Automated dose control in multi-slice CT

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Introduction to presentation

• CT contributes ~50+ % of all medical radiation dose
• Ideally all patients would receive ‘just enough’ radiation to produce a diagnostic image
  – Extra radiation provides no clinical benefit, but extra dose
• Controlling exposure usually achieved with ‘standard’ protocols
  – These usually err on the side of over-exposure
• Automatic exposure controls (AECs) introduced on CT scanners to address these issues
X-ray exposure

- X-ray film needs correct exposure to get the best image
- Phototimers used since ~1940 to set x-ray exposure time

Images:
- Overexposed
- Underexposed
AEC systems in CT

- CT uses digital detectors, not easily under or over-exposed
- Over-exposure leads to better image quality!
  - Under-exposure gives noisy or streaky images
- Manufacturers have introduced CT AEC systems in last three years
- CT has caught up with general x-ray, 60 years after introduction of the phototimer
  - In CT, tube current, not exposure time is being controlled
CT scanner exposure pattern

• CT scanner exposure is highly localised
  – Good opportunity for AEC optimisation
Variable patient attenuation

- Attenuation of x-rays varies according to patient density and thickness
  - Each patient is a different size
  - Cross sectional diameters change along patient length
  - Bones highly attenuating, lungs low attenuation
- Signal to detectors varies inversely to attenuation
CT AEC principles

- mA adjusted to compensate for attenuation differences
  - dose applied to patient only where needed
  - image quality less variable
Patient attenuation

- Assessed from SPR (plan) view, or from feedback from previous rotations
- Tube current adjusted accordingly
Advantages of AEC

• More constant level of x-ray signal to detectors
  – Avoids under- and over-exposing detectors
• Image quality is kept at a constant level
  – From patient to patient, and during single study
• Tube heat capacity is conserved
  – Avoids tube cooling delays
• Reduction in ‘photon starvation’ streak artefact
  – Caused by under exposure of detectors
• Dose optimisation becomes easier
  – CT scan setup is based on image quality, not tube current
Dose and image quality

- Dose and image quality are opposite sides of the same coin
  - Good image quality ‘costs’ x-ray exposure
- AEC systems operate by varying tube current (mA)
  - Patient dose proportional to mA
  - Image noise proportional to $1/\sqrt{\text{mA}}$
- AECs are generally operated by specifying image noise characteristics
- Specifying patient protocols using image noise levels has implications for patient dose
Present AEC systems

- AEC systems available on multi-slice systems are applied at one or more levels:

<table>
<thead>
<tr>
<th></th>
<th>Patient size AEC</th>
<th>Z-axis AEC</th>
<th>mA modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>Auto mA</td>
<td></td>
<td>SmartmA*</td>
</tr>
<tr>
<td>Philips</td>
<td>DoseRight ACS</td>
<td>DoseRight ZDOM</td>
<td>DoseRight DOM</td>
</tr>
<tr>
<td>Siemens</td>
<td></td>
<td>CAREDose 4D</td>
<td></td>
</tr>
<tr>
<td>Toshiba</td>
<td>SURE Exposure</td>
<td></td>
<td>**</td>
</tr>
</tbody>
</table>

*GE LightSpeed Pro scanners only
** Work in progress
### Methods to set AEC exposure level

- Different methods exist to define the exposure level using AEC systems

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Method for setting exposure level</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>‘Noise Index’ sets required image noise level</td>
</tr>
<tr>
<td>Philips</td>
<td>A ‘Reference Image’ is used, which has the desired level of image noise.*</td>
</tr>
<tr>
<td>Siemens</td>
<td>‘Equivalent mA’ set for standard sized patient</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Set required standard deviation (noise)</td>
</tr>
</tbody>
</table>

* new method based on reference mAs forthcoming
ImPACT cone phantom

- Conical Perspex phantom with elliptical cross section
- Based on ‘Apollo’ phantom developed by Muramatsu, National Cancer Centre, Tokyo
Cone phantom

- Images along length of phantom (AEC off)
Cone phantom

Coronal view

Sagittal view

z-axis AEC off

z-axis AEC on

Noise increases

Constant noise
Scan protocol

- **Standard conditions:**
  - 120 kV, approx 200 mA, 1 s or less rotation time,
  - wide collimation e.g. 20 mm, 5 mm slice, 45 cm reconstruction field of view

- **Scan along phantom with AEC off and on**
  - If possible select different features of AEC separately

- **Change exposure level** – increase desired standard deviation or reference mA

- **Look at effect of different kVs**

- **Change helical pitch and direction of tube movement**

- **Store DICOM images on CD**
Image analysis

- mA information retrieved from DICOM files
- Standard deviation (SD) and average CT number calculated at centre and edge of image using automatic analysis tool
- Region of Interest (ROI) size 2000 mm²
- Results analysed using Excel
Results from testing

- Aims of each AEC system are slightly different, so it is difficult to compare results
- In general, all systems successfully achieved their aims
- Following slides show a selection of the results, much more data has been gathered
Results: GE - axial

<table>
<thead>
<tr>
<th>Noise Index</th>
<th>mA</th>
<th>Mean SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEC off</td>
<td>200</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>10-783</td>
<td>4.4</td>
</tr>
<tr>
<td>10</td>
<td>10-783</td>
<td>11.0</td>
</tr>
<tr>
<td>15</td>
<td>10-500</td>
<td>18.0</td>
</tr>
<tr>
<td>20</td>
<td>10-280</td>
<td>27.3</td>
</tr>
</tbody>
</table>

Graph shows measured SD vs. AP phantom diameter (mm) for different noise indices (NI) and mA settings.
Results: GE - axial

- Tube current (mA)
- AP phantom diameter (mm)
- Auto mA OFF
- NI = 5
- NI = 10
- NI = 15
- NI = 20
Results: GE - helical

- Noise index 12, different helical pitch, table movement in and out of gantry
Results: Toshiba

- Data from RealEC on Aquilion 16
Results: Philips

- Mx8000 IDT has patient size AEC, and mA modulation

3 scans planned, at different z-axis positions, patient AEC off

3 scans, patient AEC on
Results: Siemens

- System does not aim to keep noise constant
  - Smaller patients may need better quality images
- Three ‘strengths’ of AEC
Know your AEC!

- Each AEC responds differently to changes in scan and recon parameters
  - Important to know how your system will react!

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Tube voltage</th>
<th>Rotation time</th>
<th>Helical pitch</th>
<th>Image thickness</th>
<th>Recon kernel</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>✓</td>
<td>✓</td>
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What is the is optimum AEC setting?

- Depends on the application
  - One body part may require different IQ levels depending upon clinical requirements
- How do we find this out?
  - Critical evaluation of image quality, feedback
  - Simulation studies
- Responsibility for manufacturer to develop good default protocol settings
What IQ or dose is needed?

Simulated dose: 0.9
Simulated dose: 0.8
Simulated dose: 0.7
Simulated dose: 0.6
Simulated dose: 0.5
Simulated dose: 0.4
Simulated dose: 0.3
Simulated dose: 0.2
Simulated dose: 0.15
Simulated dose: 0.1
Simulated dose: 0.075

Scanned dose: 1

Images courtesy Y. Muramatsu, NCC Tokyo
What do AECs give us?

• Lower patient doses than before?
  – Possibly, but this is by no means a foregone conclusion
  – It is possible to use AEC and give higher dose than previously
  – Keep monitoring $\text{CTDI}_{\text{vol}}$ and DLP – expect larger variations

• More consistent image quality?
  – Yes…

• The optimum image quality?
  – If they are used well
Conclusions

• AEC systems offer potential benefits for everyone
  – Radiologists: image quality consistent from patient to patient
  – Radiographers: consistent IQ for different sizes is now simple
  – Patients: potential for dose reduction, repeat exams less likely
  – Physicists: protocol optimisation is easier
• Users need to understand the systems
  – How does mA vary when changing slice thickness or kernel?
• The current systems work as intended, but there is opportunity for manufacturers to improve them further
  – Optimisation of scan protocols with AEC
  – A common method for defining image quality would be useful
  – Potential for AEC to control scan times and kV too
• ImPACT AEC report: www.impactscan.org/bluecover.htm
Challenges for manufacturers and users

• Optimisation of scan protocols
  – Work required to ensure that radiologists are getting good image quality, and patient doses are under control

• Standardisation of method to set exposure/IQ
  – A single method would aid comparison of scan protocols from many scanners or scanning centres

• Education of users
  – AEC users need to know the details of their system, how it differs from others