Dose Reduction in CT

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GE Healthcare
Manager CT Advanced Applications Software
What will be covered:

CT Dose in the news
Basics of CT Dose Measurement
Scanner features which aid in dose reduction
What we as technologist can do
  • As Low As Reasonably Achievable
What’s next for dose reduction in CT
Why all the interest in dose reduction...
Why all the interest in dose reduction...

Increased use of CT scans raises risk of higher radiation exposures
11/29/2007
By Reuters Health

NEW YORK (Reuters Health), Nov 29 - In a review article, U.S. researchers argue that the growth of CT scan use over the years has increased the risk of higher radiation exposures, which may result in a significant public health problem.
Medical Radiation Exposure

See: Fred Mettler, MD: “Magnitude of Radiation Uses and Doses in the US: NCRP Scientific Committee 6-2 Analysis of Medical Exposures”

Tom Tenforde, Ph.D., President, NCRP: “Medical exposures have risen by a factor of at least five since the 1980s, primarily due to the greatly increased use of CT and nuclear cardiology procedures.”

Courtesy of James Brink, MD Yale University

Courtesy of James Brink, MD Yale University
Review of CT X-ray dose basics

Responsible dose management requires a balanced consideration
X-rays penetration

A dense object stops more X-rays

Higher atomic no. elements stop more photons
The trees in front get more hits
The deeper into the forest, the x-rays
What is X-ray Dose

A measure of absorbed energy per kilogram

Important
Dose distribution example

Dose calculation in an anthropomorphic phantom courtesy of R. Thompson GE GRC

Attenuation

Less dense regions receive less energy per unit volume

Higher energy absorbed per unit volume

The average dose for this section would be the total absorbed energy/weight in kg
Which receives higher dose?

The average absorbed energy per kg is higher in the smaller object (more X-rays per unit)
Scout Dose – which is better?

Sensitive organs are mostly anterior (breast, thyroid, eyes)

Posterior is better!
What is dose and How is it quantified?

A measure of absorbed energy in Gray

Gray 1Gy = 1 Joule per kg

About equivalent to the energy required when operating a 1 watt light bulb for one second

Typical CT dose range: 10 mGy to 50 mGy

Lights a 1 watt bulb for 10 to 50 milliseconds
Biological Effects of Ionizing Radiation

For a whole body dose averaged over a range of ages of a reference population with an equal number of both sexes

Blood count changes 500 mSv
Vomiting (threshold) 1000 mSv
Mortality (threshold) 1500 mSv
.05 % cancer stochastic risk increase 10 mSv

CT dose is a stochastic population risk, not an acute patient risk

(mSv units are adjusted for radiation biological effect)

Important

% cancer risk vs age per Sv Effective dose

Children are considerably more sensitive to radiation
Effective dose and comparisons for various procedures

Table I - Radiation Dose Comparison

<table>
<thead>
<tr>
<th>Diagnostic Procedure</th>
<th>Typical Effective Dose (mSv) (^1)</th>
<th>Number of Chest X rays (PA film) for Equivalent Effective Dose (^2)</th>
<th>Time Period for Equivalent Effective Dose from Natural Background Radiation (^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest x ray (PA film)</td>
<td>0.02</td>
<td>1</td>
<td>2.4 days</td>
</tr>
<tr>
<td>Skull x ray</td>
<td>0.07</td>
<td>4</td>
<td>8.5 days</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>1.3</td>
<td>65</td>
<td>158 days</td>
</tr>
<tr>
<td>L.V. urogram</td>
<td>2.5</td>
<td>125</td>
<td>304 days</td>
</tr>
<tr>
<td>Upper G.I. exam</td>
<td>3.0</td>
<td>150</td>
<td>1.0 year</td>
</tr>
<tr>
<td>Barium enema</td>
<td>7.0</td>
<td>350</td>
<td>2.3 years</td>
</tr>
<tr>
<td>CT head</td>
<td>2.0</td>
<td>100</td>
<td>243 days</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>10.0</td>
<td>500</td>
<td>3.3 years</td>
</tr>
</tbody>
</table>

1. Effective dose in milliSv (mSv).
2. Based on the assumption of an average "effective dose" from chest x ray (PA film) of 0.02 mSv.
3. Based on the assumption of an average "effective dose" from natural background radiation of 3 mSv per year in the United States.


Nuclear perfusion 26 – 35 mSv

Source: Cynthia H. McCullough, Ph.D., Mayo Clinic, Rochester, MN

http://www.auntminnie.com/index.asp?sec=sup&sub=car&pag=dis&Itemld=71608
Summary of Dose Metrics

CTDI – CT Dose Index – dose delivered to a standard reference phantom (originally for CT QA)

Whole body dose - the basis for human biological risk

Effective Dose – the sum of organ doses weighted to approximate an equivalent whole body dose

Organ Doses - organ specific dose
CT Dose Index – average dose in a reference phantom

16 cm head & 32 cm body acrylic phantom (PMMA)

Center (A) and peripheral (B) CTDI\(_{100}\) measurements are combined

CTDI\(_{w}\) = 2/3 peripheral + 1/3 central CTDI\(_{100}\) doses

CTDI\(_{w}\) is called the CTDI weighted dose
What’s wrong with CTDI as patient dose?

**Human anatomy:** size, shape, & tissue variations

**CTDI:** Uniform material, & fixed size & shape
Uses of CTDI

A standard method to state CT dose delivered to a reference object

Allows relative dose delivery comparisons between different clinical protocols or scanners

Allows dose recording for CT quality assurance

An index of relative dose to a hypothetical nominal patient (it is not a patient dose)
A CT scan – usually a partial body exposure with dose to some organs

Dose region for a lung scan

Organs receiving dose: Lung, Breast, some bone and some skin
Organ doses can be weighted and added to obtain the Effective Dose.

**ICRP Tissue Weighting Factors $W_T$**

<table>
<thead>
<tr>
<th>Tissue or Organ</th>
<th>$W_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.20</td>
</tr>
<tr>
<td>Bone marrow (red)</td>
<td>0.12</td>
</tr>
<tr>
<td>Colon</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.05</td>
</tr>
<tr>
<td>Breast</td>
<td>0.05</td>
</tr>
<tr>
<td>Liver</td>
<td>0.05</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.05</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.05</td>
</tr>
<tr>
<td>Skin</td>
<td>0.01</td>
</tr>
<tr>
<td>Bone surface</td>
<td>0.01</td>
</tr>
<tr>
<td>Remainder Tissues (Nominal $W_T$ applied to the average dose to 14 tissues)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

1990 ICRP Report 60 - recommendations of the international commission on radiological protection.

Converts partial dose to an effective whole body dose.
Thinking that effective dose is hard to measure?

EUR16262 EN Guidelines on Quality Criteria for CT –
Table 2 body regions vs DLP multiplication factors

\[
E = E_{DLP} \times DLP
\]

An approximate effective dose value for estimating overall population dose effects

http://www.drs.dk/guidelines/ct/quality/index.htm
Effective Dose

Uses dose units of mSv

Is the only way to compare doses from different modalities

Difficult to estimate accurately for a patient

Controversial within the medical physics community due to lack of computation standardization and the potential for misunderstanding
What is DLP and How is it measured?

$$\text{DLP} = \text{Exposure Length} \times \text{CTDIvol}$$

- DLP: (mGycm)
- Exposure Length: (cm)
- CTDIvol: (mGy)

Helical Exposure Length

- Helical Exposure Length: (cm)
- Exposure time: (s)
- Table speed: (cm/s)
What is the effective dose for a chest scan
Where Exp Length = 25 cm, CTDIvol = 6 mGy

\[
150 = 25 \times 6
\]

<table>
<thead>
<tr>
<th>Region</th>
<th>( E_{DLP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>0.0023</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0054</td>
</tr>
<tr>
<td>Chest</td>
<td>0.017</td>
</tr>
<tr>
<td>Abdomen</td>
<td>0.015</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.019</td>
</tr>
</tbody>
</table>

\[
2.55 \text{ mSv} = 0.017 \times 150
\]
Is CTDI\text{vol} different than CTDI_{100} & CTDI_w?

CTDI_w = \frac{2}{3} \text{ peripheral} + \frac{1}{3} \text{ central} \text{ CTDI doses}

\textbf{Axial} \quad \text{CTDImvol} = \frac{\text{Detection Width}}{\text{Table Increment}} \times \text{CTDI}_w

\textbf{Helical} \quad \text{CTDImvol} = \frac{1}{\text{Helical Pitch}} \times \text{CTDI}_w
What is effective mAs?

Effective mAs = Detection Width / Table Increment \times mAs

Effective mAs = \frac{1}{\text{Helical Pitch}} \times mAs

A way to express the mAs that accounts for the effect of pitch and consequently CTDIvol
Factors that influence dose

Tube potential
Exposure time
Beam Quality
Collimation
Distance from source
Patient Size & anatomy

The IQ needed for the clinical task and system dose efficiency

\[ \text{dose} \propto kVp^2 \]
\[ \text{dose} \propto \text{mAS} \]
\[ \text{dose} \approx 1/R^2 \]

\[ \text{dose} \approx (0.133 \text{ cm}^{-1} \times \Delta_{\text{diam}}) \]

Most significant indirect factors

technologist controls

The technologist controls the

Factors that influence dose

Tube potential
Exposure time
Beam Quality
Collimation
Distance from source
Patient Size & anatomy

The IQ needed for the clinical task and system dose efficiency

\[ \text{dose} \propto kVp^2 \]
\[ \text{dose} \propto \text{mAS} \]
\[ \text{dose} \approx 1/R^2 \]

\[ \text{dose} \approx (0.133 \text{ cm}^{-1} \times \Delta_{\text{diam}}) \]
Dose information display

- $\text{CTDI}_{\text{vol}}$
- DLP (dose length product)
- Z-axis dose efficiency
- Projected DLP
- Accumulated DLP

Dose information display:

<table>
<thead>
<tr>
<th>Images</th>
<th>$\text{CTDI}_{\text{vol}}$</th>
<th>DLP $\text{mGy} \cdot \text{cm}$</th>
<th>Dose Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-73</td>
<td>5.03</td>
<td>198.60</td>
<td>97.40</td>
</tr>
<tr>
<td>SmartPrep</td>
<td>43.95</td>
<td>43.95</td>
<td></td>
</tr>
<tr>
<td>Projected series DLP:</td>
<td>242.55 $\text{mGy} \cdot \text{cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accumulated exam DLP:</td>
<td>1934.43 $\text{mGy} \cdot \text{cm}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Keep control, prospectively, of the image quality and of the dose level.
<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDI&lt;sub&gt;vol&lt;/sub&gt; (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>S30.000–S7.500</td>
<td>29.75</td>
<td>106.93</td>
<td>Body 32</td>
</tr>
<tr>
<td>2</td>
<td>Helical</td>
<td>72.500–195.000</td>
<td>29.75</td>
<td>106.93</td>
<td>Body 32</td>
</tr>
</tbody>
</table>

Total Exam DLP: 213.86
Future dicom dose structured report
(Expected effectively for new products, July 2008)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTDIvol</td>
<td>required</td>
</tr>
<tr>
<td>Phantom type (head or body)</td>
<td>required</td>
</tr>
<tr>
<td>Dose Length Product (DLP)</td>
<td>required</td>
</tr>
<tr>
<td>Free in air dose</td>
<td>optional</td>
</tr>
<tr>
<td>Effective dose (ED)</td>
<td>optional</td>
</tr>
<tr>
<td>ED calculation method</td>
<td>required if ED reported</td>
</tr>
</tbody>
</table>
Dose Management
Applying the ALARA principle

- Scanner features
- Protocol factors
Summary of dose reduction features

AutomA
Smart mA
Pediatric color coded protocols
Beam tracking/wide coverage
Cardiac bowtie filter
Cardiac Snapshot Pulse
ECG gated cardiac helical
Dose report
Adaptive image filters
How does a bowtie filter help?

There is an optimum bowtie for depending on the patient size

For LightSpeed VCT

<table>
<thead>
<tr>
<th>Size</th>
<th>Bowtie</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 15 cm</td>
<td>Small</td>
</tr>
<tr>
<td>15 to 25 cm</td>
<td>Medium</td>
</tr>
<tr>
<td>&gt; 25 cm</td>
<td>large</td>
</tr>
</tbody>
</table>

Reduces surface dose by about 1/2 and central dose slightly
Increases image noise slightly especially at the periphery

Effect of a mis-centered patient

% Effective bowtie mA contours

Patient 6 cm too low

10%

50%

100%

Increased dose to breast

High noise streaks due to mis centering

Excessive dose

Centering error

Dose too low

Average elevation error 2.5 cm low

What dose is needed for a small patient (PAI = 20.2)?

Dose is related to the IQ needed for the clinical task

Image Noise 7.83 HU
CTDI$_{vol}$ 29.1 mGy

Image Noise 15.0 HU
CTDI$_{vol}$ 7.9 mGy (-73%)

Image Noise 11.1 HU
CTDI$_{vol}$ 14.6 mGy (-50%)

Image Noise 9.0 HU
CTDI$_{vol}$ 21.8 mGy (-25%)

---

Noise artificially added to images
3D Dose Modulation (automA + smartmA)
Up to 40% Dose Reduction with Three Dimensional Modulation

Prospective 3D dose modulation

From single low dose scout

Automatically changes mA
• Along patient
• Within a slice

Constant dose

X, Y – changing mA w/in a slice

Z – changing mA along patient

X, Y, Z – 3D mA modulation
3D Dose modulation in routine acquisition

Define in the Protocol

Prospective Display

Keep control, prospectively, of the image quality and of the dose level
Protocols

Pediatric color coded protocols
• Height and weight based

Adult Protocols
• Build weight based protocols - One size does not fit all
• Build low dose protocols for exams that have a high rate of repeating i.e. Kidney stone protocol
CCTA Dose Reduction
Prospective vs. Retrospective Cardiac Gating: How it works

Prospective ECG gating Axial and Step & Shoot
Real-time heart rate monitoring and gating
Not a single phase; it is a phase range
Dose and exposure time are heart rate independent

Prospectively gated acquisition – SnapShot Pulse

Retrospective gating helical acquisition
SnapShot Pulse Acquisition: How It Works

Prospective ECG-Gated Single Sector Image Capture.....

.....Leading up to 83% CCTA Dosage Reduction
# SnapShot Pulse: Dose Comparison

<table>
<thead>
<tr>
<th>Protocols with uncompromised Image Quality</th>
<th>Dose</th>
<th>Relative Exposure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac Helical</td>
<td>20-25 mSv*</td>
<td>100%</td>
</tr>
<tr>
<td>Cardiac Helical with ECG modulation</td>
<td>6-20 mSv*</td>
<td>50 - 81%</td>
</tr>
<tr>
<td>Cardiac SnapShot Pulse - prospective ECG gating</td>
<td>3-6 mSv*</td>
<td>25 – 30%</td>
</tr>
<tr>
<td>Diagnostic Cath</td>
<td>1-10 mSv</td>
<td></td>
</tr>
</tbody>
</table>

## Dose References

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest radiographs – 2 views</td>
<td>0.08 mSv (5)</td>
</tr>
<tr>
<td>Mammogram</td>
<td>0.13 mSv (5)</td>
</tr>
<tr>
<td>Natural Background (Annual)</td>
<td>3 mSv (1,4)</td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
</tr>
<tr>
<td>Tc-99m (rest only)</td>
<td>4 – 5 mSv (1,2)</td>
</tr>
<tr>
<td>Tc-99m (rest+stress)</td>
<td>9 – 13 mSv (1,2)</td>
</tr>
<tr>
<td>TI-201 (rest+stress)</td>
<td>~34 mSv (1,2)</td>
</tr>
<tr>
<td>CT</td>
<td></td>
</tr>
<tr>
<td>VCT Coronary Angio w/ ECG mod</td>
<td>6 – 15 mSv</td>
</tr>
<tr>
<td>VCT Calcium Scoring</td>
<td>~0.6 mSv</td>
</tr>
</tbody>
</table>

* Obtained by EUR-16262 EN, using a chest factor of 0.017*DLP
ECG Automatic Dose Modulation
Up to 50% Dose Reduction for Coronary Vessel Imaging

Modulated dose based on ECG signal
User selectable parameters
  Min and Max mA settings
  Adjustable phase %
Data can be used for functional analysis
The dose management partnership

Referring physician – prescribe CT procedures only as appropriate

Radiologist – Use only the dose needed for the diagnostic clinical task

Technologists- Adjust protocol factors for patient size and exam

Manufacture – provide dose efficient equipment that is simple to use
How much dose is enough?

What Image Quality is Sufficient for Clinical task?

The patient Clinical Indication (symptoms)

Noise Index

System Dose Delivery

System Dose Efficiency

Image Quality

It’s a decision for the doctor

Use appropriate dose reduction devices
How can CT vendors help lower dose?

- Improve scanner dose efficiency (as technology allows)
- Features to minimize dose and IQ variance
- Help technologists manage patient dependent parameters
Summary
Thank you!