Dose Issues in Computed Tomography

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NCRP Reports
Ionizing Radiation Exposure of the Population of the United States

- Report #93
  - Published in 1987
  - Data from early 1980’s
  - Extensive data on medical exposures
- Report # 160
  - Updated 2009

National Council on Radiation Protection and Measurements
CT Usage

- Annual growth
  - U.S. Population: <1%
  - CT Procedures: >10%
- ~ 67,000,000 procedures in 2006
  - about 10% pediatric CT
U.S. Per Capita Exposure

Exposure Increase 1982-2006

6-fold increase in 24 years

40% CT
60% Other

Exposure Increase 1982-2006
A Quick Review of Radiation Risk

- Deterministic (non-stochastic)
- Stochastic
Deterministic (non-stochastic) Radiation Risks

- Effect has known threshold for dose
- Examples
  - Erythema
  - Cataract formation
- Clearly addressed by regulations
Stochastic Radiation Risks

• Radiation affects probability of condition which also occurs naturally
  • Genetic effects
  • Fetal abnormalities
  • Cancer
Cedars-Sinai CT Overexposures

- Brain perfusion studies
  - Repeated exposure to same anatomy
  - Table doesn’t move
- No equipment defects
- Protocols altered
  - Decreased image noise
  - Caused mA/dose to increase
A week ago, Cedars-Sinai Medical Center in Los Angeles disclosed that it had mistakenly administered up to eight times the normal radiation dose to 206 possible stroke victims over an 18-month period during a procedure intended to get clearer images of the brain. State and federal health officials are investigating the cause.
Any wonder that our patients/parents are concerned?

For reasons not yet fully understood, the X-ray technologist, Raven Knickerbocker, activated the CT scan 151 times on the same area, state investigators concluded. A normal test involves some 25 images, Mr. Schlag said. The test was terminated only after the victim’s father, who had been holding his son still, began to worry that it was taking too long.
• High dose effects well known
• What happens at low doses?
Linear No-threshold Model

- Low Doses are Harmful
- Radiation is a carcinogen

There are no “safe” levels of radiation!
Linear Model

- If a 1,000 pound lion can kill 100 Romans in an hour
Linear Model

- A 10 pound puddy tat can kill 1 Roman in an hour.

*Suffering succotash... I mean ROAR

Oh no!
Water Can Kill You!!!

Water intoxication
From Wikipedia, the free encyclopedia

Water intoxication, also known as water poisoning.
Threshold Model

- Low Doses are NOT Harmful

Things that are dangerous in excess are not dangerous in moderation.
Radiation Hormesis Model

- Low Doses are Beneficial

Radiation is good for you!
Each year, about 1.6 million children in the USA get CT scans to the head and abdomen — and about 1,500 of those will die later in life of radiation-induced cancer ...

How many children’s lives are saved by CT?
Computed Tomography — An Increasing Source of Radiation Exposure

On the basis of data from 1991-1996, ~0.4% of future cancers may be attributable to radiation from CT.

By adjusting this estimate for current CT use, this estimate may go up to 1.5-2.0%.

Based upon calculations. Not based upon observations!
Recent Article on 2011 CT Summit: “Admit we don't know CT radiation risk”

- The linear model should be used for setting radiation protection standards as it was the most "conservative," but it was senseless to use as a basis to predict cancer deaths.

Dotmed news, March 01, 2011, Brendon Nafziger
It's difficult to model cancer risk from radiation at small doses, such as that produced by CT scans. To have enough statistical power to detect such small effects, you need to track > 10 million patients for years.... At the end of the day the controversy will never go away.

(Cynthia McCollough, professor of radiologic physics at Mayo Clinic)

Dotmed news, March 01, 2011, Brendon Nafziger
Linear No-Threshold

- Following slides from “Radiation Risks of Medical Imaging: Separating Fact from Fantasy” (Hendee, O’Connor, Radiology August 2012)

Major source of knowledge for health effects to individuals from ionizing radiation
“Most population studies have revealed no or much smaller demonstrable health effects of radiation exposure”

<100 mSv, it is not possible to identify an increased incidence of cancer with any degree of statistical confidence

Evidence that LNT model ... conflicts with current understanding of biologic mechanisms
Hendee & O’Connor (cont.)

- “Studies of 500,000 occupationally exposed workers in the nuclear industry ... demonstrated reduced cancer in the exposed individuals
  - Attributed to the arguable possibility that the exposed population is in better health than the population at large.
  - BEIR VII largely excludes all of these studies from its analyses”

Beir VII: “Because of limitations in the data used to develop risk models, risk estimates are uncertain, and estimates that are a factor of two or three larger or smaller cannot be excluded.”
CT Patient Dose

- Tube rotates around patient during study
- Affects the distribution of radiation in the body
- CT head dose fairly uniform
- For body CT, surface doses ~ 2X dose at center
So what determines the “correct” CT dose?
How much image noise can your clinical situation permit?
CT Dose Tradeoff

More dose required to improve noise for same spatial resolution
CT Low-Contrast Resolution Depends on Noise

- Noise is a function of # of photons detected per pixel
  - mAs
  - Slice thickness
  - Pitch
  - filtration
CT Dose Conventions

- CTDI (Computed Tomography Dose Index)
  - CTDI$_{100}$
  - CTDI$_{W}$
  - CTDI$_{VOL}$
- DLP (Dose Length Product)
- SSDE (Size-specific Dose Estimates)
CT Dose Measurement

- Lucite phantom
  - Body (32 cm)
  - Head (16 cm)
- 5 holes
  - One center
  - Four periphery
- Pencil chamber in one hole
- Lucite plugs in remaining 4 holes
- Slice centered on phantom length
CTDI$_{100}$

- 100 mm chamber length
- Includes scatter “tails”
CTDI\textsubscript{w}:

- Weighted average of center & peripheral measurements
- Represents “average” dose in scan plane

\[ \text{CTDI}_w = \frac{1}{3} \text{Center Dose} + \frac{2}{3} \text{Avg Periphery Dose} \]
But Beam Pitch Affects Dose!

Table motion in one rotation

Beam Pitch = \[ \frac{\text{Beam thickness}}{\text{Beam thickness}} \]

Beam Pitch > 1

Beam Pitch = 1
Beam Pitch & CT Dose

It’s easy. Higher pitch means the table is moving the patient through the beam faster.

Table motion during one rotation

\[
\text{Beam Pitch} = \frac{\text{table motion}}{\text{Beam thickness}}
\]

- Dose inversely proportional to pitch

Smaller pitch
Higher dose

High pitch
Lower dose
Definition of CTDI\textsubscript{vol}

CTDI\textsubscript{vol} corrects dose for beam pitch

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

Table motion in one rotation

Beam Pitch = \text{Beam thickness}
Dose Length Product

DLP

- $\text{DLP} = \text{CTDI}_{\text{vol}} \times \text{length of scan}$
- DLP units
  - $\text{mGy} \times \text{cm}$
- Displayed on report page
"CT Dose Index & Patient Dose: They Are Not the Same Thing"

- McCollough, Leng, Yu, Cody, Boone, McNitt-Gray (Radiology, May, 2011)

**Reported Dose is Dose to Phantom, not Patient**

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy·cm)</th>
<th>Phantom cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scout</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Helical</td>
<td>S52.250–S210.375</td>
<td>38.12</td>
<td>683.81</td>
<td>Head 16</td>
</tr>
<tr>
<td>200</td>
<td>Axial</td>
<td>L100.000–L100.000</td>
<td>15.75</td>
<td>7.87</td>
<td>Head 16</td>
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<tr>
<td>4</td>
<td>Helical</td>
<td>L114.500–S189.700</td>
<td>22.39</td>
<td>785.37</td>
<td>Head 16</td>
</tr>
</tbody>
</table>

**Total Exam DLP:** 1477.06
Size-Specific Dose Estimates

- Actual patient dose estimates based upon
  - Patient size
  - Age

AAPM Report No. 204

Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations
CT Dose Reduction

- Reduce mAs
  - Increases image noise
- Increase pitch
  - Image quality considerations
- Proper technique is maximum tolerable noise as determined by radiologist
CT Noise Reduction:
Increase Slice Width

- More photons detected per voxel
  - Less noise

BUT

- More partial volume effect
  - more different tissue types in each voxel
CT Phototiming

- Allow operator to specify image quality
  - GE nomenclature: “Noise Index”
- Modulate mA as tube
  - rotates around patient
  - Patient moves through gantry
- Goal: constant photon flux to detector
Rotational Beam Modulation

- Operator specifies maximum mA
- mA reduced as tube rotates around patient to provide only as radiation as needed
Z-axis Beam Modulation

- Scanner determines changes in attenuation along z-axis from scout study
- mA changed as patient moves through gantry
CT Beam Modulation

- Combining rotational and z-axis modulation
Commercial Iterative Reconstruction

- **GE (ASIR)**
  - Up to 40% less dose with no loss of image quality
- **Siemens (IRIS)**
  - Artifact & noise reduction
  - Increased image sharpness
  - Dose savings up to 60%
Dose Reduction Mechanisms

- Customize settings to patient size / weight
  - mA
  - kVp
- Eliminate duplicate exams
- Reduce z-axis coverage
- Reduce field of view
- Consider alternate procedures

CT Protocols

- Default machine settings for particular study type
  - kVp / mAs
  - Rotation time
  - Pitch
  - Field of View
  - Reconstruction algorithm
  - mA modulation parameters
- Can be over-ridden for individual patient study
Cedars-Sinai Lessons

- Protocols
  - Easy to change
  - Protocols & changes need to be
    -Monitored
    -Documented

- Overexposures produce clean low-noise images
  - No complaints?
  - Operators need to look at default settings provided by protocols
  - Physicians need to look at dose reports for anomalies
    - $\text{CTDI}_{\text{VOL}}$ (mGy)
    - DLP (mGy-cm)
Big Brother

- California SB 1237 requires
  - Recording CT doses
  - Accreditation
  - Report overdoses
The End