tbody>
</table>

\[ \text{DLP} \times k \approx E \]
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WORKFLOW in RADIOLOGY

All images are digital (on PACS)

Radiologists look at images on computers

As they look at the images, they dictate their “findings” using voice recognition software

In California, CTDIvol & DLP need to be included into the Radiologist’s Report
The Structured Dose Report with Radimetrics Feed:

<table>
<thead>
<tr>
<th>Report: Gaga, Lady – MRN: 1234567</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXAM DATE [5/24/2012 12:35 pm]</td>
</tr>
<tr>
<td>INDICATION:</td>
</tr>
<tr>
<td>[]</td>
</tr>
<tr>
<td>DOSE:</td>
</tr>
<tr>
<td>Dose information for this CT examination:</td>
</tr>
<tr>
<td>Series 1: (no contrast)</td>
</tr>
<tr>
<td>CTDIvol = 12.4 mGy</td>
</tr>
<tr>
<td>DLP = 496 mGy-cm</td>
</tr>
<tr>
<td>Diameter = 28.2 cm</td>
</tr>
<tr>
<td>SSDE = 16.1 mGy</td>
</tr>
<tr>
<td>Series 2: (with contrast)</td>
</tr>
<tr>
<td>CTDIvol = 13.2 mGy</td>
</tr>
<tr>
<td>DLP = 577 mGy-cm</td>
</tr>
<tr>
<td>Diameter = 28.2 cm</td>
</tr>
<tr>
<td>SSDE = 17.2</td>
</tr>
<tr>
<td>UC Davis Health System CT scanners (no contrast) low dose CT practice.</td>
</tr>
<tr>
<td>FINDINGS:</td>
</tr>
<tr>
<td>[]</td>
</tr>
<tr>
<td>IMPRESSION:</td>
</tr>
<tr>
<td>[]</td>
</tr>
</tbody>
</table>
UC DOSE: Dose Monitoring Software

Institutional CT dose assessment
CT Dose Estimation

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CTDI$_{vol}$: (mGy)

Is a measurement of “dose” to a large plastic phantom, and for normal size patients CTDI$_{vol}$ underestimates their dose. Should not be considered as the “patient dose”

Uses two reference phantoms, 16 cm and 32 cm, depending on scan protocol. The 16 cm reference phantom is used for all heads and for some pediatric bodies (depends on scanner)

DLP: (mGy cm)

Includes CTDI$_{vol}$ and scan length

Scales linearly with effective dose
Summary

**Size Specific Dose Estimate (SSDE)**

Is an automatic way in which to correct for patient body size, to produce a more accurate dose estimate.

**Effective Dose ($E$)**

Is not a physical dose metric, but rather embodies organ radio-sensitivities

Is controversial to use for specific patients
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