AAPM 2014 Annual Meeting
Best Practices in Pediatric Imaging

Exposure Factor Control in Pediatric Projection Radiography

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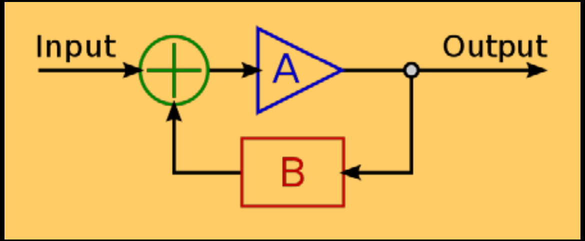
Learning Objectives:

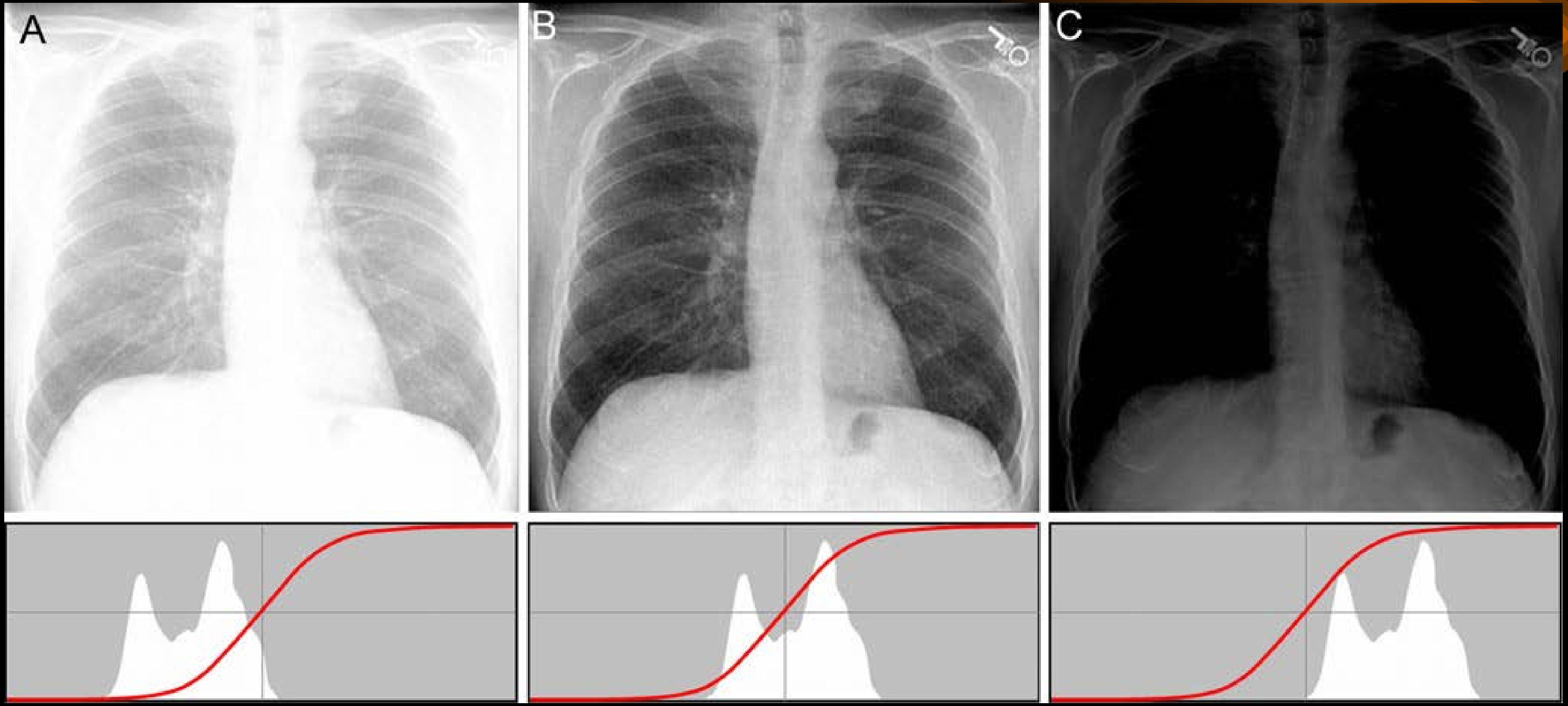
- Appreciate why exposure factor control is necessary in pediatric projection radiography using CR and DR.
- Identify the meaning of vendor-specific receptor exposure indicators and the new standardized receptor exposure indicators, and their indirect relationship to patient dose.
- Explain how general radiographic techniques can be optimized using exposure indices to improve pediatric radiography.

Introduction

- Both Computed Radiography (CR) and Digital Radiography (DR) are capable of producing acceptable diagnostic quality images over a wide range of exposures.
- Control of acquisition exposure factors is necessary in order to manage the concomitant radiation dose to patients undergoing projection radiography examinations.
- Control requires both measurement of the output and feedback to the operator to modify the input.

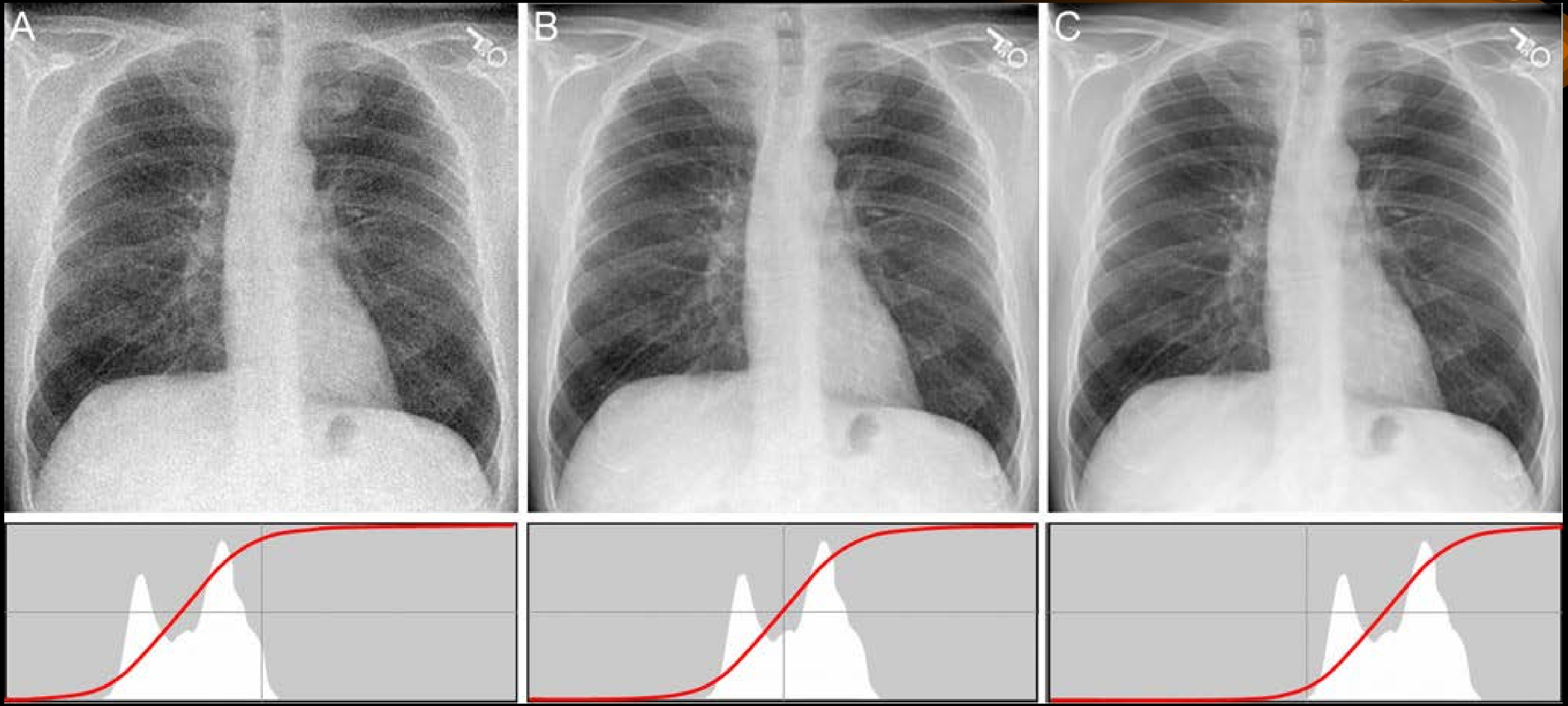


Without Auto-ranging



Seibert and Morin, Pediatr Radiol (2011) 41:573-581

With Auto-ranging



Seibert and Morin, Pediatr Radiol (2011) 41:573-581

Exposure factor creep occurs in CR and DR

- A gradual increase in exposure factor selection by technologists is observed over time.
  - *Under-exposed CR and DR images look noisy, and are likely to be rejected by radiologists.*
  - *Over-exposed CR and DR images look less noisy, and are less likely to be rejected by radiologists.*
  - *Because CR and DR have a wide dynamic range, clipping is usually not evident until images are grossly over-exposed*.

Freedman M, Pe E, Mun SK, Lo SCB, Nelson M (1993) The potential for unnecessary patient exposure from the use of storage phosphor imaging systems. *SPIE* 1897:472-479.

Gur D, Fuhman CR, Feist JH, Slifko R, Peace B (1993) Natural migration to a higher dose in CR imaging. *Proc Eighth European Congress of Radiology*. Vienna Sep 12-17.154.

Exposure Creep in Computed Radiography:

A Longitudinal Study

Dale J. Gibson, BAppSc, Robert A. Davidson, PhD, MAppSc(MI)

Academic Radiology, Vol 19, No 4, April 2012

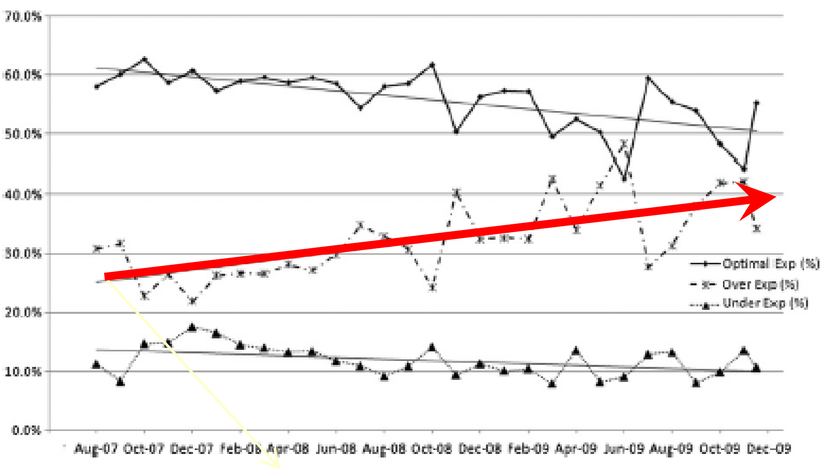


Figure 1. Plot of intensive and critical care unit chest x-ray indicating optimal, over-, and underexposed exposure indexes percentages between August 2007 and December 2009.

What can be done about exposure factor creep?

- To *detect* and *reverse* this trend, it is necessary to monitor a digital value that indicates the amount of radiation reaching the image receptor.

Why don't we just rely on Automatic Exposure Control (AEC)?

- AEC is not available in all settings (NICU, PICU, bedside)
- AEC is challenging with pediatric patients
  - *Often noncompliant*
  - *Anatomic dimensions small compared to AEC cells*
  - *Immobilization devices may introduce artifacts and dose penalty*
- AEC controls exposure delivered but not other technical factors (kVp, SID, additional filtration, use of grid)
- AEC must still be calibrated to deliver a specific target exposure.

Q1: Exposure factor control in pediatric DR requires which of the following items?

20%	1.	Automatic Exposure Control (AEC)
20%	2.	Repeat/Reject analysis
20%	3.	Autoranging
20%	4.	A digital indicator of receptor exposure
20%	5.	Personal supervision of technologists

10

4. A digital indicator of receptor exposure

- Seibert and Morin, Pediatr Radiol (2011) 41:573-581.
- Freedman M, Pe E, Mun SK, Lo SCB, Nelson M (1993) The potential for unnecessary patient exposure from the use of storage phosphor imaging systems. SPIE 1897:472-479.
- Gur D, Fuhman CR, Feist JH, Slifko R, Peace B (1993) Natural migration to a higher dose in CR imaging. Proc Eighth European Congress of Radiology. Vienna Sep 12-17.154.
- Gibson and Davidson, Acad Radiol (2012) 19(4):458-462.

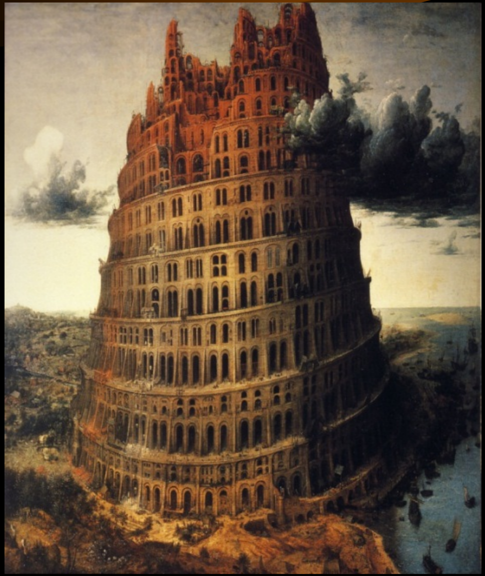
Traditional Exposure Indicators

- Historically, each vendor of CR or DR equipment invented its own Exposure Indicator
- The name, symbology, exposure dependence, and calibration conditions for each were different.

Agfa	Fuji	Kodak	Konica	GE	Siemens	Philips	Canon	Swissray	IDC
lgM	S#	EI	S#	DEI	EXI	EI_S	REX	DI	F#

Traditional Exposure Indicators - shortcomings

- The variety and inconsistency of the vendor-specific exposure indicators created a problem for technologists who work with different CR and DR systems.
- Standards organizations and medical physicists tried to solve this problem by proposing a standard scale that all vendors could adopt.



"The 'Little' Tower of Babel"
Pieter Bruegel the Elder

AAPM TG 116

The American Association of Physicists in Medicine (AAPM) Task Group 116 published a report on exposure indicators in July 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

The International Electrotechnical Commission (IEC) published a standard for Exposure Index definitions in August 2008.

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

How does the new standard exposure indicator work? Two important features:

- Exposure Index, EI

$$EI = K_{cal} \times 100 \mu Gy^{-1} (unitless)$$

  - Proportional to Air-kerma (exposure) at the receptor

- Deviation Index, DI

$$DI = 10 \times log_{10}\left(\frac{EI}{EI_T}\right)$$

  - How close did we come to the target?

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

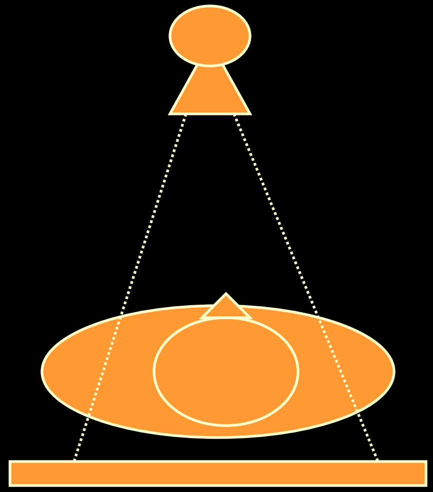
Table 1. Deviation Index *vs.* Target Exposure	
Deviation Index (*DI*)	Fraction of intended exposure (%)
-3	50%
-2	63%
-1	79%
0	100%
1	126%
2	158%
3	200%

How does the exposure indicator relate to the dose to the patient?

- These indicators have one thing in common: they attempt to represent the average exposure at the image receptor in the shadow of the patient's anatomy.
- The dose to an individual patient can only be deduced from the exposure indicator when supplemented by information about the patient, examination, and technical factors.
- *If the exposure indicator correctly reports a doubling of the exposure to the image receptor for the same examination of an individual patient, then the exposure (and dose) of the patient has likely doubled.*

Example: What was the patient exposure in this CR exam? (AP Chest Tabletop)

- Exposure indicator ?
  - *lgM = 2.2 => 1 mR (9 µGy)*
  - *EI_{IEC} = 900*
- Patient thickness ?
  - *12 cm ~3 HVL*
- Scatter reduction grid?
  - *None used*
- SID?
  - *112 cm => SSD = 100cm*
- ESE?
  - *1 mR x $(112/100)^2 / 0.5^3$ =>*
  - *10 mR (90 µGy)*



Q2: What additional information is needed to deduce patient exposure from EI in a non-grid exam?

20%	1.	Backscatter factor
20%	2.	HVL of beam exiting patient
20%	3.	Target air kerma
20%	4.	Both SSD and SID
20%	5.	No additional information is necessary

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4. Both SSD and SID

- An additional assumption must be made about the attenuation of the x-ray beam through the patient tissue. HVL = 4 cm is not a bad guess for diagnostic x-ray energies.
- NCRP Report No. 102 (1995) Appendix B Table B.8

Pediatr Radiol (2011) 41:592–601
DOI 10.1007/s00247-010-1951-9

MINISYMPOSIUM

Quality assurance: using the exposure index and the deviation index to monitor radiation exposure for portable chest radiographs in neonates

Mervyn D. Cohen · Matt L. Cooper · Kelly Piersall · Bruce K. Apgar

Table 1 Four manufacturers' ways of measuring image receptor exposure. This is contrasted with the new IEC exposure index

Exposure in microgray	Fuji S number	Canon REX	Agfa Healthcare LGM	Carestream EI	Exposure index
2.5	710	30	1.96	1,451	250
5	355	60	2.26	1,751	500
10	177	120	2.56	2,051	1,000
20	89	240	2.86	2,351	2,000

Depends on calibration!

So does this!

Table 2 Deviation index. This table shows how the deviation index varies for fixed percentage changes in the exposure index

Microgray	Exposure index	Target exposure index	Deviation index	Exposure factor	Percentage change
13	1,300	500	4	2.60	160%
10	1,000	500	3	2.00	100%
8	800	500	2	1.60	60%
6.3	630	500	1	1.26	26%
5	500	500	0	1.00	0%
4	400	500	−1	0.80	−20%
3	300	500	−2	0.60	−40%
2.5	250	500	−3	0.50	−50%
2	200	500	−4	0.40	−60%

Assuming this target!

AAPM TG116 provided some guidance on how DI could be used

Table 2. Exposure Indicator DI Control Limits for Clinical Images	
DI	Range Action
> +3.0	Excessive patient radiation exposure Repeat only if relevant anatomy is clipped or “burned out” Require immediate management follow-up.
+1 to +3.0 Overexposure	Overexposure: Repeat only if relevant anatomy is clipped or “burned out”
−0.5 to +0.5	Target range
Less than −1.0	Underexposed: Consult radiologist for repeat
Less than −3.0	Repeat

Why is this controversial?

DI	% of Target	Range Action	Controversy
> +3.0	200%	Excessive patient radiation exposure Repeat only if relevant anatomy is clipped or “burned out” Require immediate management follow-up.	When/why is it appropriate to repeat an over-exposed image? What level of management follow-up is recommended?
+1 to +3.0 Overexposure	120-200%	Overexposure: Repeat only if relevant anatomy is clipped or “burned out”	Ranges not inclusive: what about +1<DI<0.5? -0.5>DI>-1.0?
−0.5 to +0.5	89-112%	Target range	Too narrow?
Less than −1.0	<79%	Underexposed: Consult radiologist for repeat	Radiologist approval necessary?
Less than −3.0	<50%	Repeat	In every instance?

Pediatr Radiol (2012) 42:668–673
DOI 10.1007/s00247-011-2290-1

ORIGINAL ARTICLE

Quality assurance: a comparison study of radiographic exposure for neonatal chest radiographs at 4 academic hospitals

Mervyn D. Cohen · Richard Markowitz · Jeanne Hill ·
Walter Huda · Paul Babyn · Bruce Apgar

According to TG 116 guidelines, over ½ of these images would be considered under- or over-exposed!

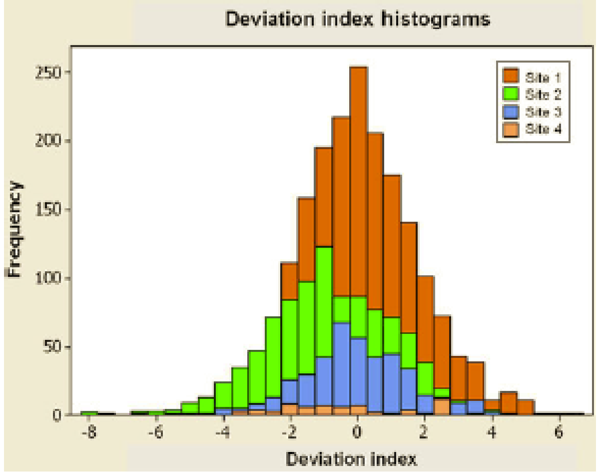


Fig. 1 Graph shows the distribution of the deviation index at each hospital

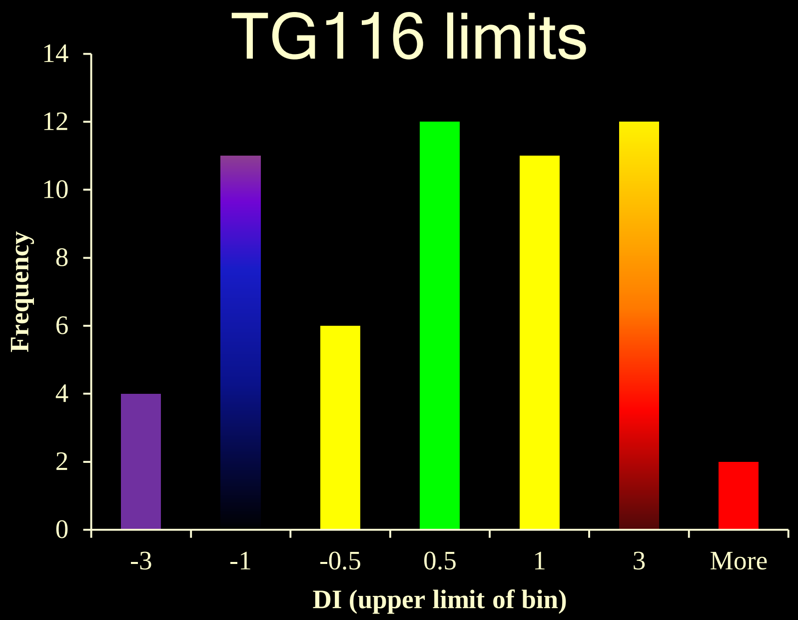
Table 5 Deviation index results for the four hospitals

Table BB deviation index			Deviation index distribution			
	Mean	St Dev	−1 to 1	−2 to 2	−3 to 3	−4 to 4
Site 1	0.08	1.68	46%	78%	93%	98%
Site 2	−0.82	1.89	36%	68%	87%	95%
Site 3	−0.07	1.67	49%	79%	91%	98%
Site 4	−0.48	1.94	31%	58%	92%	98%
Combined normalized results	0	1.75	45%	76%	92%	98%

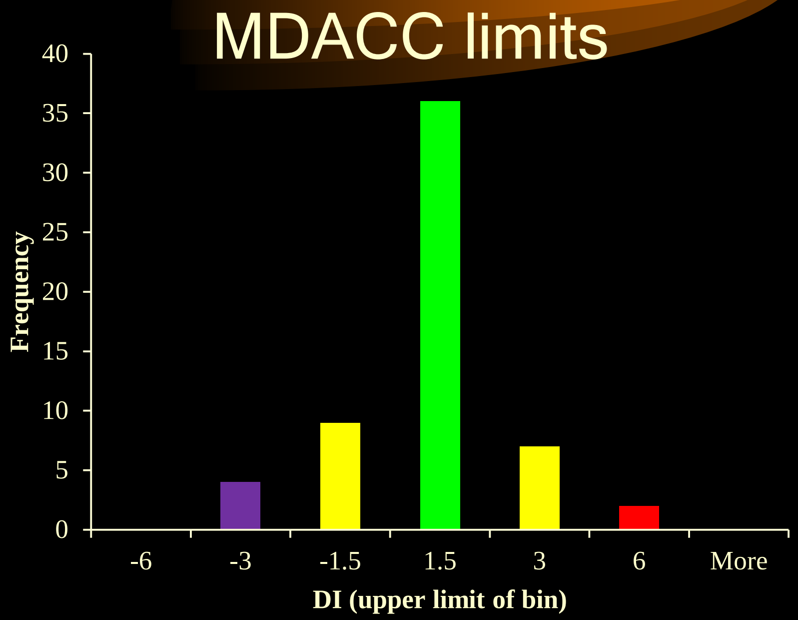
AAPM Task Group No. 232

"To investigate the current state of the practice for CR/DR Exposure and Deviation Indices based on AAPM TG116 and IEC 62494, for the purpose of establishing achievable goals (reference levels) and action levels in digital radiography."

DI distribution for 58 bedside chest exams



21% within target; 50% outside range



62% within target, 10% outside range

Q3: Which of the following is *not* needed in order to use EI and DI effectively for QA?

20%	1. EI properly calibrated on DR system
20%	2. Reasonable target value for EI
20%	3. Appropriate action limits for DI
20%	4. DAP properly calibrated on DR system
20%	5. Proper choice of SID

10

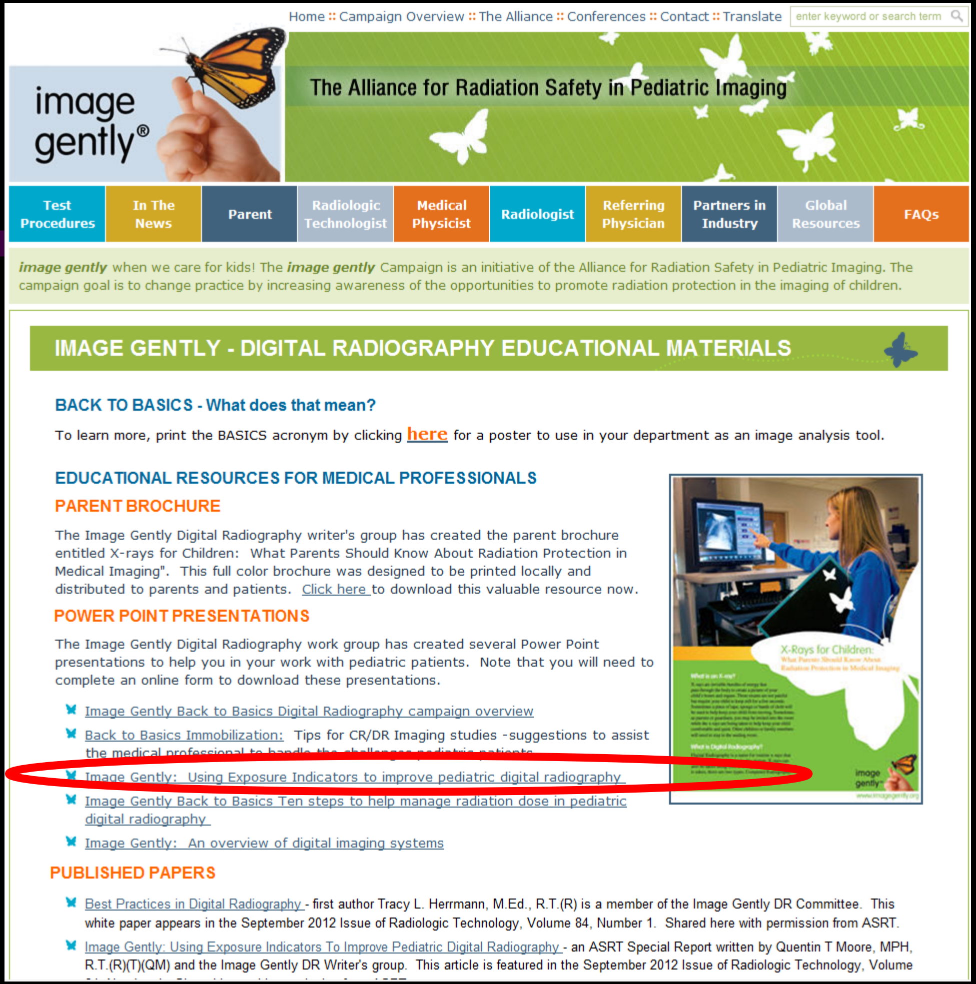
#4. DAP properly calibrated on DR system

- EI properly calibrated on DR system
- Reasonable target value for EI
- Appropriate action limits for DI
- Proper choice of SID, or SID reported by system

Don S, Whiting BR, Rutz LJ, Apgar BK (2012) "New Exposure Indicators for Digital Radiography Simplified for Radiologists and Technologists" AJR 199: 1337-1341

Best practices

- Don, et al. (2013) “Image Gently Back to Basics Initiative: Ten Steps to Help Manage Radiation Dose in Pediatric Digital Radiography” AJR 200: W431-W436



AAPM Task Group No. 252

"To establish a methodology for the development of pediatric technique charts for CR/DR based on the goal of obtaining consistent, appropriate detector air kerma."

There is wide diversity in technique recommendations for the same examination and view

				6 months	10 cm thick	
Exam name	**kVp**	**mAs**	**SID (cm)**	**Grid**	**Speed Class**	**Source**
Chest, Pediatric	60	2	110	none	?	FCR 7000 System Application: X-ray Exposure Condition
Thorax, 6 yr	70	1.2	?	?	400	Agfa ADC Pediatric Software User Manual
Chest, AP or PA, 6 mos	65	1.5	102	none	LnxR/OrthG	Kirks "Practical Pediatric Imaging" 1984 p796
Chest, Child, PA, 10cm	60	9.8	183	none	200	Fuji Computed Exposure Guide 1996
Chest/Abdomen Ped upto 12 Small	95	1	183	yes	200	Agfa Technique Guide ADC CR 1997
Chest/Abdomen Ped upto 12 Small	70	1	183	none	200	Agfa Technique Guide ADC CR 1997
Chest (HI-kV)	95	0.5	183	yes	200	Agfa Technique Guide ADC CR 1998
Chest (LOW kV)	70	0.3	183	none	200	Agfa Technique Guide ADC CR 1998
Chest PA/AP TT	56	3	102	none	200	Wright Patterson AFB
Chest Piggostat	82	4	183	none	200	Wright Patterson AFB
Chest (0-6 mos)	60	3	102	none	200	Madigan Army Medical Center, 1995
Chest 10 cm	66	1.2	122	screen	200	Texas Childrens Hospital, Clinical Care Center, 1997
Chest AP 10 cm	62	1.1	112	screen	200	Texas Childrens Hospital, Main Hospital, 1997
CXR AP 10 cm	70	1.3	112	none	200	Texas Childrens Hospital
Chest AP-PA Obl 14 cm	85	0.9	183	none	OrthR/ST-L	Texas Childrens 1991
Chest, Neonate	60	1	?	none	300	Cohen et al 1989
Newborn, 3.01-5.00 kg	54	1.25	89	none	300	Cohen et al 1991

image gently®/MITA/FDA survey

Examination	kVp range	mAs range
Neonatal Chest	54 - 80	0.8 - 2.0
5 y/o Chest AP	65 - 125	1.0 - 7.0
5 y/o Chest LAT	68 - 125	2.0 - 10.0
5 y/o Abdomen	40 - 80	0.5 - 12.0
5 y/o Wrist AP/OBL	40 - 64	0.5 - 9.0
5 y/o Wrist LAT	40 - 65	1.7 - 12.0
13 y/o Scoli AP/PA	70 - 100	3.2 - 45
13 y/o Scoli LAT	72 - 110	10.0 - 125

Problem solved?

Pediatr Radiol (2013) 43:568–574
DOI 10.1007/s00247-012-2555-3

ORIGINAL ARTICLE

A method to derive appropriate exposure parameters from target exposure index and patient thickness in pediatric digital radiography

Menglong Zhang · Kai Liu · Xuecai Niu · Xinli Liu

- NRPB model for patient thickness
- Exponential attenuation of beam and Bucky Factor
- Chest, abdomen, pelvis
- Neonate, ≤2 y/o, >2 - 7 y/o
- 110 cm SID, 60 kVp
- EI target 1300 (*EI_{IEC} = 200)*
- Reported difference in ESD between default and target mAs

- *μ not reported*
- *Scatter ignored*
- *No inverse square correction*
- *Grid attenuation ("bucky factor") = 3*
- *Limited age/size range*
- *Limited examinations*

Q4: What information is not needed to create a technique chart?

20%	1.	Model for output of the x-ray generator
20%	2.	Model for thickness of patient
20%	3.	Model for attenuation by patient
20%	4.	Target for exposure to image receptor
20%	5.	Age of the patient

10

#5. Age of the patient.

- Patient age is a very poor determinant of patient size and body habitus. At the very least, technique guides should be designed to accommodate a range of patient thickness.
- In addition to generator output, patient thickness, patient attenuation, and receptor target, you must also account for …
  - *Patient support*
  - *Grid, if used*
  - *Geometry (SID)*
  - *Equipment limitations (available mAs stations, kVp, focal spot)*

Shah C, Jones AK, Willis CE. "Consequences of Modern Anthropometric Dimensions for Radiographic Techniques and Patient Radiation Exposures." Med Phys 35(8):3616-3625, 8/2008.

What could possibly go wrong?

- The exposure indicator (EI) is the median of the histogram of the segmented image, *a.k.a.* Values of Interest (VOI).

- *What would happen if the image is incorrectly segmented?*

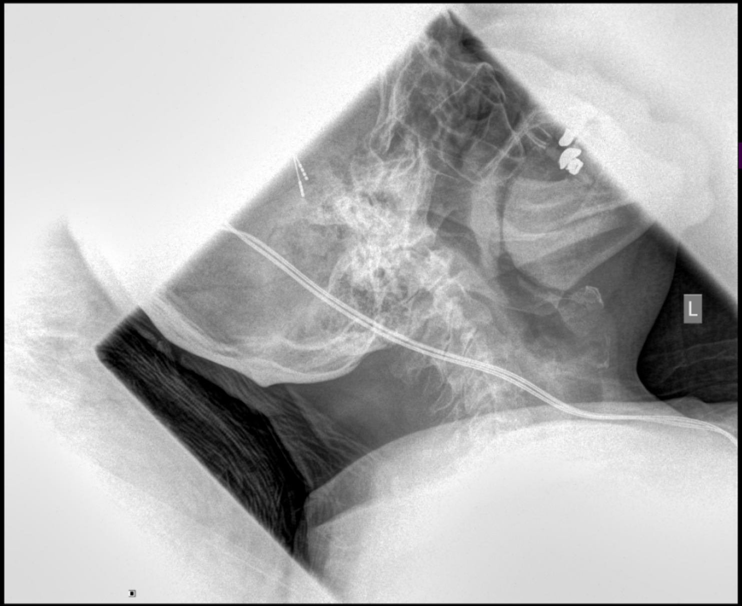


Image processing segmentation error:
IgM = 18 (target = 200)
DI = -18.2

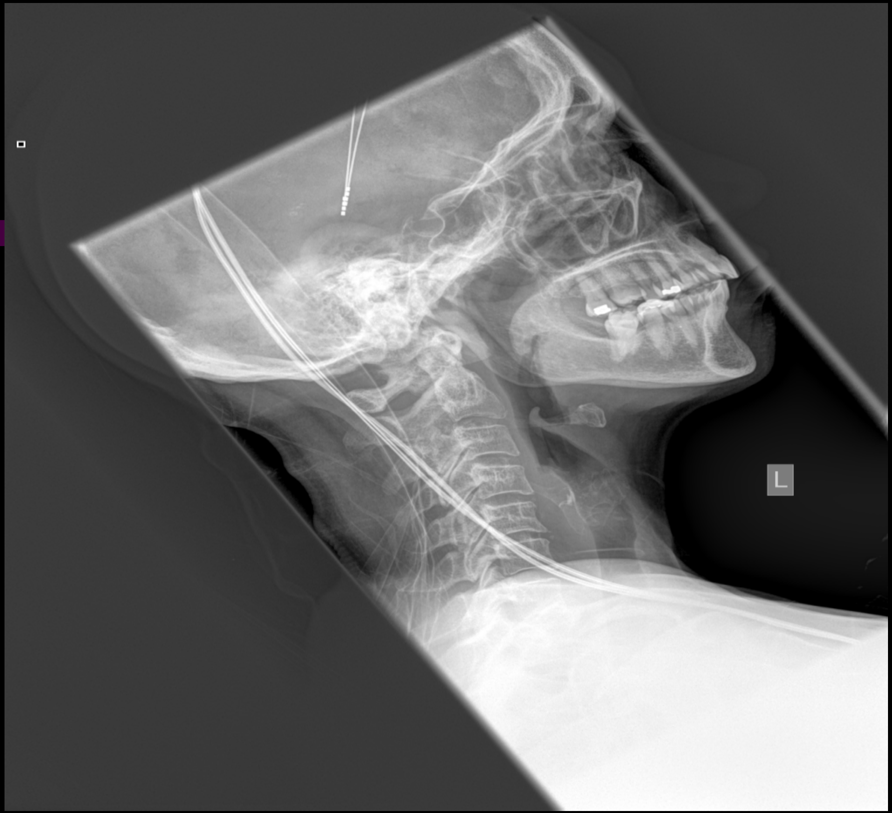


Image processing segmentation ok:
IgM = 196 (target 200)
DI = -0.4

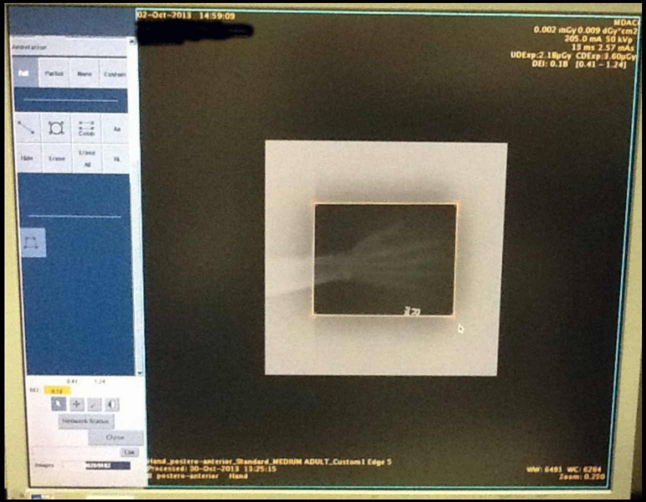
Interferences: Collimator Edge Detection

Original image, EI=180

Failed autoshutter, EI=180
(target range: 410-1240)

Correction of Failure of Collimator Edge Detection

Manual Shutter applied



Reprocessed image, EI=1160
(target range: 410-1240)

Conclusions:

- Exposure factor control is important in pediatric CR and DR to avoid “exposure creep”.
- Even though they have an indirect relationship to patient dose, both traditional and the new exposure indicators can be used to monitor exposure factor practice.
- Effective exposure factor control in pediatric radiography requires a technique guide that incorporates a target for receptor exposure an appropriate action limits.