Standardized Exposure Index for Digital Radiography – Technical Issues

International Congress of Medical Physics
Brighton, England
2013

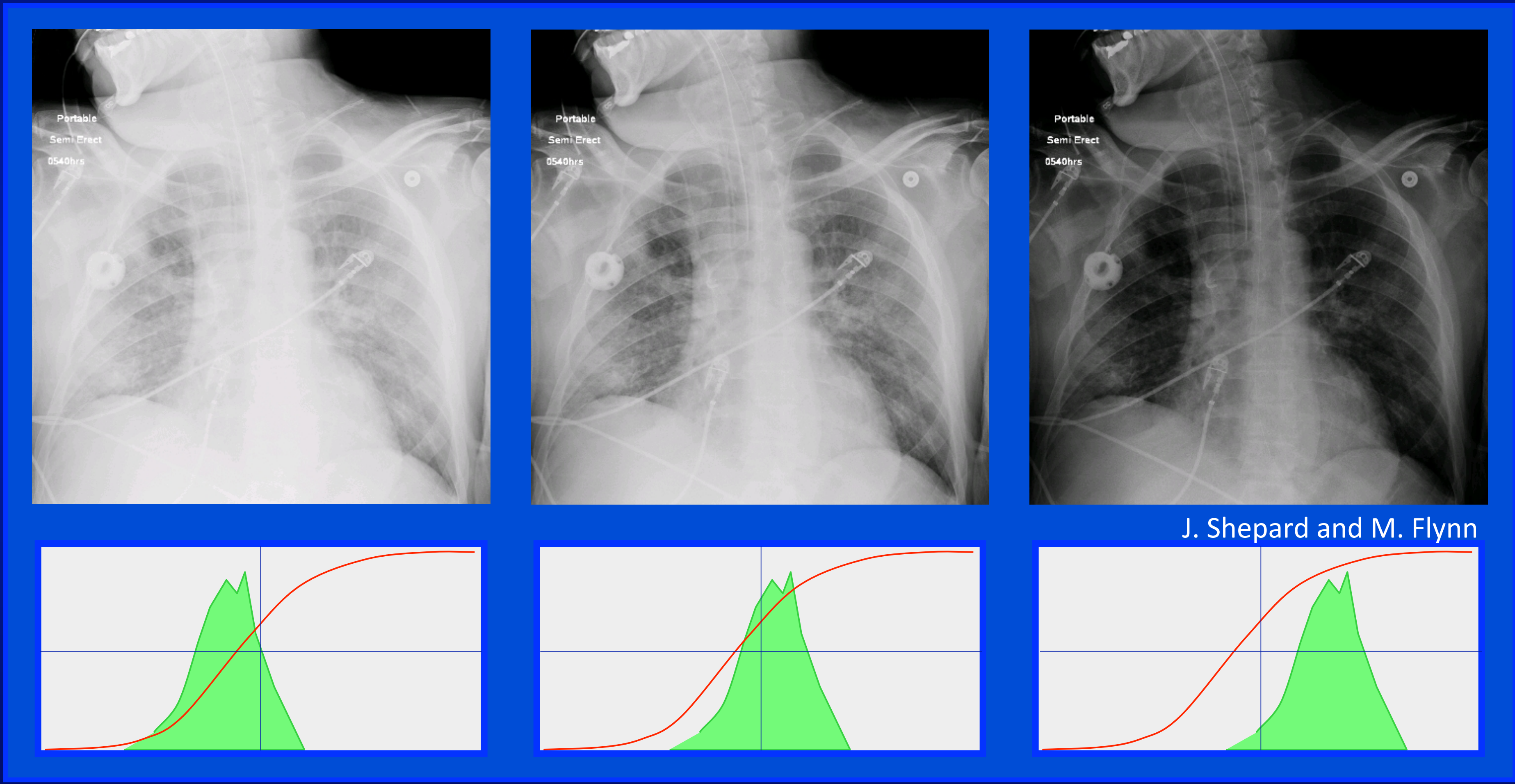
J.A. Seibert, Ph.D.
Department of Radiology
UC Davis Medical Center
Sacramento, California

The Issues

- CR & DR systems have variable speed, wide dynamic range, and internal signal scaling
- Consistent (and often inconsistent) image appearance eliminates exposure feedback loop
- There is no direct link between image appearance and detector “speed class”
- Overexposures can easily be unnoticed, resulting in needless overexposure to the patient
- Underexposures have increased image noise that can reduce diagnostic accuracy

Screen-Film system indicators

Traditional screen-film systems use overall film density as an exposure indicator

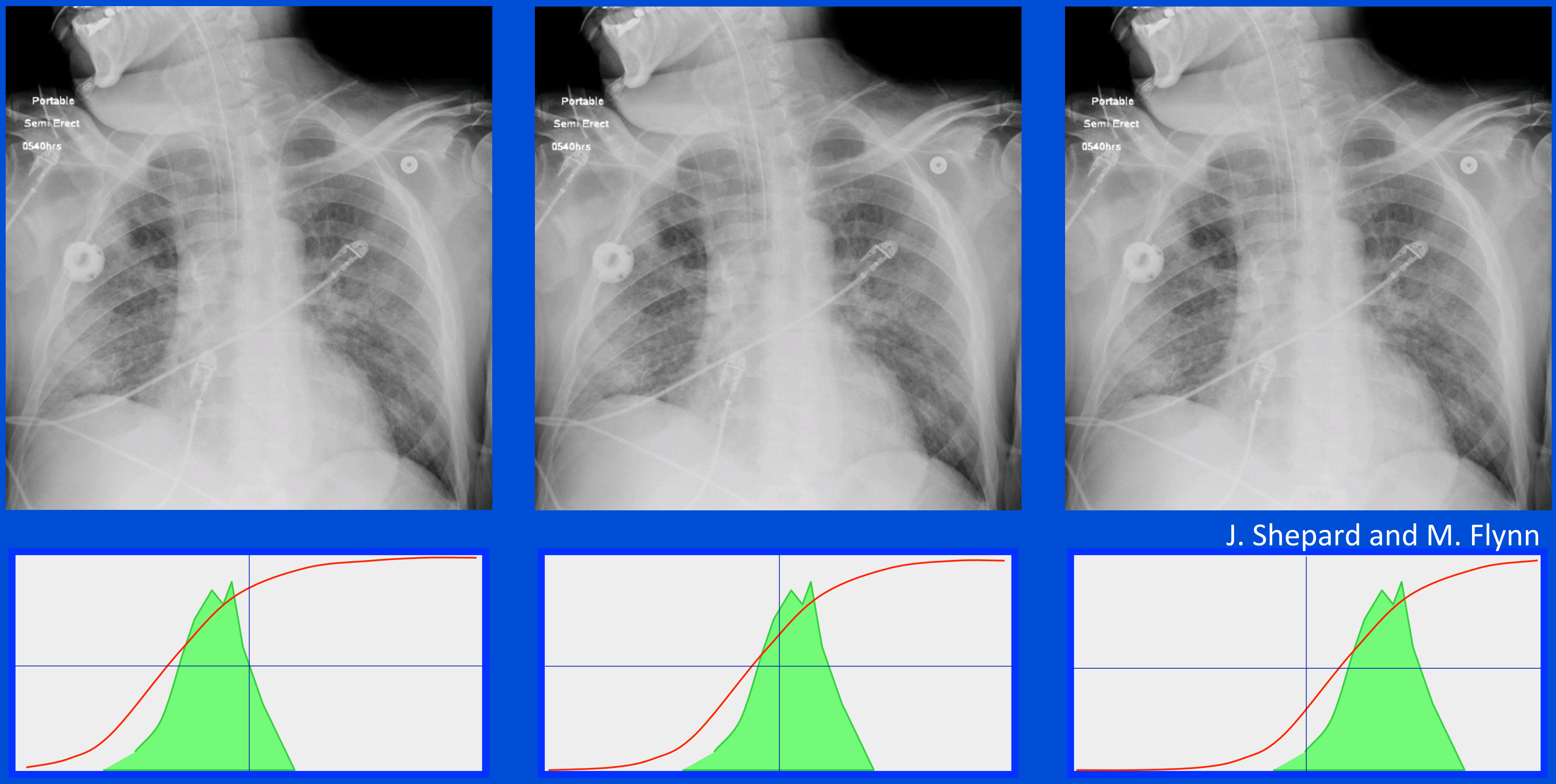


J. Shepard and M. Flynn

➡ Direct feedback to the technologist regarding exposure

CR & DR system indicators

CR & DR systems use image processing to align the grayscale with the signals



J. Shepard and M. Flynn

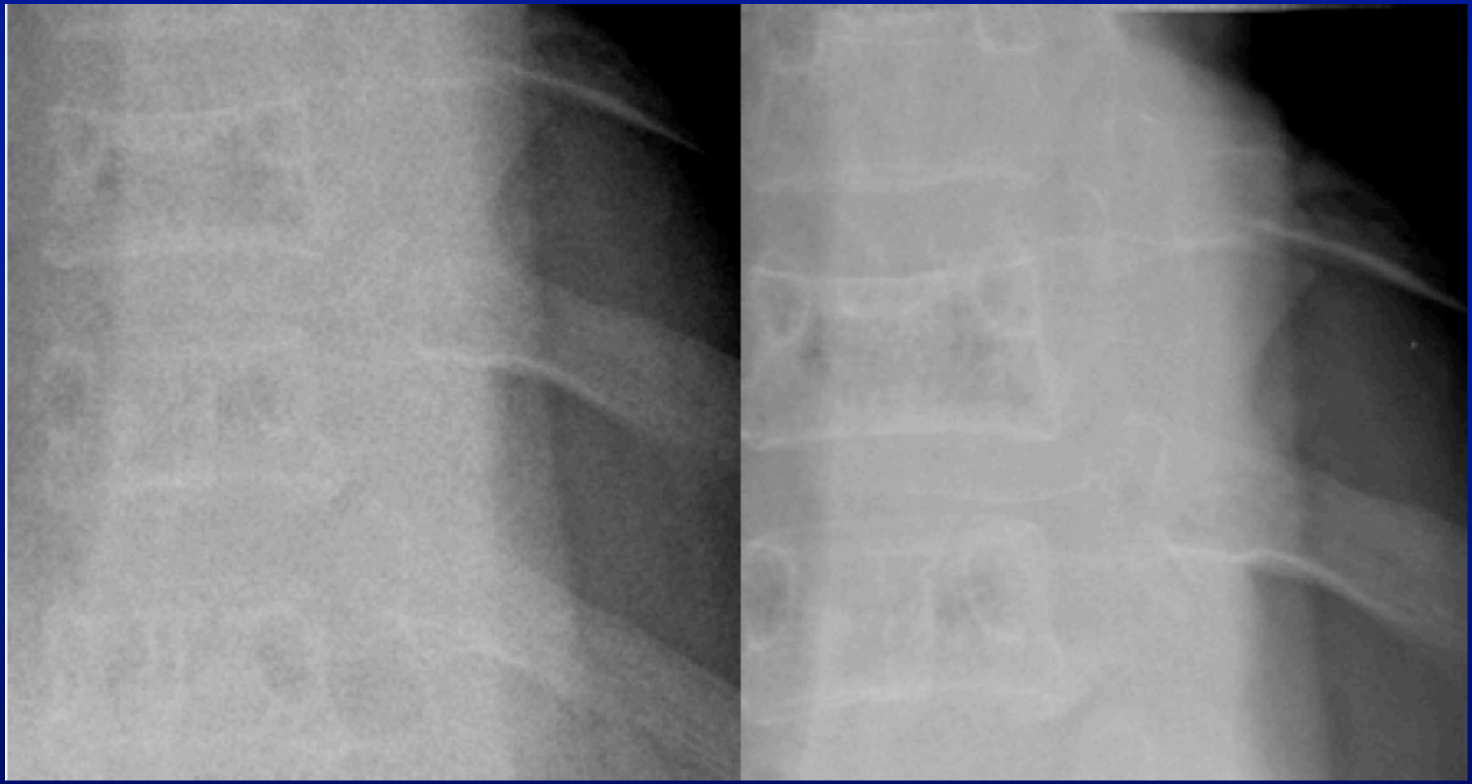
Direct visual cues (dark/light) are lost regarding exposure

Noise

The image processing adjusts the grayscale, however;

- Images with low signals are noisy *and*
- Images with high signal are associated with high dose

Exposure Indicators describe image quality in terms of the signal to noise ratio (SNR)



Underexposed, low SNR | Overexposed?, high SNR

Exposure Indicators

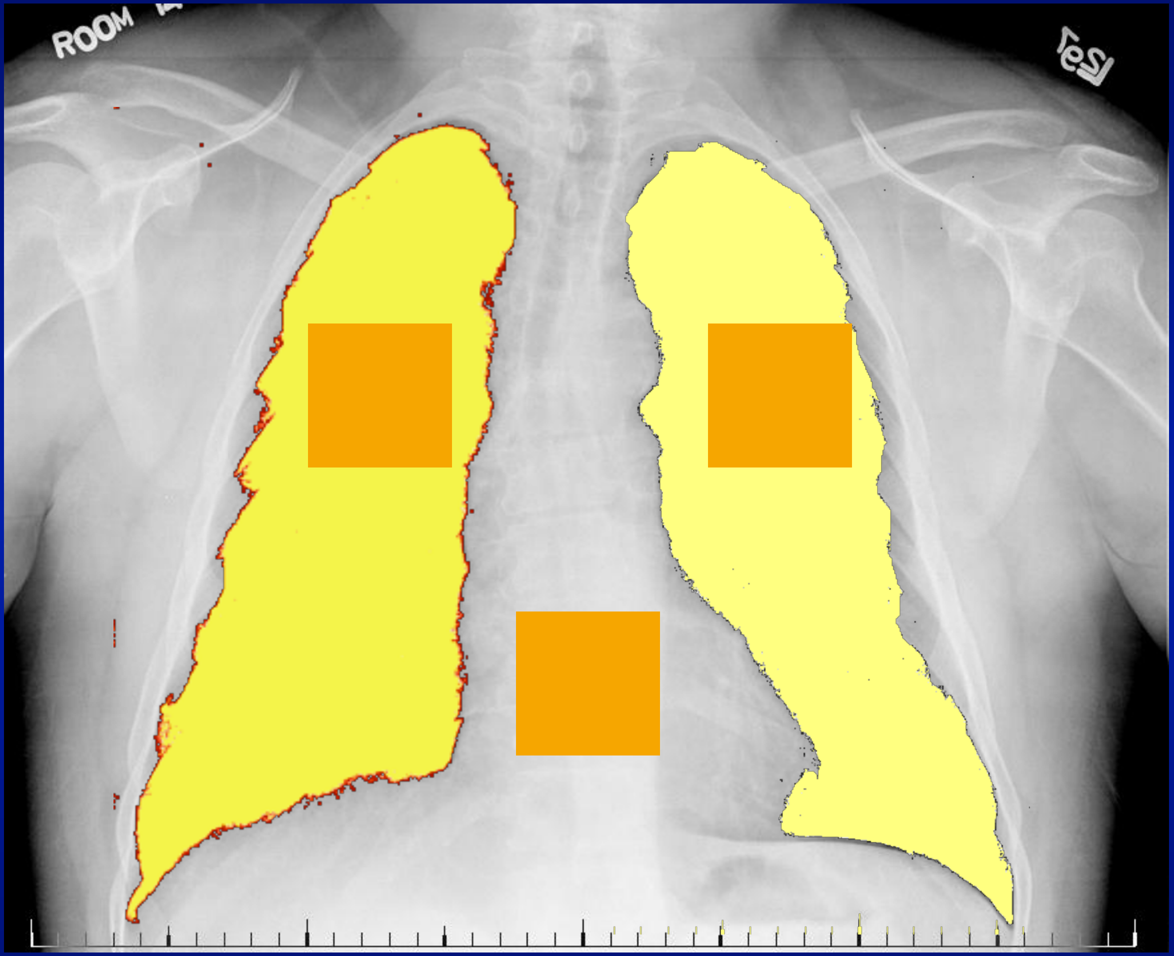
CR and DR systems assess the recorded signal to indicate whether the radiographic technique used is appropriate

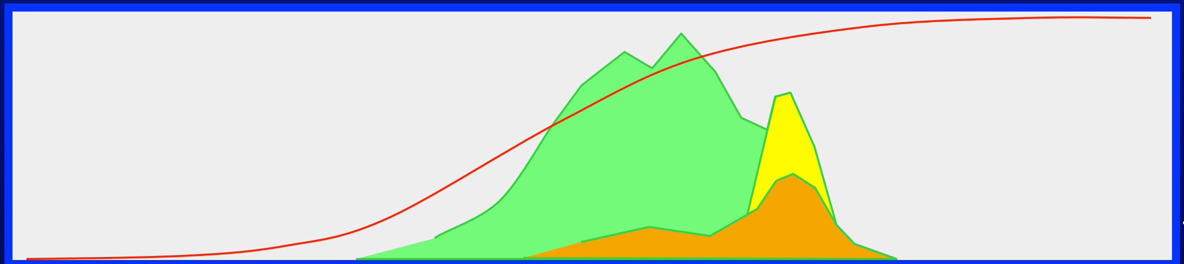
- Tests with defined beam conditions are used to verify that correct indicators are being reported
- Recommended exposure indicator ranges are used by technologists to check each radiographic exposure

Region to assess signal indicator

Systems vary in the region used to assess the signal for an image.

- Full Image
- Regular regions
- Anatomic regions



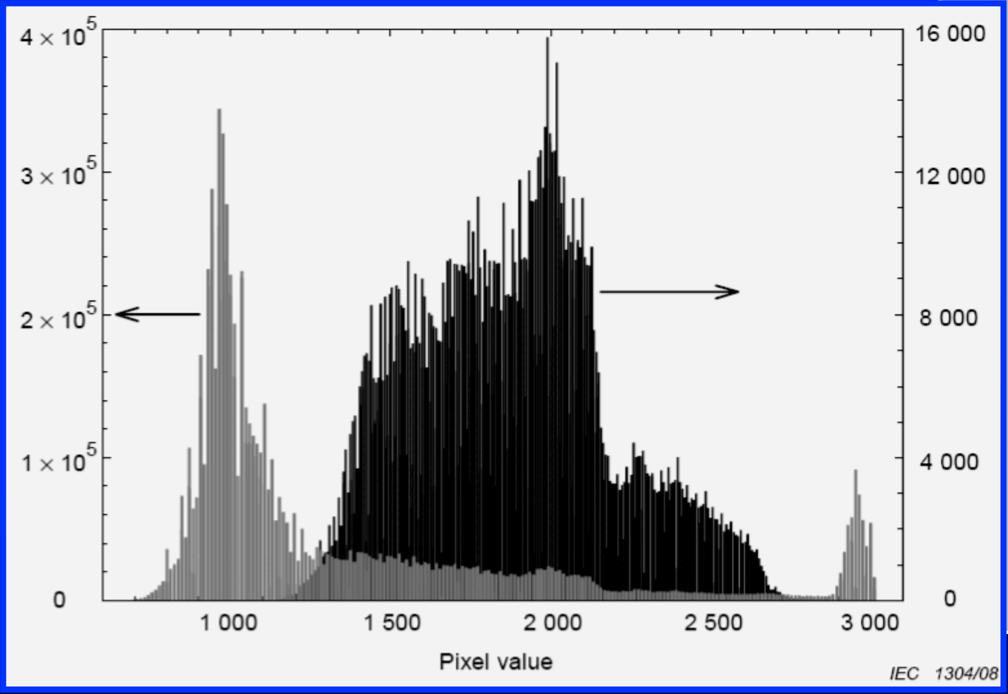


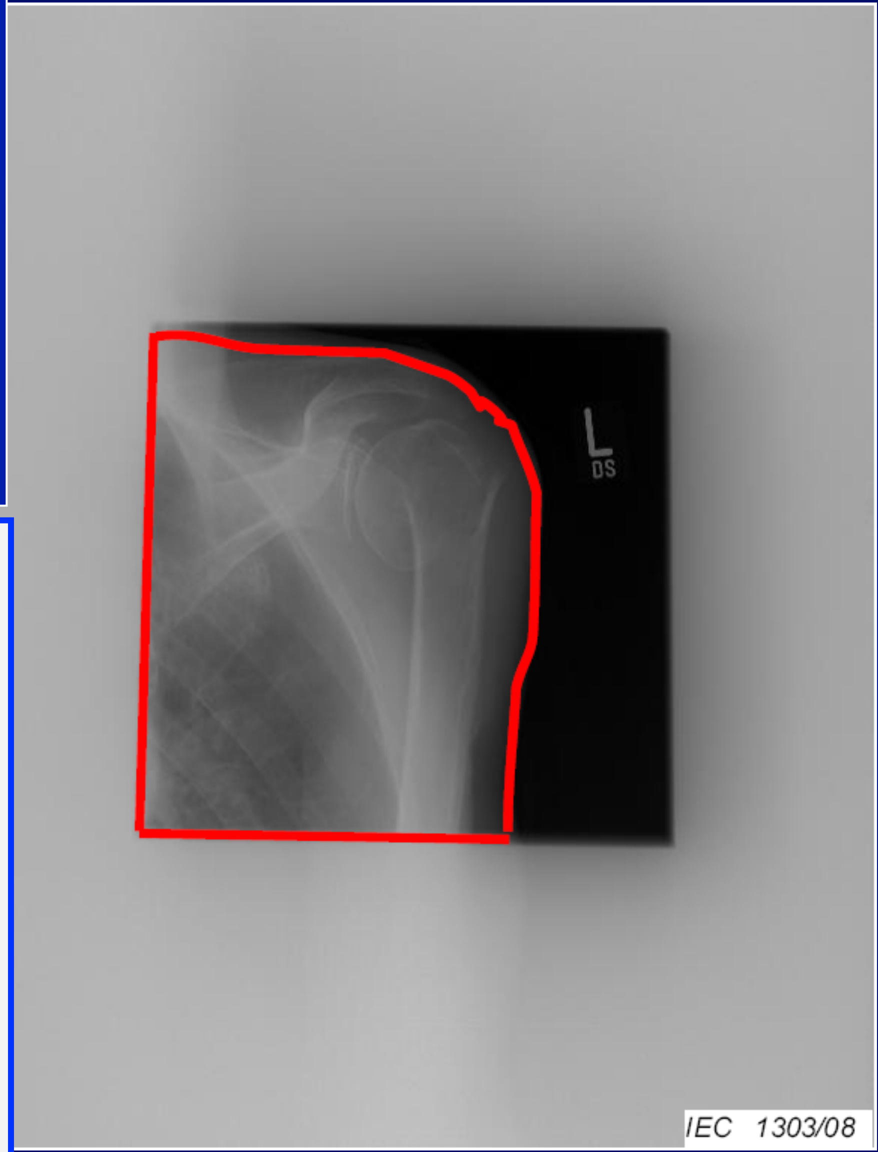
J. Shepard and M. Flynn presentation

Region to assess signal indicator

IEC 62494-1

- Gray histogram for the entire image
- Black histogram for the anatomic region (relevant region)





Computation of an exposure indicator

…. typically computed from the probability distribution of signal values that are determined in the relevant image region, using a recognized statistical method (e.g., median)

Manufacturers have adopted *proprietary* methods

- Algorithms, values, and calibration methods are widely different, leading to confusion amongst users
- Inappropriate image segmentation or histogram 'values of interest' range can produce inaccuracies

Summary of manufacturer Exposure Indices

Manu-facturer	Indicator Name	Symbol	Units	Exposure Dependence	Calibration Conditions
Fujifilm	S Value	S	Unitless	200/S ∝ X (mR)	80 kVp, 3 mm Al "total filtration" S=200 @ 1 mR
Kodak	Exposure Index	EI	mbels	EI + 300 = 2X	80 kVp + 1.0 mm Al + 0.5 mm Cu EI = 2000 @ 1 mR
Agfa	Log of Median of histogram	lgM	bels	lgM + 0.3 = 2X	for 400 Speed Class, 75 kVp + 1.5 mm Cu lgM=1.96 at 2.5 μGy
Konica	Sensitivity Number	S	Unitless	for QR = k, 200/S ∝ X (mR)	for QR=200, 80 kVP S=200 @ 1 mR
Canon	Reached Exposure Value	REX	Unitless	Brightness = c_1, Contrast = c_2, REX ∝ X [1]	for Brightness = 16, Contrast = 10, REX ≈ 106 @ 1 mR[1]
Canon	EXP	EXP	Unitless	EXP ∝ X	80 kVp, 26 mm Al HVL = 8.2 mm Al DFEI = 1.5 EXP = 2000 @ 1 mR

[1] From empirical data

Summary of manufacturer Exposure Indices

Manu-facturer	Indicator Name	Symbol	Units	Exposure Dependence	Calibration Conditions
GE	Uncompensated Detector Exposure	UDExp	µGy Air KERMA	UDExp ∝ X (µ Gy)	80 kVp, standard filtration, no grid
GE	Compensated Detector Exposure	CDExp	µGy Air KERMA	CDExp ∝ X (µ Gy)	
GE	Detector Exposure Index	DEI	Unitless	DEI ≈ 2.4X (mR) [1]	Not available
Swissray	Dose Indicator	DI	Unitless	Not available	Not available
Imaging Dynamics Company	Accutech	f#	Unitless	$2^{f\#}=X(mR)/X_{tgt}(mR)$	80 kVp + 1 mm Cu
Philips	Exposure Index	EI	Unitless	100/S ∝ X (mR)	RQA5, 70 kV, +21 mm Al, HVL=7.1 mm Al
Siemens Medical Systems	Exposure Index	EXI	µGy Air KERMA	X(µGy)=EI/100	RQA5, 70 kV +0.6 mm Cu, HVL=6.8 mm Al
Alara CR	Exposure Indicator Value	EIV	mbels	EIV + 300 = 2X	1 mR at RQA5, 70 kV, +21 mm Al, HVL=7.1 mm Al => EIV=2000
iCRco	Exposure Index	none	Unitless	Exposure Index ∝ log [X (mR)]	1 mR at 80 kVp + 1.5 mm Cu => =0

Approximate EI Values vs. Receptor Exposure

Manufacturer	**Symbol**	**5 μGy**	**10 μGy**	**20 μGy**
Canon (Brightness =16, contrast = 10	REX	50	100	200
IDC (S_T = 200)	F#	-1	0	1
Philips	EI	200	100	50
Fuji, Konica	S	400	200	100
Kodak (CR, STD)	EI	1700	2000	2300
Siemens	EI	500	1000	2000

….. The need for a standard clearly evident

Standardization

- American Association of Physicists in Medicine Task Group 116 and International Electrotechnical Commission (IEC)
- Collaborative effort
  - Physicists
  - Manufacturers/Vendors representatives
  - MITA (Medical Imaging and Technology Alliance)
- Develop common "Exposure Indices" and "Deviation Indices" across detectors and manufacturers/vendors
- Provide means for placing data in DICOM metadata

AAPM TG 116

The AAPM TG 116 report on exposure indicators was published in July of 2009

An exposure indicator for digital radiography: AAPM Task Group 116 (Executive Summary)

S. Jeff Shepard[a] and Jihong Wang
Imaging Physics Department #056, Division of Diagnostic Imaging, University of Texas M. D. Anderson Cancer Center, 1515 Holcombe Boulevard, Houston, Texas 77030

Michael Flynn
Department of Radiology, Henry Ford Health System, Radiology Research 2F, 1 Ford Pl., Detroit, Michigan 48202

Eric Gingold
Department of Radiology, Thomas Jefferson University Hospital, 132 South 10th Street, Philadelphia, Pennsylvania 19107

IEC Standard

IEC published a standard for Exposure Index definitions in August of 2008

IEC

IEC 62494-1

Edition 1.0 2008-08

INTERNATIONAL STANDARD

**Medical electrical equipment – Exposure index of digital X-ray imaging systems –
Part 1: Definitions and requirements for general radiography**

Description of Exposure Indices Parameters

	AAPM TG116 Med Physics 2009	IEC 62494-1 IEC:2008
Exposure Index	Air-kerma at the receptor $K_{IND} = K_{CAL}$ (µGy)	$EI = K_{CAL} \times 100\ \mu Gy^{-1}$ (unitless)
Calibration Energy	RQA-5 66 - 74 kVp	RQA-5 66 - 74 kVp
Calibration Filtration	RQA-5 Equivalent 0.5 mm Cu (+ 0-3 mm Al) or 21 mm Al 6.8 ± 0.2 mm Al HVL	RQA-5 Equivalent 0.5 mm Cu + 2 mm Al or 21 mm Al 6.8 ± 0.3 mm Al HVL
Deviation Index	Deviation Index $DI = 10*\log_{10}(K_{IND}/K_{TGT})$	Deviation Index $DI = 10*\log_{10}(EI/E_T)$
DI format	Signed decimal string with 1 decimal point	Unspecified

Exposure Indices

Deviation Index (DI)

$$DI = 10 \times Log_{10}\left\{\frac{EI}{EI_T(b.v)}\right\}$$

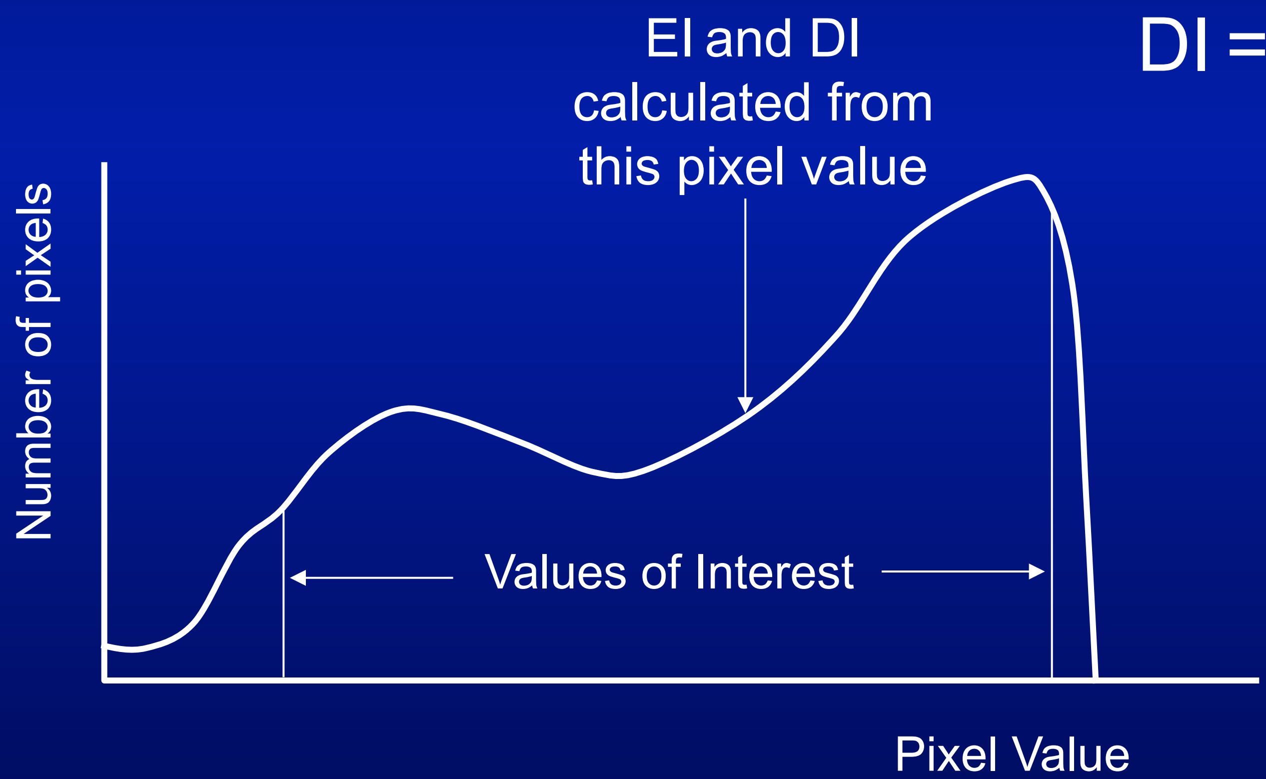
- EI_T is a target index value that is to be determined for each body part *b*, view *v*, procedure type, and clinical site
- When *EI* equals EI_T, $DI = 0$
  - *DI = +3.0* for 2x target exposures
  - *DI = -3.0* for ½ target exposure
  - ± 1 is one step on a standard generator mAs control or AEC compensation (ISO R5 scale)

Need to have robust methods of determining DI

What about VOI modification by the technologist?

$EI = EI_T$

$DI = 0.0$



Need robust methods of determining EI & DI

VOI recognition algorithm fails

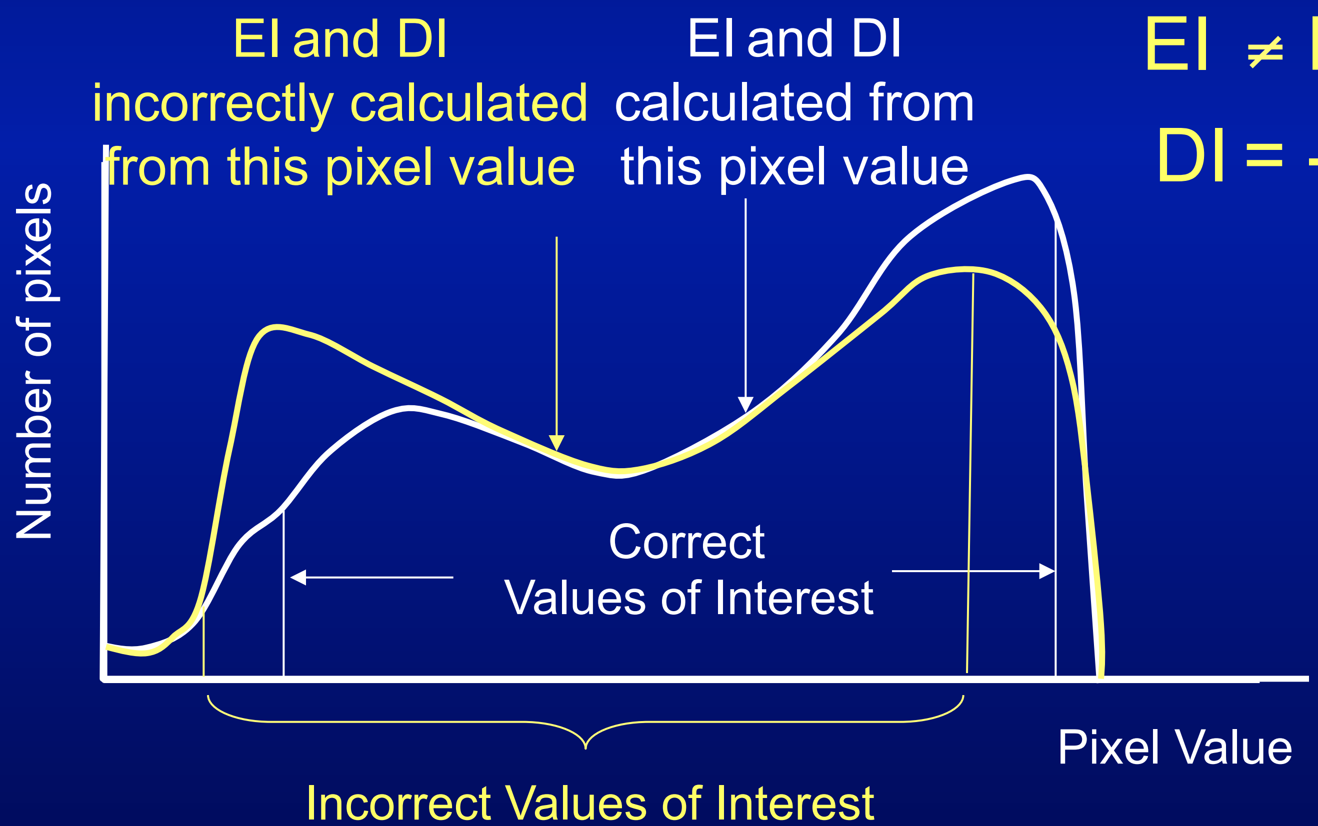
- Gonadal shields, prosthetics, etc.
- False DI reported

$EI = EI_T$

DI = 0.0

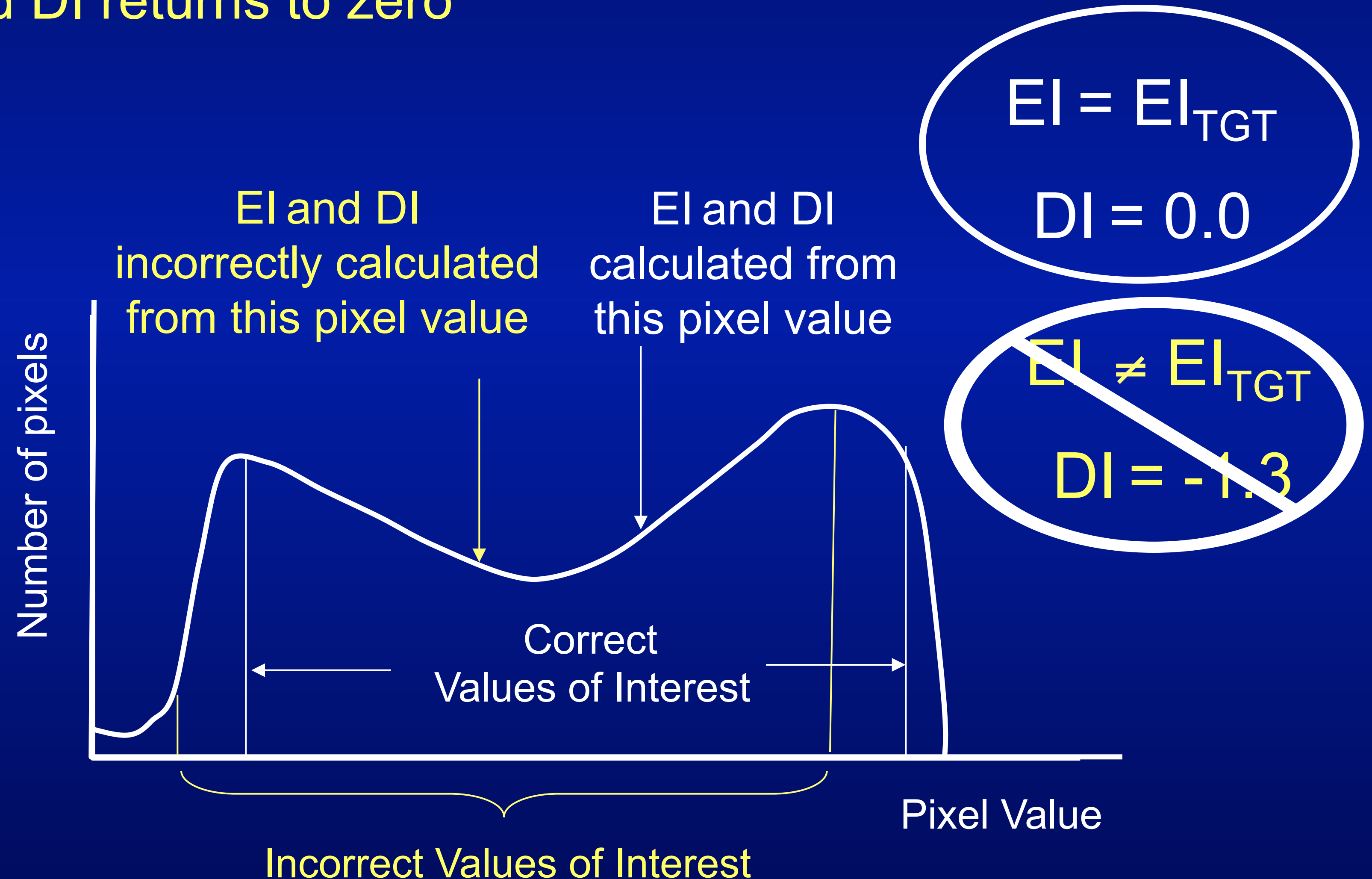
$EI \neq EI_T$

DI = -1.3



Need robust methods of determining EI & DI

Tech adjusts VOI for proper grayscale rendition manually, and DI returns to zero



Need to determine recommendations for repeats

- DI target is -2.0 to +2.0
- Check for noise. Consult with radiologist on need for repeat if EI is ≤ 63% of target (DI≤ -2)
- Investigate cause (do not repeat) if EI is between 160% and 200% of target (+2.0 ≤ DI ≤ +3.0)
- Consult with radiologist (check for saturation) on need for repeat and counsel of technologist if EI is ≥200% of target (DI ≥ +3.0)

IEC 62494-1: Target Exposure Index EI_T

- EI_T may depend on detector type, examination type, diagnostic question and other parameters
- Establishing target exposure index values needs medical knowledge – may be done by professional societies
- EI_T values should be provided as a data base in the digital imaging system

Ulrich Neitzel
Project Leader,
Convenor IEC SC62B WG 43

Caveats

- The EI does not describe patient dose
  - EI is derived from detector signal (dose at the detector)
- The EI is not a dose measurement tool
  - Dose calibration only valid at one radiation quality
- Images with same EI obtained on different digital systems might not have similar image quality
  - Influence of detector DQE, scattered radiation, beam quality differences

Ulrich Neitzel

Project Leader,

Convenor IEC SC62B WG 43

Exposure Index & Deviation Index monitoring

- Collect EI and DI for every image and analyze
  - By technologist
  - Technique factors
  - X-ray system
  - Plate scanning unit (CR)
  - Processing unit (CR - DR)
  - Anatomical view

- Longitudinal studies
  - Track performance over time
  - Mean and Standard Deviation of EI and DI
  - Watch for trends upward (Dose Creep)

Consensus goals

- To adopt IEC standard 62494-1
- To determine “appropriate” EI_T values for pediatric exams as correlated to digital detector types and optimized SNR…. How?
- To set “allowable” DI range as suggestions for “appropriate” exposure
- To mandate methods for capturing and tracking EI and DI values for trend analysis

Consensus goals

- To address AEC calibration for procedures and patient attributes amenable to AEC use
- To acquire kVp, mAs, beam filtration (HVL), and tube output data per study, for patient dosimetry evaluation when possible
- To request manufacturers to provide on-line training and continuing education materials regarding the practical use of EI & DI

Calculation of Patient Dose

- Technique factors
  - kV, mA, time, added filtration
- Calibration factors
  - HVL at kV, output (mGy/100 mAs), focal spot
- Geometric factors
  - SID, OID, collimation,
- Anatomic factors
  - Area irradiated, patient attributes, shielding

Dose estimation

- Entrance skin air kerma
  - Reference point AK, KAP
  - Tube output determination
- Monte Carlo photon transport
  - PCXMC or similar program
  - Area, beam HVL, kV, mAs

Radiography DICOM RDSR

- New radiography efforts

Example calculation and reference to exposure index

American College of Radiology Dose Index Registry

- CT is now underway…….

- Radiography is the next input
  - Reference doses
  - Comparative data

Conclusions

- Digital radiography devices have enabled robust patient dose tracking
- Active acquisition technologies provide technical factors for the study
- Patient size and habitus metrics are needed as input for dose estimates
- Exposure indices assist the radiographer in ensuring proper techniques with feedback
- Radiation dose levels appropriate for the exam enhance patient safety and care