Dose Modulation Technique in CT

Short Overview

- Overview
- Dose Saving Features
- Take Home Point
- Conclusions

Content

Scanner Generations

Development of CT

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
<th>Detector Type</th>
<th>Beam Angles</th>
<th>Slice Thickness</th>
<th>Radiation Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>Multi-slice CT</td>
<td>Flat Panel</td>
<td>200°</td>
<td>10 mm</td>
<td>Low</td>
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<tr>
<td>1980</td>
<td>Multi-slice CT</td>
<td>Flat Panel</td>
<td>360°</td>
<td>1 mm</td>
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<tr>
<td>1990</td>
<td>Multi-slice CT</td>
<td>Flat Panel</td>
<td>360°</td>
<td>0.5 mm</td>
<td>Very High</td>
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<tr>
<td>2000</td>
<td>Multi-slice CT</td>
<td>Flat Panel</td>
<td>360°</td>
<td>0.25 mm</td>
<td>Extremely High</td>
</tr>
</tbody>
</table>

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### Radiation Risk and Effective Dose

#### Schematic Graph:
- **Assumption for radiation protection (ICRP):**
  - Linear extrapolation without threshold
  - Improbable correlations for low dose
  - Data from radiation victims (Hiroshima, Nagasaki)

#### Typical range of CT

#### Effective Dose (mSv)
- **Radiation Risk**
  - •••• ••
  - •• •••• ••

#### Data from radiation victims

For children: Higher Risk !

### News 1

On Friday, 08 Oct. 2009, the FDA sent out a notice concerning “Safety Investigation of CT Brain Perfusion Scans: Initial Notification.”

According to the FDA notification, 206 patients were exposed over a time period of 18 months with inappropriately high levels of radiation dose during CT Perfusion (CTP) examinations.

As a consequence of the exposure, some patients suffered from erythema and partial hair loss.

**Example of chronic skin injury due to cumulative skin dose of ~20,000 mGy (20 Gy) from coronary angiography and x2 angioplasties**

**Cataract in eye of interventionist**

**after repeated use of over table x-ray tube**

**Example of chronic skin injury due to cumulative skin dose of ~20,000 mGy (20 Gy) from coronary angiography and x2 angioplasties**

- 21 months after first procedure, base of ulcer exposes spinous process
CHICAGO (Reuters) - Radiation from CT scans done in 2007 will cause 29,000 cancers and kill nearly 15,000 Americans, researchers said on Monday.

About 70 million CT scans were done on Americans in 2007, up from 3 million in 1980. Amy Berrington de Gonzalez of the National Cancer Institute and colleagues developed a computer model to estimate the impact of so many scans.

They estimated the scans done in 2007 will cause 29,000 cancers. A third of the projected cancers will occur in people who were ages 35 to 54 when they got their CT, two-thirds will occur in women and 15 percent will arise from scans done in children or teens.

The researchers estimated there will be an extra 2,000 excess breast cancers just from CT scans done in 2007.
Reference Dose Levels

Various countries or organisations have defined Reference Levels for CT dose:

- American College of Radiology (ACR):
  - CT Head: 47 mGy
  - CT Abdominal Aorta: 770 mGy
  - CT Thorax: 360 mGy
  - CT Brain: 1050 mGy

- Germany (Federal Office of Radiation Protection):
  - Lumbar Spine: 280 mGy
  - Upper Abdomen: 750 mGy
  - Pelvis: 1500 mGy
  - Abdomen: 650 mGy
  - Thorax: 200 mGy
  - Cranial (Face) / Paranasal Sinuses: 1500 mGy

**Diagnostic Reference Values for CT Examination for adults**

<table>
<thead>
<tr>
<th>Examination</th>
<th>CT Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumbar Spine</td>
<td>280</td>
</tr>
<tr>
<td>Upper Abdomen</td>
<td>750</td>
</tr>
<tr>
<td>Pelvis</td>
<td>1500</td>
</tr>
<tr>
<td>Abdomen</td>
<td>650</td>
</tr>
<tr>
<td>Thorax</td>
<td>200</td>
</tr>
<tr>
<td>Brain</td>
<td>1050</td>
</tr>
</tbody>
</table>

**Advantage and Risk of Diagnostic with X-rays**

A careful consideration of advantage against risk is demanded for every individual patient!

- "Deterministic damage":
  - Radiation burns

- "Stochastic damage":
  - Generally, stochastic damage includes the risk of developing cancer.

"Radiation-induced cancers" are usually expected to occur only after months or years.
**Advantage and Risk of Diagnostic with X-rays**

Significant information about pathology

How to give a definition about Good Image Quality?
- Higher Image Contrast & less noise
- or less image contrast & acceptable noise

How to give a definition about Good Image Quality?
- Significantly Information about pathology

A careful consideration of advantage against risk is demanded for every individual patient!

* Basic radiation induced cancer*
CARE Dose 4D
Automatic Exposure Control

The human body is not a homogeneous cylinder
X-ray attenuation varies along the spiral path of a CT scan

Optimal diagnostic image quality in every slice at lowest dose levels
Adaptation of tube current to attenuation
Automatic Exposure Control

Accordingly, the noise in projection data varies (for constant tube output)
**mAs-Adaptation along the patients z-axis and to patient size**

Example: Thorax Protocol

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**Results of Clinical Image Quality Assessment**

Image Noise should not be constant
resp. mAs should not be proportional to object attenuation

- Noise in pediatric patients would be too high
- mAs for obese patients would deliver excessive dose levels and exceed the power limits of current scanners

→ mAs should be adapted by an empirical function, according to diagnostic information requirements

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**How does CARE Dose 4D work?**

1. Evaluation of Topogram for attenuation in lateral and AP direction
2. Calculation of appropriate axial tube current profiles in lateral and AP direction
3. Axial tube current variation during scan
4. Angular online tube current modulation during scan

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CAREDose mA = X/Y mA

CARE Dose 4D: mA is set proportional to (A/Aref) b

Measuring the attenuation in z-axis

Dose Modulation Technical Aspects

Why is an angular modulation needed?

Using angle modulation

Dose Modulation – Phantom scan
Dose reduced by 51%

Scan without dose modulation
Scan with dose modulation

Improved image quality at lower dose

Advantage of Online Modulation

Optimal mA for AP and lateral Views:
On-line mA modulation

CARE Dose 4D – First Results

<table>
<thead>
<tr>
<th>Protocols</th>
<th>Dose Reduction</th>
<th>Organ specific Reduction in Scan Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>Average</td>
<td>Head 51% Neck 66% Shoulder 17%</td>
</tr>
<tr>
<td>Thorax</td>
<td>Average</td>
<td>Shoulder 38% Thorax 4% Abdomen</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Average</td>
<td>Shoulder 37% Thorax 64% Abdomen 37% Pelvis 33%</td>
</tr>
<tr>
<td>Abdomen / Pelvis</td>
<td>Average</td>
<td>Thorax 40% Abdomen 34% Pelvis 30%</td>
</tr>
</tbody>
</table>

Dose reduction in %, compared to SOMATOM Sensation16 standard protocols (140 patient studies)
CARE Dose 4D
Automatic Exposure Control for Siemens CT-Scanners (since SW VB10n)

Features:
- mAs setting automatically adapted to patient size
- full mAs variation over the patient’s long axis
- real-time modulation during tube rotation (current CARE Dose)

Benefits:
- same scan protocols for slim/obese, (adult/pediatric patients)
- optimal diagnostic image quality in every slice
- achieved at lowest dose levels

How to work with CARE Dose 4D

Since SW version VB10/VB19, Siemens’ default scan protocols use CARE Dose 4D, resulting in ability to scan immediately without any adjusting of mAs after performing a Topogram (*resulting in default image quality).

Adjustment of image quality to individual preference is possible.

A Topogram is needed to utilize CARE Dose 4D

- If the scan range exceeds the Topogram range:
  - Outside the Topogram range the last measured/calculated mA-value of the Topogram range will be used (warning pops up).
- If more than one Topogram of the current examination exists:
  - Information of all valid Topograms will be used to calculate mA values
  - If overlapping in the same direction, e.g. lateral, the newest information will be used

Isocenter positioning of patient is essential!

Distorted Topogram does influence the mAs Calculation!
indicates CARE Dose 4D is switched on for the current protocol displays the average eff. mAs that will be applied by CARE Dose 4D for the current scan range (will be updated to the real applied eff. mAs after the scan - might differ somewhat)

The Quality Reference mAs value defines the overall image quality (noise) of the current protocol and may be adapted for each protocol to the user's individual preference of image quality.

Switch for CARE Dose 4D.
CD4 adjusts the tube current over the patient’s long axis

- The ‘1D’ approach, like our competitors on some scanners
  - CD4 adjusts the tube current in x and y (tube angle): 3D

- The 3D approach based on Topogram evaluation
  - Data needed to plan the scan: dose information, tube load

During the scan:
  - Real-time measurement of attenuation and mA modulation
  - Real 4D modulation in space and time

- Automatic Exposure Control (CARE Dose 4D) => see e-learning!

Dose Saving Features (Extract)

- Reference-Level-based Dose-Adaptation to patient size
- Dose-Modulation along z-axis
- Angular Online-Dose-Modulation

Note: Without CARE Dose 4D
  - the dose has manually adapted to patient size, which will frequently result in too high patient dose or reduced image quality.
  - the dose is constant over the whole scan range. Excessive dose in thin regions and excessive image noise in thick regions will result.
  - in inhomogeneous regions (shoulder, pelvis) the dose will be too high, without improvement of image quality.

- Image Noise Reduction (Adaptive Filter, Image filtration)
- Adaptive Dose Shield
- ECG-Pulsing
**Principle of Radiation Protection**

- Time
- Distance
- Shielding

**Principle of Radiation Protection for Patient (ASAP)**

- Time (exp time): As soon as possible
- Distance (Coverage): As short as possible
- Shielding (H/W improvement): As shielding as possible
Adaptive cardiac Sequence scan

Flash scan

1 heart beat scan

Cardiac Dose Approaches
Overview

SOMATOM Definition Flash
Bhatti, SCCT 2007 abstract 19
Hausleiter, JAMA, Feb 2009
Stolzmann, Eur Radiol 2007
Stolzmann, Radiology 2007
Scheffel, Heart 2008
Stolzmann, Radiology 2008
Earls, SCCT 2007, abstract 16
Cole, SCCT 2007 abstract 15
Sablayrolles, RSNA 2007, abstract 17
McCollough, Radiology 2007
Hausleiter, SCCT 2007 abstract 17
Earls, SCCT 2007, abstract 16
Cole, SCCT 2007 abstract 15
Sablayrolles, RSNA 2007, abstract 17
McCollough, Radiology 2007
- Take Home Point

How dose technologist can do more better?

Dose Saving Features (Extract)

- Proper filtration of X-ray beam
  (x-ray quanta energies that produce only dose and don’t contribute to the image)

- Shaped Filters

- Predefined Siemens Scan Protocols (in particular for children)
  - Proper setting of kV, eff. mAs, collimation, etc.

Lower Dose Technique

For Conventional Radiography

- Image contrast of Film = Subject Contrast * Film Contrast (γ) * Dose
- Image contrast = Subject Contrast * Film Contrast (γ) * kVp * mA * sec
- $\text{CKR} = \text{Lung} \cdot (\gamma) \cdot \text{kVp} \cdot \text{mA} \cdot \text{sec} \cdot (\gamma)$

For CT:

- Image contrast of CT = Subject Contrast * kVp * mA*sec
- Lower Dose CT Technique for Lung Screening

Tube Voltage (kV)

The tube voltage controls the used x-ray spectrum.

Increasing the kV (at constant mAs) will

- increase Pt dose
- decrease image noise
- decrease image contrast
  - (especially iodine contrast)
- improve image quality for big patients
- Change CT No.

Dual Energy - Field of View

Patient Positioning Important Hints

Some general but Important Hints

Dual Energy information is only available in a FOV of

26 cm.
Dose correlation - Overview

1.) CTDIvol ~ mAs

<table>
<thead>
<tr>
<th>kV</th>
<th>80 kV</th>
<th>100 kV</th>
<th>120 kV</th>
<th>140 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 kV</td>
<td>≈30%</td>
<td>80%</td>
<td>100%</td>
<td>150%</td>
</tr>
<tr>
<td>100 kV</td>
<td>≈60%</td>
<td>80%</td>
<td>100%</td>
<td>150%</td>
</tr>
<tr>
<td>120 kV</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>140 kV</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

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2.) CTDIvol ↔ kV

- 80 kV
- 100 kV
- 120 kV
- 140 kV

---

Note: Special parameter settings (e.g., UHR) may lead to significantly higher values.

Tube current (mA)

The tube current controls the number of photons.

Increasing the mA (at constant kVp) will:
- increase Pd dose
- decrease image noise
- improve image quality for big patients

Slice Sensitivity Profile (SSP)

The user controls the SSP by choosing the effective slice width.

Increasing the slice width will have the effect of:
- reducing image noise,
- blurring structures in the image with strong z dependence,
- reducing contrast of small structures.

Note: The effective slice width can only be wider than the collimation!

Pitch

In spiral CT, the pitch is defined as:

\[
\text{Pitch} = \frac{\text{Table feed per rotation}}{\text{Total detector collimation}}
\]

Increasing the pitch has the following impact:
- The tube mA has to be increased to achieve the same noise or dose (this will be done automatically by the SureView concept)
- The maximum achievable dose is reduced.
- The scan time is shortened.
- In scans without z-sharp, stronger windmill artifacts may appear.

SureView

SureView is a unique feature of all SOMATOM Scanners.

- Due to the patented SOMATOM reconstruction algorithms, Siemens offers image quality independent of the pitch.
- At a given mA (or mAs) value, the noise will vary with the pitch.
- To achieve the same noise and dose with varying pitch, it makes sense to introduce a new mA-related quantity...

Effective mAs Concept

\[
\text{Effective mAs} = \frac{\text{mA} \cdot \text{RotTime}}{\text{PitchFactor}}
\]

- Holding the eff. mA constant, the tube current increases with pitch.
- Image noise depends only on eff. mAs.
- Patient dose depends only on eff. mAs.
- System mAs limitation, effective mA = (mA * sec).
- Only eff. mAs appear on UI (without CARE Dose 4D).
### Overview

#### Scan & Recon Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Noise</th>
<th>Sharpness</th>
<th>Contrast</th>
<th>Artifacts</th>
<th>Obese Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>same</td>
<td>same</td>
<td>same</td>
<td>worse</td>
<td>worse</td>
</tr>
<tr>
<td>Coll. Slice</td>
<td>less</td>
<td>less (2)</td>
<td>less (2)</td>
<td>worse</td>
<td>improved</td>
</tr>
<tr>
<td>kV</td>
<td>less</td>
<td>same</td>
<td>more</td>
<td>same</td>
<td>improved</td>
</tr>
<tr>
<td>Eff. mAs</td>
<td>less</td>
<td>same</td>
<td>same</td>
<td>same</td>
<td>improved</td>
</tr>
<tr>
<td>Rot Time</td>
<td>same</td>
<td>same</td>
<td>worse (motion)</td>
<td>improved</td>
<td></td>
</tr>
<tr>
<td>Eff. Slice</td>
<td>less</td>
<td>less (2)</td>
<td>less (2)</td>
<td>less</td>
<td>improved</td>
</tr>
<tr>
<td>Kernel</td>
<td>more</td>
<td>more</td>
<td>same (more)</td>
<td>worse</td>
<td></td>
</tr>
</tbody>
</table>

Worse: motion

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### Conclusions

Patient Dose has to be weighted against the diagnostic use to reduce the radiation risk.

CTDIvol and DLP are well established to describe the physical dose of a CT-examination.

Dose saving features help to reduce dose, if applied.

Careful adjustment of scan parameters to patient type and examination type has to be done.

Displayed dose values have to be observed.

Thank you for your attention!