Using Automatic Exposure Control in Digital Radiography
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Automatic Exposure Control
- The purpose of AEC is to deliver consistent, reproducible exposures across a wide range of anatomical thicknesses, tube potentials, and users
- Detectors used in AEC systems include fluorescent screens with PMTs/photodiodes, ionization chambers, and possibly solid state detectors

AEC System Diagram

Fundamental AEC performance characteristics
- Initial acceptance testing
- Tube voltage
- Anode rotation
- Grid rotation
- Rectangularity, equal spacing
- Density correction
- Smear correction
- Slight variations do exist between cells and should be evaluated upon acceptance testing

Remember this
- Test your system at the SID for which the grid is focused and your system calibrated
- AEC detectors themselves have an inherent energy dependence
- Slight variations do exist between cells and should be evaluated upon acceptance testing

For example, Siemens Imaging systems with reciprocating grids. AEC builds themselves fail to test when tested at an SID of 115 cm. Moving the tube to an SID of 100 cm resulted in the test passing. Cause: Slight variations do exist between cells and should be evaluated upon acceptance testing.
Inter-cell differences exist

Density control

- Adjusts mAs upward or downward in increments of 25-30% per step
- Some newer DR systems do not incorporate this feature
- Published guidelines/recommendations
  - Tested for proper operation and similar step size (NCRP 99)
  - 0.15 to 0.30 OD per step (AAPM 79)
  - 4-step controller should adjust by 20-25% per step (AAPM 14)
- Fundamental differences from S/F: Absence of feature in some systems
  - Further, different systems will include this feature

Air kerma vs. sensitivity selection

- Many DR systems feature selectable ‘sensitivity’ settings for imaging protocols
  - Refers to AEC, not digital detector
  - These settings adjust the sensitivity of the AEC cells resulting in higher or lower image receptor exposures
    - Akin to using different speed screen/film combinations for different body regions – e.g. 200 speed for chest and 400 speed for general
  - While no regulations or guidelines exist, it is prudent to verify that exposure varies logically and predictably with selection
    - Inversely proportional

Air kerma vs. sensitivity

- Fundamental differences from S/F: Similar to screen selector setting
- Philips DR system – Phil Rauch
  - Resolution of EI is not sufficient to identify changes in sensitivity setting

\[
mAs_2 = mAs_1 \times \frac{S_2}{S_1}
\]
AEC Balance

- Field sensitivity matching
- To achieve consistent exposures, AEC cells should be balanced
- Manufacturers of x-ray systems use several different schemes for AEC balancing
- Thus, a one-size-fits-all test will not be valid if you work with a variety of systems
- Fundamental difference from S/F: Some manufacturers have changed schemes

Common AEC balance schemes

- 1 1
- 1.15 1.15
- 1
- 1

AEC Balance

- Test AEC balance during acceptance testing to set a baseline standard for balance
- Ask your service engineer about the calibration/balancing procedure
  - Many manufacturers today use AEC systems that are not serviceable for balance - they can only be replaced
  - Other manufacturers still have tunable AEC cells
  - Pots in generator
  - Software interlace
  - Pots in detector housing
- Published guidelines/recommendations
  - ±5% across all combinations (AAPM 14)

Backup timer

- In the case of a system malfunction or technical error, the exposure must be terminated after a certain period of time or delivered mAs
  - 500 mAs ± 100 mAs
  - 600 mAs ± 100 mAs
- Many digital radiography systems have preset time limits based on kVp and mA settings, and some will terminate if no signal is detected

Reproducibility

- K, delivered by the AEC system should be reproducible
- Published guidelines/recommendations
  - COV < 0.05 (AAPM 14)
  - ± 5% of average (NCRP 99)
- I’ll leave it as an exercise to prove that these guidelines do not say the same thing
Minimum exposure duration

- Thin or less dense body parts can lead to very short exposure times for AEC-controlled radiography.
- E.g., chest imaging, small patients
- AEC systems should be capable of delivering appropriate exposures at these exposure times

Published guidelines/recommendations

<table>
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<th>mm</th>
<th>keV</th>
<th>Ttmin</th>
<th>mAs</th>
<th>etc.</th>
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Conclusion: 0.43 mR required to achieve similar detectability for small low-contrast targets

Minimum exposure duration - DR

- However, for DR systems, some of which require less exposure than film/screen systems, this limit is insufficient.
- Typical PA view is 120 kVp and 180 mA 1-4 ms
- Most measurement equipment is incapable of measuring these extremely short times.
- kVp divider
- Spinning top
- Oscilloscope
- Acquire a series of images with a phantom that yields clinically relevant exposure times (1-10 ms).
- Examine exposure time in DICOM header
- Measure SNR in a uniform portion of the image
- COV < 0.05
- Also, it is very important to find the minimum response time (MRT) of your AEC/generator and ensure that your AEC exposure times do not fall below this time.

Use of a rating system based on degrees of mottle to determine what sensitivity number of a Fujifilm CR would be needed to match the mottle in a 600-speed s/f system, then use the actual sensitivity numbers measured to compare CR to s/f.

Conclusion: To achieve comparable mottle to 600-speed s/f system a threshold increase in exposure is needed as compared to mottle sensitivity number. An exposure consistent with a 300-speed s/f system would be needed to achieve negligible mottle.

AEC sensitivity

- Typically referenced to the center cell
- Manufacturer has calibrated the AEC system to the air kerma they believe their detector needs
- You may need to calibrate the AEC system to the air kerma you and your radiologists know the detector needs

AEC Sensitivity

- AEC system must be calibrated to deliver the necessary but sufficient Kaa to the image receptor
- Relatively simple task with screen/film imaging – achieve O.D. in linear portion of H+D curve (~ 1.4)
- Digital imaging is not contrast-limited, but noise limited
- How can you set up your AEC system to deliver the necessary amount of noise in an image?
- Functional difference from S/F:  Wide range of Kaa
- How can you set up your AEC system to deliver the necessary amount of noise in an image?
- Functional difference from S/F:  Wide range of Kaa

Compare indirect digital radiography and cassette-based digital radiography systems in terms of fundamental image quality metrics.

**Conclusion:** Indirect digital radiography detector has significantly higher DQE and lower NPS than cassette-based digital radiography detector. The magnitude of the differences is illustrated in the graphs from the manuscript.

**Caveats**

- Image processing has a large impact on noise (low-contrast detectability) and high-contrast resolution, and thus AEC sensitivity should be configured with this in mind.
- Also, pixel size has an impact on noise in images – this is especially important for digital receptors where pixel size is variable, such as PSP systems.

I have a confession to make…

- I have been using a very simplistic method of calibrating our AEC systems for sensitivity (cassette-based).
- Eight inch PMMA phantom imaged using 80 kVp.
- Processed with Sensitivity.
- S number used as indicator of proper calibration.
- Properly calibrated reader.
- DR – compare with acceptance testing data.
- It isn’t that easy.

Methods for calibrating sensitivity

- Noise-based method.
- K<sub>n</sub>-based methods:
  - Use a CR cassette with a cutout for a detector.
  - Solid-state detector behind grid.
  - Pre-detector K<sub>n</sub> and primary transmission through grid.
- Use an exposure indicator (EI).

A word on exposure indicators

- Sometimes the relationship between EI and detector exposure is well understood or intuitive.
  - Cassette-based digital radiography.
  - Sometimes the relationship between EI and detector exposure is not obvious/proprietary.
- Exposure indicator must be verified.
- Goldman AAPM Summer School.
Noise-based AEC calibration

- For each kVp, an S number can be associated with the standard deviation of pixel values that produce the desired noise characteristics
  - STDEV is proportional to the square root of the x-ray fluence absorbed in the IP (after correcting for structured noise)
- Recommend use of an SNR-based threshold for choosing noise level
  - Example: SNR\text{threshold} of 5 \rightarrow Signal difference of 50 can be seen with \sigma \leq 10
- Setting up AEC in Semi-automatic EDR mode yields clinically valid results in Automatic EDR mode


K_a-based methods

- CR cassette with cutout
- S = 200/E, E = exposure (mR) for Fuji CR
- Cutout machined into IP cassette to accept 15 cm pancake ionization chamber
  - Introduces realistic scatter from cassette, overcomes cassette sensing
  - Example: \text{SNR}_{\text{threshold}} of 5 \rightarrow Signal difference of 50 can be seen with \sigma \leq 10
  - Setting up AEC in Semi-automatic EDR mode yields clinically valid results in Automatic EDR mode


K_a-based methods

- Solid-state dosimeter with lead backing should be used to eliminate the effect of backscatter
- Not possible for all DR systems


Pre-detector K_a

- Simple measurement to make
- Scatter avoidable
- Necessitates measurement of primary transmission of anti-scatter grid
- Some inaccuracy introduced due to beam hardening by grid which is not accounted for in this measurement

Measuring grid characteristics

- Anti-scatter grids are labeled with information such as:
  - Line rate
  - Grid ratio
  - Intercaster material
  - Focus distance
- They are not, however, labeled with other information
  - Contrast improvement factor
  - Primary attenuation
- Fetterly/Schueler poster SU GG-153

180 cm focused grid measurement

Chamber 1
Chamber 2
Measuring the Bucky factor

- Rear chamber behind grid
- Entire setup
- A level grid is imperative
- Measurement w/o grid

Typical exposure readings
- Measuring for clinical grid

100 cm focused grid measurement

- Patient-equivalent phantom
- Chamber centered in field
- Support for grid
- Complete setup

Table

- Chamber centered in field
- Centering and leveling of grid is imperative

EI-based methods

- Once the EI has been verified to be accurate across the range of kVps and patient thicknesses used and seen clinically, it should be used to perform these tests
- EI verification involves some of the same skills and measurements discussed here
- More from Jeff Shepard coming up

You’re not done yet…
The Problem

- Many of our AEC systems have been calibrated for use with screen-film systems.
- The energy response of gadolinium oxysulfide (Gd$_2$O$_2$S) screens is substantially different from that of image receptors used in digital radiography.
- Thus, to properly expose digital radiographs, we must recalculate the kVp correction curve for our AEC systems to respond correctly considering the image receptor characteristics.

The Solution

- Beam-quality dependent calibration curves for AEC systems used for digital radiography.

- Doyle and Martin have calculated theoretical kVp correction curves for both CR and IDR detectors.
- Also note that the addition of small amounts of Cu filtration does not significantly affect the calibration.
The overall variation I have seen when kVp tracking and thickness tracking are combined is 25-30% for one vendor (60 kVp) and 15% for another vendor.

When considering the combined impact of kVp and thickness variation, there is likely to be less variation for digital radiography systems (SNR) than in S/F (O.D.) due to the fact that the variation in Bucky factor over a range of kVp’s no longer matters.

Methods to attempt to improve on patient thickness tracking might include:
- Further tightening kVp correction curve
- Calibrating with and using thin metal filters

What about phantoms?
- Simple, uniform phantoms are desired for AEC testing
- Also, consulting physicists probably don’t want to lug around 65 lbs. of PMMA – and engineers certainly won’t either
- But, what about realistic patient scatter…

Phantoms for AEC calibration
- Metal of the story: PMMA, water, and aluminum, in the appropriate amounts, deliver similar transmitted spectra to the AEC system and digital receptor
  - So did 0.2 mm of Cu, but fluence was too high to achieve reasonable exposure times. 2 mm of Cu significantly altered the transmitted spectrum
  - Introduction of scatter is a different situation

Scatter and AEC calibration
- Scatter does influence absolute calibration of AEC sensitivity, however, but does not have a large impact on the kVp correction curve
- Many manufacturers do adjust the sensitivity of the AEC system based on the presence/absence of the anti-scatter grid

Moral of the story: PMMA, water, and aluminum, in the appropriate amounts, deliver similar transmitted spectra to the AEC system and digital receptor

Scatter and AEC calibration
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Moral of the story: PMMA, water, and aluminum, in the appropriate amounts, deliver similar transmitted spectra to the AEC system and digital receptor
Future of Automatic Exposure Control in Radiography

- Fluoroscopy/angiography has already altered the way ADRC is performed
- Monitoring signal value in a region of pixels
- Detector is read many times per second
- These methods with TFT arrays do not work in radiography
- Detector readout is destructive
- Fischer stereo unit – CCD array (Tony Siebert)
- CMOS (Tony Siebert)
- Pixel architecture, with multiple transistors, allows for sampling without destroying the contained information

US Patent 5937027

- Thevenin B, Glasser F, Martin J-L, “Method and device for the taking of digital images with control and optimization of the exposure time of the object to X or g radiation,”
- Sobol W
- CCD array with two ‘classes’ of pixels
- Integrator/comparator
- Image corrected later

Other resources

- Sobol WT, Advances in and specifications for radiographic X-ray systems, pg. 1-68
- Goldman LW, Speed values, AEC performance evaluation, and quality control with digital receptors, pg. 271-297