CT Dose Reporting Requirements of CA Senate Bill 1237

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*California Clinical and Academic Medical Physicists (C-CAMP)

* With the best of intentions in addressing this new regulation in a practical & expedient fashion!
CT Dose to Patients

• In U.S., CT comprises only 11% of all exams but generates 67% of total diagnostic dose

» Mettler 2000
Sources of I.R. Exposure (*then*)

- U.S. average: about 360 mrem (3.6 mSv) /year
- 15% or about 60 mrem (0.6 mSv) from medical
Population Radiation Exposure **(NOW)**

*NCRP - 2008*

6.2 mSv (620 mrem) ED per US citizen

50% background still around 300 …

… But now 48% or 300 mrem (3 mSv) from medical and half of that from CT alone!
Increased Utilization: 

*Technology, Speed, Reimbursement*

- Sub-second, helical rotation, multi-slice technology increases throughput
- Potentially improved diagnostic capabilities & higher billing rates
- Significant increase in pediatric applications brings additional concerns
  - ↑ radio-sensitivity
  - ↑ organ and effective doses, particularly when technical factors are not adjusted
## Typical effective dose and background equivalents for diagnostic exams

*Radiologyinfo.org*

<table>
<thead>
<tr>
<th>For this procedure:</th>
<th>Your approximate effective radiation dose is:</th>
<th>Comparable to natural background radiation for:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abdominal region:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computed Tomography (CT)-Abdomen and Pelvis</td>
<td>10 mSv</td>
<td>3 years</td>
</tr>
<tr>
<td>Computed Tomography (CT)-Body</td>
<td>2-10 mSv</td>
<td>8 months to 3 years</td>
</tr>
<tr>
<td>Intravenous Pyelogram (IVP)</td>
<td>3 mSv</td>
<td>1 year</td>
</tr>
<tr>
<td>Radiography (X-ray)-Lower GI Tract</td>
<td>8 mSv</td>
<td>3 years</td>
</tr>
<tr>
<td><strong>Bone:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiography (X-ray)-Spine</td>
<td>1.5 mSv</td>
<td>6 months</td>
</tr>
<tr>
<td>Radiography (X-ray)-Extremity</td>
<td>0.001 mSv</td>
<td>Less than 1 day</td>
</tr>
<tr>
<td><strong>Central Nervous system:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computed Tomography (CT)-Head</td>
<td>2 mSv</td>
<td>8 months</td>
</tr>
<tr>
<td><strong>Chest:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computed Tomography (CT)-Chest</td>
<td>7 mSv</td>
<td>2 years</td>
</tr>
<tr>
<td>Computed Tomography (CT)-Chest Low Dose</td>
<td>1.5 mSv</td>
<td>6 months</td>
</tr>
<tr>
<td>Radiography-Chest</td>
<td>0.1 mSv</td>
<td>10 days</td>
</tr>
<tr>
<td><strong>Women's Imaging:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone Densitometry (DEXA)</td>
<td>0.001 mSv</td>
<td>Less than 1 day</td>
</tr>
<tr>
<td>Mammography</td>
<td>0.7 mSv</td>
<td>3 months</td>
</tr>
<tr>
<td>Added perspective ...</td>
<td>Approximate effective dose (mSv)</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td>Round-trip flight, New York – London</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Single screening mammogram (breast dose)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Background dose due to natural radiation exposure</td>
<td>3 / yr</td>
<td></td>
</tr>
<tr>
<td>Dose (over a 70 year period) to 0.5 million individuals in rural Ukraine in the vicinity of the Chernobyl accident</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Dose range over 20 block radius from hypothetical nuclear terrorism incident [medical gauge containing cesium]</td>
<td>3-30</td>
<td></td>
</tr>
<tr>
<td>Pelvis, Chest/Abdomen/Pelvis CT Scan</td>
<td>10, 15</td>
<td></td>
</tr>
<tr>
<td>Neonate CT scans</td>
<td>25-65</td>
<td></td>
</tr>
<tr>
<td>Radiation worker exposure limit</td>
<td>50 / yr</td>
<td></td>
</tr>
<tr>
<td>Exposure on international space station</td>
<td>170 / yr</td>
<td></td>
</tr>
</tbody>
</table>
Federal Stance  (2005)

- X-rays officially inducted to FDA list of carcinogens
- Sanction of the no-threshold model
- No safe dose of radiation
- Any increase in dose increases risk
Background: CT/Radiation News

- Literature & media: “high CT utilization increases cancer risk...”
  - Dose from CT same as AB survivor 1-2 miles from ground zero
  - In 2007 70 million CT scans $\rightarrow$ 29,000 cancers (Berrington, Arch Int Med 2009)
  - 600,000 annual CT scans on children under 15 $\rightarrow$ 500 cancer deaths (Brenner AJR)
    - Children more sensitive $\rightarrow$ Image Gently program

- NY times 2010: Articles on radiation injuries from medical procedures prompts response from professional organizations
Physician Knowledge

(Radiology - May ‘04)

• Patients not given info about dose, risk, and benefit from CT
• Only 47% of radiologists believe increased cancer risk from CT
• 9% of ED physicians & 3% patients believe increased risk
• Majority of radiologists/EDs unable to make a reasonable estimate of dose
Current Events

• CT “overdose” incidents & reaction (2009-2010)
  – Cedars: >200 patients overdosed over 18 months up to 10x “normal” dose → hair loss, skin burns, cataractogenesis?
  – Subsequent incidents/discoveries: Glendale Adventist, St. Josephs, Alabama

• Class action lawsuits against multiple hospitals and vendors

• Media attention & requests for CT experts/opinions

• UCLA as community resource ...
  – UCLA Consulted by CA DPH prior to original FDA notification
  – Multiple requests for training from govt. entities
  – UCLA Practice/Protocols/Dose as community standard?
  – Inquiries from lawyers representing plaintiffs, defense, and government.
  – Consult calls from patients specifically radiated in these incidents
Reaction

• UCLA Reaction (day original story broke …)
  – Inquiries from Vice Chancellor’s office
  – Emergency meeting called by hospital administration
  – Requests through media relations office
    … asking about doses, procedures, calibrations…

• Patient\referring physician reaction
  – Numerous prospective & retrospective dose requests
  – Inquiries about exam necessity, staff qualifications & training, equipment makes & models, calibrations, etc.
Professional Response

• ACR, ASNR, AAPM:
  • Over reliance on automation
  • Review/ consider dose reference levels
  • Importance of accreditation
  • Protocol review by lead radiologist, technologist, physicist
  • Enable dose reporting functions
  • CT specific training for all parties involved
  • Topic specific symposia already scheduled
  • Position statements in response to media stories on increase in medical radiation utilization, cancer risk, overdoses and accidents
Government Response

• Recommendations to Health Care Providers:
  – Investigate for potential injuries
  – Review protocols & implement QC procedures
  – Adjust for appropriate dose & be familiar with dose indices

• Recommendations to Public:
  – Consult with their physician
  – Track their individual dose (now an i-phone app.)
FDA initiative

(https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm200085.htm)

Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging

February 2010

Center for Devices and Radiological Health
U.S. Food and Drug Administration
Specific Government Response

• FDA Initiative to: “reduce unnecessary radiation from CT, fluoro, & nuc-med exams” 2/8/10
  – Safety including safeguards in scanner design, technology, and training
  – Processes for informed clinical decision making & appropriate use criteria
  – Increase patient awareness.
  – Display, record, & report equip. settings & rad. dose
  – Capture & transmit rad. dose to electronic med. record & dose registries

• NIH → now requires dose reporting mechanism for it’s imaging equipment

• Congressional investigation has been launched
  – Testimony from representatives of the AAPM and ACR
Specific Government Response

• Regulation – Senate Bill 1237 (California)
  – passed 8/30/2010, first in the country
  – Dose & incident requirements for CT
  – **2011**: Repeats, or scan of unintended body part, that exceed
    specified dose limits (unless ordered by a physician) must be
    reported to CA DPH - Radiologic Health Branch
  – **2012**: Record radiation dose on every CT study produced
    during a CT examination. Data must be sent to PACS & be
    included in Radiologist’s Report. Displayed dose must be
    verified by a Medical Physicist
  – **2013**: ALL CT facilities must be accredited
Who’s responsible?

• FDA – regulates equipment design

• State (CA.) regulates use of equipment and the users.
  – Supervisor & Operator Permit (Typically Radiologist or specifically permitted physician)
  – Radiologic Technologist (Can only operate under supervision of above)

• Technologist watching dose numbers?

• Physician in charge supervising?

• Vendor responsibilities?
Radiology Dept. Responses

• **We need a common and consistent message.**

• Vetting CT protocols (*concurrent*)
  – Accurate
  – Consistent
  – Appropriate
  – Determine doses

• Process for responding to questions & reporting dose
Dept. response-to-questions process

to assure consistency ...

- CT Manager acts as first level triage
- All faculty & staff receiving questions about dose from patients:
  - Happy to assist you
  - Want to be sure you get an accurate and consistent answer
  - Take down name, MRN, and return phone number
  - Your call will be returned within two working days
- As appropriate, CT Manager may refer patients to pamphlet and/or web-site with generic script on CT, radiation risk, and “typical” doses
- OR forward to Medical Physics for dose calculation and/or patient consult.
- Specific dose inquiries must be requested in writing and authenticated.
- Prospective vs. retrospective dose inquiries
• “Your physician has determined that a Computed Tomography (CT) scan is necessary in the course of your health care. CT scans are an essential tool in the practice of medicine for diagnosis of disease as well as for the assessment of response to treatment. The detailed assessment of anatomy and function that CT imaging provides requires the use of X-rays. X-rays are a form electromagnetic radiation similar to visible light but much higher in energy. We are constantly exposed to natural radiation in the course of our daily lives including terrestrial (e.g. radon), cosmic, and radiation from within our own bodies. The additional radiation from a CT exam varies considerably depending on the type of exam performed. but is typically on the order of what a U.S. citizen receives from natural sources in 1-5 years. The additional risk to an individual from medical X-ray is not well known but believed to be very small. However, as the risk is assumed to not be zero and is believed to increase with radiation dose it is important that optimal quality images are obtained at the lowest X-ray dose possible. At UCLA, we are constantly evaluating our CT imaging protocols with teams of academic and clinical experts - including specialty radiologists, licensed technologists, and board certified medical physicists - to ensure that the lowest possible radiation dose is used to achieve the diagnostic image quality required for the study.”
So what are we specifically concerned with when we use ionizing radiation in healthcare?

- Cancer?
- Genetic damage/Birth defects?
- Acute injury like skin burns or hair loss? For *diagnostic* exams??
How did this become an issue?

- Regardless of what stochastic risks may exist (cancer risks) it was the deterministic effects that got everyone’s attention ...
CT perfusion scans in California
(Cedars-Sinai, Glendale Adventist, Providence St. Joseph)
Within weeks of Alabama teacher Becky Coudert's CT perfusion brain scan, a bald strip circled her head. She reportedly had received several times the correct dose of radiation. (December 7, 2009)

Courtesy of Seibert
Classification of Effects

• **Stochastic**
  – Probabilistic
  – Chances increase with dose
  – Behavior of most rad. induced cancers, genetic effects
  – Independent of severity of effect
    • *A cancer deriving from 100 rads is no more virulent than one deriving from a 1 rad exposure.*
  – Thought to have **No threshold**
  – Implies any small amount of radiation has some associated risk
  – Basis of ALARA and radiation protection programs
Classification of Effects

• Deterministic
  – Associated with “high” doses involved with cell killing
  – Need to exceed threshold to see effect
  – Severity of effect increases (often rapidly) with dose
    • Cataracts
    • Embryological effects
    • *Skin Burns*
    • Reproduction
Skin effects are deterministic

- Radiation dose must exceed threshold to occur.
- Past threshold, severity increases with dose.
- Some minimum number of cells damaged to manifest response. If enough dose will have 100% occurrence.
- Dependent on dose & dose rate, some effects occur immediately (weeks) while others may manifest over years.
- Skin is the limiting organ for X-ray procedures as it receives highest dose.
- Radiodermatitis: inflammatory changes occurring after irradiation.
Acute Radiation Health Effects--Skin Effects

• 2 Gy -- Transient redness, bad erythema at 6 Gy (hrs)
  – vasodilation, perhaps vasculature damage
• 3 Gy -- Some hair loss, permanent at 6-7 Gy (3 wks)
• 8-10 Gy -- Dry desquamation (heavy peeling) (3 wks)
  – damage to germinal layer
• 15 Gy -- Wet desquamation with fluid exudate (4 wk)
  – heavily damaged germinal layer, some stroma degeneration
• 18 Gy -- Necrosis and Ulceration (6 weeks and on)
How do we estimate dose?

• Exposure (to air)
  – (Roentgen or coulomb/kg)
• Dose to a substance (e.g. water or tissue)
  – rad (100 erg/gm) or Gy (Joule/kg)
  – 100 rad per 1 Gy
  – Volume independent
• Effective dose or E.D. (100 rem or 1 Seivert)
  – Attempts to consider type of radiation and actual organs at risk exposed in a partial body exposure (as we typically experience in diagnostic X-ray)
Radiation Exposure

• The amount of ionization created in the air by the x-ray photons

• Not reported on the patient protocol (dose report)

• Measured using radiation detectors
  – Ionization chambers, TLDs, OSLs, etc.
Absorbed Dose (rad or Gray)

- Describes the amount of radiation energy deposited in the patient’s body per unit mass as a result of exposure (1 Joules/kg = 1Gy).
- 1 Gy = 100 rad = 100 erg/gm
- Not reported on the patient protocol (dose report)
- Calculated from radiation exposure
- Volume independent!
- *Dose to patient with 20 slices?*
Effective Dose (E.D. in rem or Sv)

• Attempts to determine stochastic risk from non-uniform exposures delivered to different parts of the body with risk from whole body exposure.

• Considers organs exposed: weighted average of the dose to different body tissues ($H_i$), with the weighting factors ($W_i$) for different radiosensitivities of the tissues: $E = \sum_i H_i W_i$

• (breast has higher risk & weight than brain)
Effective Dose organ weighting coefficients

<table>
<thead>
<tr>
<th>Tissue</th>
<th>ICRP 60 Tissue weights ($w_T$)</th>
<th>ICRP 103 weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.20</td>
<td>0.08</td>
</tr>
<tr>
<td>Red Bone Marrow</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Colon</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Breast</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>Liver</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Skin</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Bone Surface</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>
How do we determine CT Dose?

• Unique geometry of multiple, relatively thin, axial exposures, where the source of exposure completely encircles the body.

Dose distribution within scanned tissue much more uniform than with conventional projectional imaging
• \( D(z) = \) dose profile along z-axis (along the table) from:

Single acquisition

Multiple slice acquisition
Multiple Slices

Total dose at any point is *higher* than from a single slice due to scatter from adjacent slices.
CTDI (CT Dose Index)

• Fundamental radiation dose parameter in CT
• Represents the average absorbed dose to a specific homogenous, cylindrical plastic phantom, along the longitudinal axis, from a series of contiguous exposures
• Measured in milligray (mGy) or rad

CTDI ≠ patient dose
(CTDI) – defined

- How to get area under single scan dose profile?
  - Using a 100 mm “pencil” chamber
  - one measurement of an axial scan
  - Includes the primary and scatter
CTDI

- CTDI_{100} Measurements are done in both head & body phantoms:
- CTDI_w is a **weighted average** of center and peripheral CTDI_{100} to arrive at a single descriptor
  - \[ CTDI_w = \frac{1}{3}CTDI_{100,\text{center}} + \frac{2}{3}CTDI_{100,\text{peripheral}} \]
- Same scan **technique** will lead to very **different** doses in the two different size phantoms!

![Diagram showing different CTDI values for head and body phantoms](image)
Volume CTDI (CTDI\textsubscript{vol})

- Calculated from CTDI\textsubscript{w}
- Represents the average dose in the central region of a multiple scan exam
- Takes into account scan pitch

\[
\text{CTDI}_{\text{vol}} = \frac{\text{CTDI}_w}{\text{Pitch}}
\]

PITCH = table index per rotation (I) / total nominal scan width (NT)
CTDI\textsubscript{vol}

- Represents dose from a **specific CT imaging protocol** to the homogenous CTDI phantom
  - 32 cm diameter phantom is used for Adult Abdomen protocols
  - 16 cm diameter phantom is used for pediatric and head protocols

- **CTDI\textsubscript{vol}** is affected by:
  - kVp, mAs (tube current –time product), pitch, beam collimation
  - Other factors (e.g. scanner make and model, bowtie filter, etc.)

- **For Helical Scans, Siemens uses the term “effective mAs”**
  \[
  \text{Effective mAs} = \frac{\text{Tube current} \times \text{Rotation time}}{\text{Beam pitch}}
  \]

- **CTDI\textsubscript{vol}** is calculated using the average effective mAs reported in the patient protocol.
CTDInv = 20 mGy

How do we represent the greater biologic risk?
Dose Length Product (DLP)

• Represents integrated dose in terms of total scan length (# slices • slice width)

• $\text{CTDI}_{\text{vol}} \text{ (mGy)} \cdot \text{scan length (cm)} = \text{DLP (mGy-cm)}$
DLP = 200 mGy•cm

CTDl\text{vol} = 20 mGy
ten 1-cm slices

DLP = 400 mGy•cm

CTDl\text{vol} \textit{is STILL} = 20 mGy
twenty 1-cm slices
Patients vs. phantoms

- Patients are not standard, cylindrical, or homogeneous plastic
- CTDI tends to:
  - overestimate dose for large patients and
  - underestimate dose for small/pediatric patients
Patient Size Effects

• A larger patient has more mass than a smaller or pediatric patient
• As dose is energy deposited PER unit mass \((\text{erg/gm or joules/kg})\) then a given CT technique used on a larger patient will result in LESS absorbed dose because there’s more mass
• Conversely, an adult technique used on a child or small person will result in INCREASED absorbed dose
• So even to keep the SAME dose in a child as for an adult the technologist would need to reduce the tube current and would need to reduce current even further to reduce pediatric dose to below adult levels \(\rightarrow \text{IMAGE GENTLY}\)
Tube Current Modulation

• An “automatic” exposure mechanism that adjusts tube output (mA) to compensate for differences in patient size/attenuation
• Can compensate for overall patient size
• Can compensate for changes in patient attenuation from PA to lateral projection
• Can compensate for changes in patient attenuation along the axis of the patient
XY Modulation (in axial plane)

Attenuating Object

$I_0_A$  

$I_B$  

$I_A$  

$I_0_B$

A: AP/PA projection  
B: Lateral projection
Z-axis Modulation

Approximations to Detailed TCM Function

- detailed TCM function from raw data
- discrete TCM function from image data
- single tube current value (average mA across the scan)
CARE Dose 4D (Siemens)

- Shoulder Region
- Breast Tissue
- Lung Region
- Abdomen

Graph showing tube current (mA) vs. table position (mm) with regions marked at 180 degrees (LAT) and 90 degrees (AP).
Quality Reference mAs for CareDose4D

• A parameter defined by Siemens to represent the image quality that would have been achieved if a fixed tube current exam had been performed at that specific mAs level on an average sized patient.

• It is set by the user to select the desired image quality for a tube current modulated exam.
  – CareDose4D is Siemens’ version of tube current modulation
Average Effective mAs

• It is the total average effective mAs over the scan for a given TCM exam.

\[
\text{Effective mAs} = \frac{\text{Tube current } \times \text{ Rotation time}}{\text{Beam pitch}}
\]

• This is what is reported in the Dose Report
  – under “mAs”
• Typically lower than Quality Ref mAs for smaller Pts
• Typically higher than Quality Ref mAs for larger Pts
• But not always....
### Patient Protocol (Dose Report)

<table>
<thead>
<tr>
<th>Patient Position F-SP</th>
<th>Scan</th>
<th>KV</th>
<th>mAs / ref</th>
<th>CTDI&lt;sub&gt;vol&lt;/sub&gt;</th>
<th>DLP</th>
<th>TI</th>
<th>cSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPTope</td>
<td>1</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td>5.3</td>
<td>1.0</td>
</tr>
<tr>
<td>PreMonitoring</td>
<td>2</td>
<td>100</td>
<td>20</td>
<td>2.40</td>
<td>2</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>I.V. Bolus</td>
<td>3</td>
<td>100</td>
<td>20</td>
<td>2.40</td>
<td>2</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Monitoring</td>
<td>4</td>
<td>100</td>
<td>99 / 65</td>
<td>4.48</td>
<td>107</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Arterial</td>
<td>5</td>
<td>100</td>
<td>140 / 55</td>
<td>6.30</td>
<td>155</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Chest</td>
<td>6</td>
<td>100</td>
<td>97 / 65</td>
<td>4.85</td>
<td>158</td>
<td>0.5</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Total mAs 5369**  
**Total DLP 424**

CTDI<sub>vol</sub> & DLP ≠ patient dose
Neither CTDI or DLP are patient dose

• CTDI & DLP do not consider patient size, age, gender, specific organs/region radiated
• A patient that has twice the DLP or CTDI of another does NOT necessarily receive more dose
• DLP *under*estimates dose considerably for exams where there is no table movement
• CTDI *over*estimates dose for stationary exams by a factor of approximately TWO
Estimating ED from DLP

- ED can be estimated from DLP multiplied by a coefficient specific for different body parts and sizes
- \( K \ (mSv \ mGy^{-1} cm^{-1}) \times \text{DLP} \ mGy\text{-cm} = \text{Effective Dose (mSv)} \)
- Rough approximation dependent on several assumptions

<table>
<thead>
<tr>
<th>Region of Body</th>
<th>0 year old</th>
<th>1 year old</th>
<th>5 year old</th>
<th>10 year old</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>0.013</td>
<td>0.0085</td>
<td>0.0057</td>
<td>0.0042</td>
<td>0.0031</td>
</tr>
<tr>
<td>Head</td>
<td>0.011</td>
<td>0.0067</td>
<td>0.0040</td>
<td>0.0032</td>
<td>0.0021</td>
</tr>
<tr>
<td>Neck</td>
<td>0.017</td>
<td>0.012</td>
<td>0.011</td>
<td>0.0079</td>
<td>0.0059</td>
</tr>
<tr>
<td>Chest</td>
<td>0.039</td>
<td>0.026</td>
<td>0.018</td>
<td>0.013</td>
<td>0.014</td>
</tr>
<tr>
<td>Abdomen &amp; pelvis</td>
<td>0.049</td>
<td>0.030</td>
<td>0.020</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>Trunk</td>
<td>0.044</td>
<td>0.028</td>
<td>0.019</td>
<td>0.014</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Or... dose calculators w/ specific knowledge of scanner & area scanned

Assumes a geometric hermaphrodite patient model of standard size.
## CTDI, DLP vs actual ED

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Study</th>
<th>kVp: Total mAs:</th>
<th>CTDIvol</th>
<th>DLP</th>
<th>Organ dose est.</th>
<th>ED est. (ICRP103)</th>
<th>ED est. (DLP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens Definition (S64)</td>
<td>Brain Perfusion Scan</td>
<td>80 kVp 5750 total mAs</td>
<td>212.4 mGy</td>
<td>612 mGy-cm (note 28.8 mm collimation)</td>
<td>Brain: 55 mGy Lenses: 58 mGy</td>
<td>2.1 mSv</td>
<td>1.28 mSv</td>
</tr>
<tr>
<td>Siemens Sensation 16</td>
<td>Brain Perfusion Scan</td>
<td>80 kVp 5750 total mAs</td>
<td>404.2 mGy</td>
<td>970</td>
<td>Brain: 85 mGy Lenses: 100 mGy</td>
<td>3.3 mSv</td>
<td>2.04</td>
</tr>
<tr>
<td>Siemens Definition</td>
<td>KUB</td>
<td></td>
<td>7.83 mGy</td>
<td>402 mGy</td>
<td>Colon: 11 mGy Bladder: 12 mGy</td>
<td>6.7 mSv</td>
<td>6.03</td>
</tr>
<tr>
<td>Siemens Sensation 16</td>
<td>Abdomen/Pelvis</td>
<td></td>
<td>16.36 mGy</td>
<td>793 mGy</td>
<td>Colon: 11 mGy Bladder: 13 mGy</td>
<td>6.3 mSv</td>
<td>11.9</td>
</tr>
</tbody>
</table>
Limitations

• Extrapolating calculated organ dose estimates for mathematical models of a standard man to actual patients is problematic.

• Actual patient size & morphology can have significant impact on dose (Huda, Cody) as can age, gender, and ethnicity.
Monte Carlo Simulation Application: Evolution of Phantom Dosimetry

Model and benchmark against “conventional” dosimetry phantoms

Calculate the irradiation patterns and whole-body dose effective in patient-specific voxelized phantoms with segmented organs
## Summary

<table>
<thead>
<tr>
<th>Term</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTDI&lt;sub&gt;100&lt;/sub&gt;</td>
<td>mGy (or cGy or Gy)</td>
<td>Dose in cylindrical phantom (CTDI phantom) over 100 mm pencil chamber (periphery or center)</td>
</tr>
<tr>
<td>CTDI&lt;sub&gt;w&lt;/sub&gt;</td>
<td>mGy (or cGy or Gy)</td>
<td>Weighted average of dose from periphery and center of CTDI phantom</td>
</tr>
<tr>
<td>CTDI&lt;sub&gt;vol&lt;/sub&gt;</td>
<td>mGy (or cGy or Gy)</td>
<td>CTDI&lt;sub&gt;w&lt;/sub&gt; / pitch</td>
</tr>
<tr>
<td>DLP</td>
<td>mGy – cm</td>
<td>Product of CTDI&lt;sub&gt;vol&lt;/sub&gt; and length of scan</td>
</tr>
<tr>
<td>Effective Dose*</td>
<td>mSv</td>
<td>Calculated value designed to assess whole body stochastic risk from partial body exposure</td>
</tr>
</tbody>
</table>

* NOT indicated at scanner. Estimate only. Difficult to calculate. Involves many assumptions.
CT doses for “typical” Exams for website and/or pamphlet

• ACR has reference doses (CTDI) for three exams for accreditation purposes that can be quoted and compared to
  – Adult head $\rightarrow$ 75 mGy
  – Adult abdomen $\rightarrow$ 25 mGy
  – Peds abdomen (age 5) $\rightarrow$ 20 mGy

• Need to define/standardize facility’s typical exam, both in protocol and designation, e.g.
  – Routine head, abdomen, chest

• Need to determine representative doses for standard protocols at each facility
Calif. Senate Bill 1237 – Section 3

- Requires a facility that uses CT to report to DHS any scan that is repeated, or a scan of the wrong body part, that results in:
  - An Effective Dose (E.D.) that exceeds 0.05 Sv (5 rem)
  - A dose in excess of 0.5 Sv (50 rem) to any organ or tissue
  - Shallow dose to the skin of 0.5 Sv (50 rem) to the skin

- UNLESS:
  - Repeat due to movement or interference of patient.
  - Ordered by a physician
S.B. 1237 Section 3 (continued)

– Requires a facility that uses CT to report to CA DHS
- RHB:
  • Unanticipated permanent damage to organ, hair-loss, or erythema.
  • Dose to fetus that is greater than 50 mSv (5 rem)
  • Therapeutic radiation delivered to the wrong person or that differs from prescribed dose by more than 20%
Practical Implementation

• While actual enforcement of these provision may be problematic, failure to comply is a **CRIME**.
• In most clinical situations it is unlikely that the notification dose limits would be exceeded.
• The following slides are designed to assist the institution by alerting the user to scenarios that might exceed action levels by converting the state’s threshold dose reporting levels into CT dose values that are actually reported by the CT scanner.
S.B. 1237 Section 3 (continued)

— Requires facilities that use CT to report to DPH:
  • Unanticipated permanent damage to organ, hair-loss, or erythema.
  • **Dose to fetus that is greater than 50 mSv (5 rem) for known pregnancies**
  • Therapeutic radiation delivered to the wrong person or that differs from prescribed dose by more than 20%.
Practical Implementation

• While actual enforcement of these provision may be problematic, failure to comply is a **CRIME**.

• **Except** for scans of *known pregnant* women (fetal dose threshold), it is unlikely that the notification dose limits would be exceeded in most clinical scenarios.

• The following slides are designed to **assist** the institution by **alerting** the user to scenarios that might exceed action levels by converting the state’s threshold dose reporting levels into CT dose values that are actually reported by the CT scanner.

• The following “trigger” values are **guidelines** only and should be considered as **investigatory thresholds** to engage a Qualified Medical Physicist to determine if reporting is required.

• The trigger values are based on **scanner displayed CTDI/DLP** values that should be verified by a Qualified Medical Physicist.
Patient Effective Dose Threshold: 50 mSv

- For most standard CT scans, an approximate patient effective dose can be estimated from the product of Dose Length Product (DLP) and a conversion factor (k-factors) specific for a given body part and patient age. Based on those k-values the following cumulative DLPs will yield effective doses **exceeding 50 mSv**:

- Table below is for scanners that use:
  - CTDIvol and DLP from **16 cm diameter phantom for all head and all peds (ped head and ped body) scans**
  - CTDIvol and DLP from **32 cm diameter phantom ONLY for adult body scans**

<table>
<thead>
<tr>
<th>DLP Reporting Thresholds for Incorrect/Repeated Exams</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLP in mGy*cm</td>
</tr>
<tr>
<td>0 year old</td>
</tr>
<tr>
<td>head and neck</td>
</tr>
<tr>
<td>head</td>
</tr>
<tr>
<td>neck</td>
</tr>
<tr>
<td>chest</td>
</tr>
<tr>
<td>abd/pelvis</td>
</tr>
<tr>
<td>trunk (C/A/P)</td>
</tr>
</tbody>
</table>
Patient Effective Dose Threshold: 50 mSv

- For most standard CT scans, an approximate patient effective dose can be estimated from the product of Dose Length Product (DLP) and a conversion factor (k-factors) specific for a given body part and patient age. Based on those k-values the following cumulative DLPs will yield effective doses exceeding 50 mSv:
- Table below is for scanners (e.g. Siemens) that use:
  - CTDIvol and DLP from **16 cm diameter phantom ONLY for head scans** (Peds and Adult head)
  - CTDIvol and DLP from **32 cm diameter phantom for BOTH pediatric AND adult body scans**

<table>
<thead>
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<th>DLP Reporting Thresholds for Incorrect/Repeated Exams</th>
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<td>DLP in mGy*cm</td>
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<tr>
<td>trunk (C/A/P)</td>
</tr>
</tbody>
</table>
Organ Dose Threshold: 500 mSv

- Computed Tomography Dose Index (CTDI) as reported by the CT scanner represent dose to a cylindrical plastic phantom of a specific diameter. Therefore CTDI tends to overestimate dose to large patients and underestimate dose to a small patient.
- Thus organ doses can only be approximated from CTDI values when combined with specific knowledge about patient size and morphology (as well as the amount of organ in question is included within the extents of the scan range).
- While all of the above are required to make accurate estimates of organ dose, the total CTDI$_{vol}$ as reported by the scanner for a given body region can be used to provide an estimate for organ dose for the body region containing the scanned organ.
Organ Dose Threshold: 500 mSv <500 mGy>

- While organ doses can only be approximated from CTDI values and specific knowledge about patient size and morphology - as well as extent to which the organ in question is included within the extents of the scan range - are all required to make accurate estimates of organ dose, the total CTDI$_{vol}$ as reported by the scanner for a given body region can be used as a proxy for organ dose for the body region containing the scanned organ.

- **Thus, if the cumulative CTDI$_{vol}$ for any given body part scanned exceeds 500 mSv there is a likelihood that an organ contained within that scan region may have also exceeded 500 mSv.**
Organ Dose Threshold: 500 mSv

- The following situations may result in an organ dose exceeding the reporting threshold of 500 mSv:
  - Scans with table movement (any axial or helical scan)
    - For Pediatric, if the cumulative CTDIvol for any given body part exceeds 200 mGy
    - For Adult, if the cumulative CTDIvol for any given body part exceeds 250 mGy
  - Scans with NO table movement (e.g., neuroperfusion scan)
    - For Pediatric if the cumulative CTDIvol for any given body part exceeds 650 mGy
    - For Adult, if the cumulative CTDIvol for any given body part exceeds 650 mGy
- Here “cumulative” CTDIvol means if the same anatomic region is scanned multiple times (e.g. pre- and post-contrast of the same region), then these CTDIvol should be added.
- NOTE: if different regions are scanned (e.g., pre-contrast abdomen, post-contrast thorax and pelvis), then the CTDIvol are not added.
Skin Dose Threshold: 500 mSv <500 mGy?>

- For dose to the skin, the immediate concern is potential for deterministic injury such as erythema (reddenning), or hair loss (epilation), or more serious skin burns.
- In this case we want to identify what scans might result in a total PEAK skin dose that exceeds 500 mGy.
- In general, peak skin dose is greatest when the scan table is held stationary and multiple scan “slices” are performed in the same anatomical location.
- The principal scan where the table is held stationary and doses might result in a skin injury are brain-perfusion scans
- For these types of scans, Dose Length Product (DLP) tends to underestimate peak skin dose as a relatively small length of the body is actually being scanned.
- By definition CTDI\text{vol} reports dose assuming multiple contiguous scan slices and considers scatter radiation from adjacent slices and thus overestimates peak skin dose for repeated scans in a fixed location.
- Measurement data for actual skin dose received from brain-perfusion scans indicates that CTDI\text{vol} overestimates peak skin dose by approximately a factor of two.
- Thus, if the cumulative CTDI\text{vol} for a head scan exceeds 1000mGy (1 Gy) there may be likelihood of deterministic injury to the skin.
Skin Dose Threshold: 500 mSv

- It is unlikely in CT that skin dose averaged over entire organ will exceed 500 mSv.
- **Rather for skin the immediate concern is potential for deterministic injury such as erythema (reddening), or hair loss (epilation), or more serious skin burns.**
- In this case we want to identify what scans might result in a total **peak** skin dose that exceeds 500 mGy.
- In general, peak skin dose is greatest when the scan table is held stationary and multiple scan “slices” are performed in the same anatomical location.
- The principal scan where the table is held stationary and doses might result in a skin injury are neuro-perfusion scans.
- For these types of scans, Dose Length Product (DLP) tends to **underestimate** peak skin dose as a relatively small length of the body is actually being scanned.
- By definition CTDI\textsubscript{vol} reports dose assuming multiple contiguous scan slices and considers scatter radiation from adjacent slices and thus **overestimates** peak skin dose for repeated scans in a fixed location.
- Data for skin dose received from neuro-perfusion scans indicates that CTDI\textsubscript{vol} overestimates peak skin dose by 30 to 100%.
Skin Dose Threshold: 500 mSv

• Thus, the following situations may result in an skin dose exceeding the reporting threshold of 500 mSv:
  – Scans with NO table movement (e.g., neuroperfusion scan)
    • For Pediatric, if the cumulative CTDIvol for any given body part exceeds 650 mGy
    • For Adult, if the cumulative CTDIvol for any given body part exceeds 650 mGy
  – Scans with table movement (any axial or helical scan)
    • For Pediatric, if the cumulative CTDIvol for any given body part exceeds 200 mGy
    • For Adult, if the cumulative CTDIvol for any given body part exceeds 250 mGy
• Here “cumulative” CTDIvol means if the same anatomic region is scanned multiple times (e.g., pre- and post-contrast of the same region), then these CTDIvol may be added.
• NOTE: if different regions are scanned (e.g., pre-contrast abdomen, post-contrast thorax and pelvis), then the CTDIvol are not added.
Fetal Dose Threshold: 50 mSv

• SB-1237 also requires that a CT or therapeutic dose to an embryo or fetus greater than 50 mSv (5 rem) dose equivalent be reported if dose delivered is to a *known pregnant individual* unless the fetal dose was specifically approved, in advance, by qualified physician.

• Exceeding the specified fetal dose threshold may occur in certain clinical scenarios.

• For CT the following situations may result in an embryo or fetal dose exceeding the reporting threshold of 50 mSv:
  – Scans with table movement (any axial or helical scan)
    • If the cumulative CTDIvol for a scan of the abdomen/pelvis including the uterus exceeds 25 mGy
  – Scans with NO table movement (e.g., perfusion scan of abd/pelvis)
    • If the cumulative CTDIvol for a scan including the abdomen/pelvis including the uterus exceeds 65 mGy

• Here “cumulative” CTDIvol means if the uterine/abdomen region is scanned multiple times (e.g. pre- and post-contrast of the same region), then these CTDIvol should be added.

• NOTE: if regions outside of the abdomen/pelvis are scanned then the CTDIvol are not added.
Conclusions

• Questions about individual patient doses should be referred to a Qualified Medical Physicist for calculation.

• Protocol review by a Qualified Medical Physicist is required for compliance with State of CA and accreditation bodies.
For Further Information

• Contact any of the C-Camps Members or Melissa@TherapyPhysics.com

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