Radiation Dose Reduction Strategies in CT, Fluoroscopy, and Radiography: Part 3. Radiography

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Radiation dose optimization

- What is the optimization criteria?
  - Figure of Merit:
    - $FOM = \frac{SNR^2}{dose}$
  - Minimum dose needed to achieve a target SNR
  - Maximum SNR possible for a given dose
- ALARA → minimize the dose to achieve a target SNR

How to measure dose in radiography

- Entrance skin dose
  - Calculated from exposure factors and radiation output data
- Dose (kerma) area project (DAP or KAP)
  - Calculated or measured
  - Often reported by radiography unit

How to establish target SNR

- Work with radiologists to determine the **EI** that achieves:
  - Acceptable image quality (low contrast detectability and noise)
  - For each body part/view
  - For the image receptor in use
- Enter those EI values into the CR/DR acquisition computer(s) as the Target EI (EI_T)

IEC Standard Exposure Indicators for Digital Radiography

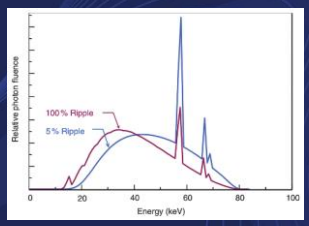
- Exposure Index, EI
  - $EI = K_{cal} \times 100\ \mu Gy^{-1}$ *(unitless)*
  - Proportional to Air-kerma (exposure) at the receptor
- Deviation Index, DI
  - $DI = 10 \times \log_{10}(EI/EI_T)$
  - How close did we come to the target?

Once target EIs are established to achieve the target SNR, you can work on minimizing dose

Minimizing dose in General Radiography: Factors to consider

- X-ray source
- Beam filtration
- Collimation
- Patient positioning and instruction
- Scatter control
- Image Receptor
- Automatic Exposure Control
- Image post-processing
- Exposure management
- Repeat/Reject Analysis

Effect of x-ray source on patient dose: Generator waveform



X-ray generator / exposure control

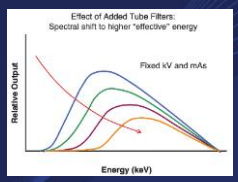
- Verify:
  - kVp accuracy
  - Exposure reproducibility
  - Timer accuracy
  - mA linearity
  - mAs linearity
- Experiment with higher kVps

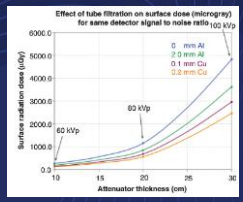
Effect of beam filtration

- For 9 common radiographic projections, increasing total filtration to from 1.5 to 4.0 mm Al while holding kVp and exit dose fixed, avg effective and skin entrance doses were reduced by 17% and 38%, respectively.
- Adding 1 – 1.5 mm Al filtration beyond the 2.5 mm regulatory minimum does not pose problems for tube loading or image quality (based on screen-film image receptor).

Behrman, Yasuda. Effective dose in diagnostic radiology as a function of x-ray beam filtration for a constant exit dose and constant film density. Med Phys 25, 780 (1998).

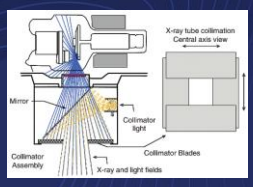
Effect of beam filtration





Bushberg et al. Essential Physics of Medical Imaging, 3rd Ed. 2012

Collimation



Bushberg et al. Essential Physics of Medical Imaging, 3rd Ed. 2012
AMX-4 aperture photo courtesy Charles Willis PhD

Collimation

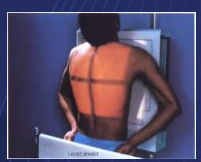
- Use the smallest practical field of view
  - Reduces the patient's integral dose (total energy imparted)
    - Reflected in DAP/KAP
  - Reduces scatter / improves CNR
- Ensure that light field = radiation field (≤2% of SID)
- Caveats
  - Beware of "cutting off" anatomy
    - May require a repeat → more exposure
  - Beware of "cutting off" an AEC sensor
    - May inadvertently increase the central ray exposure

Patient positioning and instructions

- Use maximum practical source-image distance (SID)
- Align image receptor to radiation field
- Maximize source-skin distance (SSD)
- Use the highest practical kVp
- Use contact/shadow shields
  - Protect radiosensitive organs in or near the primary beam
    - Thyroid
    - Breasts
    - Bone marrow
    - Lens
    - Gonads
- Verbal communication
  - Hold still
  - Hold breath

Patient positioning and instructions

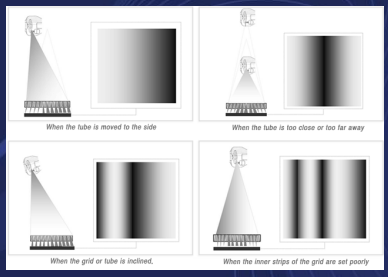


Scatter control

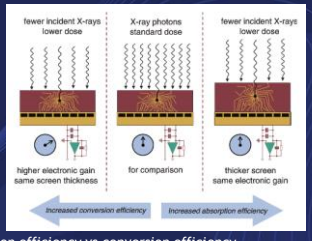
- Grid selection
  - High Grid Ratio
    - Better scatter cleanup (Contrast Improvement Factor)
    - Higher dose (Bucky factor)
  - High grid frequency
    - May be necessary to avoid aliasing (Moire interference patterns)
    - Higher l/cm gives means thinner (lower CIF) at a given grid ratio
- Grid usage
  - Proper alignment
  - Dilemma of 40”-72” focal length grid
  - Use lower ratio grid when SID can vary

Grid cutoff



http://www.jpi.co.kr/korean/03_technical_information/book_grid.html

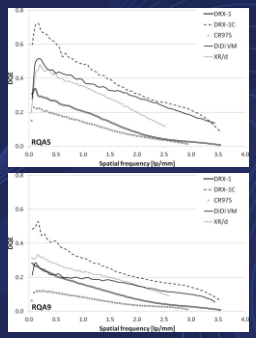
Image receptor



Absorption efficiency vs conversion efficiency
Absorption allows dose reduction for same SNR
Conversion allows dose reduction but reduced SNR

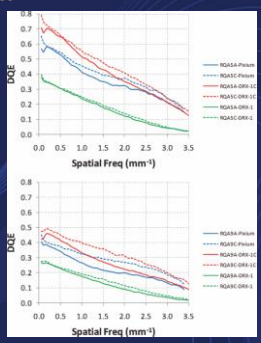
Bushberg et al. Essential Physics of Medical Imaging, 3rd Ed. 2012

Image receptor



Bertonlini et al. Med. Phys. **39**, 2617 (2012)

Image receptor

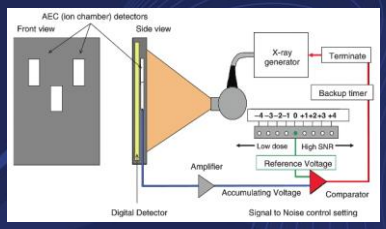


Samei E, Murphy S, Christianson O. Medical Physics 40, 081910 (2013).

Image Receptor

- Higher DQE image receptors allow a given SNR to be achieved at lower dose, all else being equal

Automatic Exposure Control



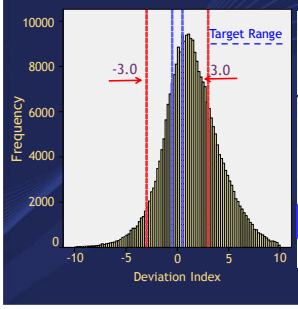
Bushberg et al. Essential Physics of Medical Imaging, 3rd Ed. 2012

Exposure Management

DI change of 1 corresponds to 1 mAs "station" (Renard Series; ISO R'10)

DI value	Change in exposure
3	x2
2	x1.6
1	x1.3
0	1
-1	x0.8
-2	x0.6
-3	x0.5

Example DI Analysis



Mean ± Standard Deviation	1.4 ± 2.7
Median	1.3
Skewness	0.04
Kurtosis	0.51

DI Range	% of cases
Above +3	26
0.6 to 3.0	37
-0.5 to 0.5	14
-3.0 to -0.6	18
Below -3	5

Dave JK, Gingold EL. RSNA 2013

EI/DI analysis should be performed regularly and results reviewed with staff to ensure that dose optimization goals are being achieved.

Repeat/Reject Management

Repeated/Rejected Images

- Unnecessary radiation exposure to patient
- Inefficiency in imaging operation
- Unproductive use of time and resources

But …

- An inherent and unavoidable part of radiography

Need for reject analysis in CR/DR

- Because of the ease of repeating an exposure, the repeat rate may be higher for digital than screen/film
- Without physical evidence, not conducting a reject analysis may allow a quality problem to go undetected
- → The need for reject analysis is greater than ever

Reports of digital repeat/reject analysis

Table 2. Number of Rejected Images According to Reason for Rejection

Reason for rejection	Number of rejects	Percentage of rejects
Positioning	4,639	77.3
Exposure Error	588	9.8
None	571	9.5
Artifact	100	1.7
Test Images	54	0.9
Patient ID	50	0.8
Totals	6,002	100

Jones et al, Journal of Digital Imaging, Vol 24, No 2 (April), 2011: pp 243-255

Targets and investigation levels

- CRCPD "QA Collectible" (Oct 2009)
  - Recommend <10%
- AAPM TG 151 (2014?) recommendations
  - 8% = overall target reject rate
  - 10% = upper threshold for investigation & possible corrective action
    - Pediatric: 5% target, 7% threshold for investigation
  - 5% = overall lower threshold
    - Low reject rate may reflect acceptance of poor quality images, poor compliance with minimum quality standards

Conclusion: Take-home points

- Use the highest DQE image receptor that you can afford
- Establish Target Exposure Index (EI_T) values carefully
- Calibrate AEC to achieve Target EI
- Use the correct grid
- Review EI statistics regularly, and re-educate staff
- Analyze Repeat/Reject statistics regularly, and review with staff
- Compare measured entrance doses with reference levels

Which image receptor characteristic will reduce radiation exposure in digital radiography?

23%	1. A photoconductive x-ray converter
10%	2. Higher electronic gain
23%	3. Higher absorption efficiency
23%	4. Less electronic noise
20%	5. An integrated anti-scatter grid

According to the forthcoming AAPM TG 151 report, a reasonable target repeat rate for digital radiography is:

20%	1. 3%
17%	2. 5%
17%	3. 8%
13%	4. 10%
33%	5. 12%

Which parameter must be proactively configured in CR/DR workstations in order for DI to behave as intended?

17%	1. K_{cal}
27%	2. EI
17%	3. DI
13%	4. EI_T
27%	5. $\log_{10}$

Jefferson
HEALTH IS ALL WE DO

SAM questions: Correct answers and references

- #1:
  - 3 Higher Absorption Efficiency
  - Ref: Bushberg et al. Essential Physics of Medical Imaging, 3rd Ed. 2012
- #2:
  - 3 8%
  - AAPM Report #151 (2014)
- #3:
  - 4 EI_T
  - AAPM Report #116 (2009)