Considerations and strategies for setting target exposure indicator (EI_T) in digital radiography

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Disclosures

- None

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"The nice thing about standards is that you have so many to choose from"

-Andrew S. Tanenbaum

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Outline

1. Why use DI and EI_T?
   i. Pros/Cons
   ii. Manufacturer presets
2. Necessary steps
   i. EI Accuracy
   ii. AEC calibration
   iii. Processing
3. Set and review

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Why use DI and EI_T?

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

PROS

- Do not need to worry about different EI implementations
- One number for technologist/radiologist

Why use DI and EI_T?

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

PROS

- Do not need to worry about different EI implementations
- One number for technologist/radiologist

CONS

- Does not necessarily point to over/under-exposure
- Can be mis-used for repeat imaging

Manufacturer EI_T presets

Exam	DR 1	DR 2	DR 3	DR 4	Range
Chest PA	250	206	175	216	1.4X
Humerus	250	N/A	245	150	1.7X
Abd Supine	600	252	595	175	3.4X

Manufacturer EI_T presets

Exam (Abdomen)	DR 1	DR 2
KUB	595	250
AP	595	250
Bladder	175	250
Supine	315	250
Lateral	1050	250
Upright	525	250

Manufacturer EI_T presets

Exam (Abdomen)	DR 1
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Manufacturer EI_T presets

Exam (Abdomen)	DR 2
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Step 1: EI Accuracy

SOD	SID	Plate	Focus	Processing Menu			Add. Filter
110	110	Small	1 mm	Service: EI_s	Unique/Service		21 mmAl

mR (IC)	uGy (IR)	kV	mAs	ms	Cu/Al	HVL	EI_s	%
	10.59	70	7.1		0/0	6.76	1125	5.87
	0.93	70	0.7		0/0		98	4.80
	76.14	70	50		0/0	6.77	7840	2.88
						max % @ 70 kV:		5.87
	1.54	50	7.1		0	4.43	107	-43.93
	4.76	60	7.1		0	5.7	454	-4.85
	10.59	70	7.1		0	6.76	1125	5.87
	19.75	80	7.1		0	7.69	2239	11.79
	32.63	90	7.1		0	8.31	3691	11.60
	48.37	100	7.1		0	9	5401	10.44
	66.82	110	7.1		0	9.47	7242	7.73
	88.16	120	7.1		0	10.1	9258	4.77
	77.97	130	5		0	10.4	8026	2.85
	76.75	140	4		0	10.8	7653	-0.29
	93.04	150	4		0	11	8666	-7.36

SOD	SID	Plate	Focus	Processing Menu
110	110	Large	1 mm	Other: EI_s

mR (IC)	uGy (IR)	kV	mAs	ms	mm Cu	HVL	EI	%
	11.32	70	7.1		0	6.77	1211	6.52
	1.00	70	0.7		0		104	4.04
	80.95	70	50		0	6.73	8299	2.46
						max % @ 70 kV:		6.52

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Step 2: AEC Calibration

Grid: f_0= 110 cm / r = 8 / L = 40
Grid: f_0= 140 cm / r = 12 / L = 40
Attenuation factor: 1.9

Chamber 1	K_T [µGy]	tolerance
S200	9.5	± 2.0
S400 /Data Set 1	4.8	± 1.0
S800	2.4	± 0.5
S1000	1.9	± 0.36

=2.5 uGy +/- 0.5

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Step 2: AEC Calibration

Exam	DR 1	DR 2	DR 3	DR 4	Range
Abd Supine	600	252	595	175	3.4X
Chest PA	250	206	175	216	1.4X
Humerus	250	N/A	245	150	1.7X

AEC Sensitivity = 200
i.e. 1000/200 = 5 uGy, EI = 500
Not internally consistent

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Step 3: Understand VOI

Method 1: Exam (anatomy) – specific VOI

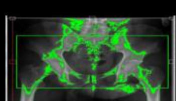
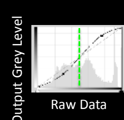


Image Courtesy of Stefan Specht, Philips Healthcare



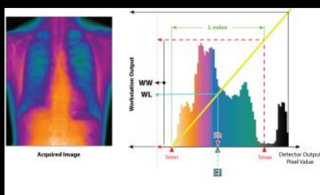
Example VOI: Bone 25%
Lung: 90%

Method 1: Exam (anatomy) – specific VOI

Image Courtesy of Stefan Specht, Philips Healthcare

- EI_T based on Image Quality (SNR) in VOI

Method 2: Central tendency of histogram



- Defined by IEC
- Requires wider range of exam-specific EI_T

Image Courtesy of FujiFilm

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Step 3: Set and review

- Perfect is the enemy of good!
- Start somewhere
  – e.g. Abdomen (300), Chest (400), Extremity (700)
- Select subset (e.g. one room)
  – ensure correct collimation VOI/processing
- Radiologist review
  – bookend image noise using outliers

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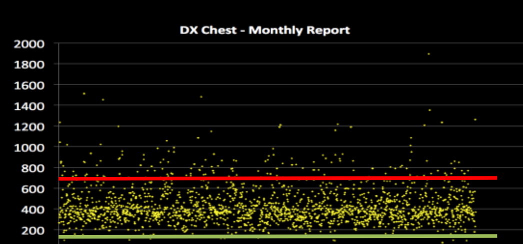
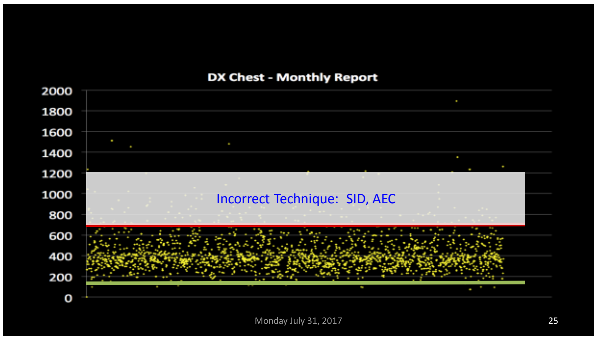
BCH Values

Exam	Philips Digital Diagnost*
Abdomen Supine	300
Chest PA	400
Humerus	700

Ongoing Review

- Hawthorne effect:
  - “productivity gain occurred as a result of…interest being shown to them”
- i.e. the act of reviewing data drives quality improvement more than the reporting results




DX Chest - Monthly Report
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Incorrect Technique: SID, AEC
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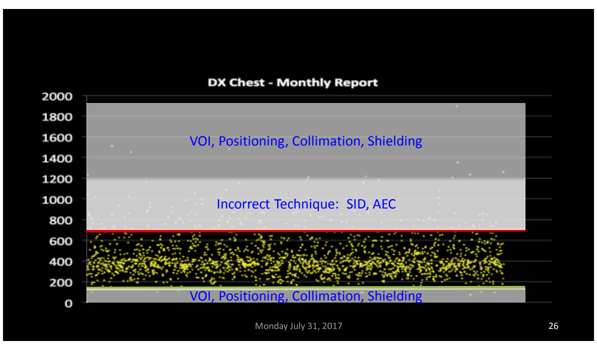
DX Chest - Monthly Report
2000
1800
1600
1400
1200
1000
800
600
400
200
0
VOI, Positioning, Collimation, Shielding
Incorrect Technique: SID, AEC
VOI, Positioning, Collimation, Shielding
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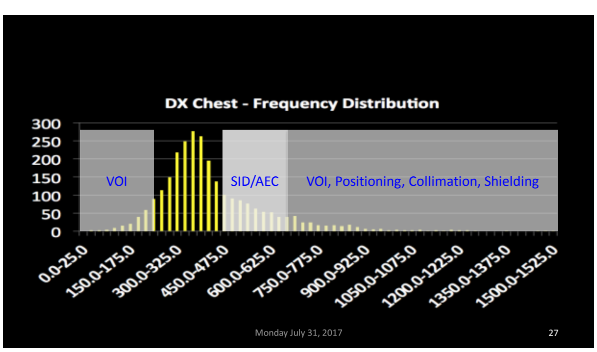
DX Chest - Frequency Distribution
300
250
200
150
100
50
0
VOI
SID/AEC
VOI, Positioning, Collimation, Shielding
0.0-25.0
150.0-175.0
300.0-325.0
450.0-475.0
600.0-625.0
750.0-775.0
900.0-925.0
1050.0-1075.0
1200.0-1225.0
1350.0-1375.0
1500.0-1525.0
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- Member of X-Ray Medical Advisory Board GEMS

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Introduction

- EI target values were deliberately avoided by AAPM TG 116.
- Too broad scope for the TG.
- State of practice largely unknown but expected to be widely variable.
- Expectation that manufacturers should be able to define appropriate target values for their specific technologies – like screen/film speed classes.
- AAPM TG 232 survey data confirmed state of practice was highly variable.
- leads to question of how to establish target EI values.

II. Preconditions

- DR system properly calibrated for EI
- Consistent configuration management
- Operator compliance with
  - technique guides,
  - patient positioning,
  - collimation,
  - SID,
  - use of grids,
  - patient size estimation and size/technique selections.

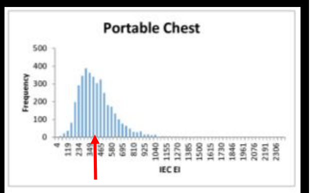
III. Three Approaches for discussion

- Statistical approach
- Deterministic approach
- Experimental approach

Statistical approach
aka laissez-faire approach

- Collect data to determine *state of practice*
- Set the EI target to the median of the histogram of the EI observed for each view
- Not unlike method of TG 232
- Remember that EI distributions are *log-normal*

Example of Statistical Approach



EI_T = 375

Portable Chest AP	
Mean	406.3386591
Standard Error	3.105351909
Median	374.84
Mode	262.56
Standard Deviation	193.7550474
Sample Variance	37541.0184
Kurtosis	6.32321265
Skewness	1.597613721
Range	2378.31
Minimum	4.26
Maximum	2382.57
Sum	1581876.4
Count	3893
Confidence Level(95.0%)	6.08827127

Deterministic approach *aka* AEC approach

- Set the EI_T to some value of air kerma that you expect to produce an acceptable image by the technology used
- What TG 116 expected that the manufacturers would do

Example of a Deterministic Approach

- Assume SNR = 30 desired
- For quantum limited system, about 1000 photons contribute per pixel
- Only about ½ incident photons contribute, so need 2000 incident
- Detector element is about $2X10^{-8}$ cm^2
- The energy fluence would be 50 X 10^3 eV times 1.0 X 10^7 photons per cm^2 or 5 X 10^{11} eV/cm^2. We have to know the conversion factor (the charge on an electron is 1.6 X 10^{-19} C) or 1.6 X 10^{-19} J/eV to get about 8 X 10^{-8} J/cm^2
- To get the air KERMA from the energy fluence, you multiply times the ratio of the linear attenuation coefficient for air divided by the density of air. At 50 keV, it's 40 cm^2/kg.
- Multiply this times the energy fluence and you get 3 X 10^{-6} J/kg.
- One Gy is 1 J/kg, so the air KERMA is 3 X 10^{-6} Gy or 3 μGy.
- 3 μGy times 100 μGy^{-1} yields EI_T of 300.

Another Example of Deterministic Approach: *Speed Class*

Speed Class	Receptor Exposure (mR)	Receptor Exposure (µGy)	IEC EI_T
100	1.0	8.76	876
200	0.5	4.38	438
250	0.4	3.50	350
350	0.3	2.50	250
400	0.25	2.82	282
800	0.125	1.41	141
1600	0.063	0.71	71

Caveats: *Neither of these deterministic approaches really dealt with secondary photons. The detector doesn't distinguish between primary or secondary photons. In a bedside chest examination the SPR is at least 1 without a grid and likely 0.5 even with a grid, so EI_T may need to be adjusted upward accordingly to compensate. This is just the median – what about the tail of the exposure distribution? 1/10 SNR_{median} ?*

Experimental approach *aka* Phantom approach

- Use geometric or anthropomorphic phantoms to simulate the anatomy of interest
- Set the EI target for what is observed when reasonable radiographic techniques or AEC is used and acceptable quality metrics are obtained
- Adjust EI target based on clinical results

Experimental Approach:

Choice of patient-equivalent phantom

- Anthropomorphic phantom
  - Potential difficulties with positioning, segmentation, image processing
- Geometric phantom
  - PMMA
  - ANSI/AAPM phantoms (configurable to Chest, ABD. Skull, extremity)
  - LucAl phantoms (Chest, Abdomen, Pedi Chest/Abd)
  - ACR RF phantom (configurable to Chest, ABD. Skull, extremity)

Rambo Phantom, not to be confused with Rando Phantom

May also measure entrance skin exposure (ESE) for comparison to Reference Values or Regulatory Limits

Example of Experimental Approach

- Five mobile DR systems *(5/2014: we were pretty ignorant about EI)*
- LucAl Chest phantom followed by clinical demo
- 100 kVp, 1.6 mAs, 50" SID, no grid

Vendor	EI_T	EI_{ave}
GE	787	856
Carestream	850	562
Philips	586	621
Seimens	560	703
Fuji	876	2127
average	731.8	973.8
w/o Fuji	695.8	685.5
Standard deviation	21%	19%

Adjusting technique for thickness: *expecting too much?*

ACR Chest Phantom (Non-grid)								
Image	**kVp**	**mAs**	**Raw PV**	**Raw SD**	**Raw SNR**	**DI**	**EI**	**(+) PMMA**
14	100.0	1.6	1378.3	5.7	241.8	2.4	390.8	None
15	105.0	1.6	1435.4	6.4	224.3	1.7	331.5	2 cm
16	110.0	1.6	1509.8	7.2	209.7	0.8	272.4	4 cm
17	110.0	1.6	1521.6	7.4	205.6	1.0	281.5	4.1 cm/ACR
		Average:	**1461.3**	**6.7**	**220.3**	**1.4**	**319.1**	
		COV:	**0.046**	**0.117**	**0.074**	**0.497**	**0.171**	
		COV < 10%:	***PASS***	***FAIL***	***PASS***	***FAIL***	***FAIL***	

ACR Chest Phantom (Grid)								
Image	**kVp**	**mAs**	**Raw PV**	**Raw SD**	**Raw SNR**	**DI**	**EI**	**(+) PMMA**
10	100.0	5.0	1309.1	15.9	82.3	3.7	530.2	None
11	105.0	5.0	1374.2	15.0	91.6	2.8	434.7	2 cm
12	110.0	5.0	1436.4	14.2	101.2	2.1	365.2	4 cm
13	110.0	5.0	1451.4	14.5	100.1	2.3	383.9	4.1 cm/ACR
		Average:	**1392.8**	**14.9**	**91.7**	**2.4**	**394.6**	
		COV:	**0.047**	**0.050**	**0.096**	**0.162**	**0.091**	
		COV < 10%:	***PASS***	***PASS***	***PASS***	***FAIL***	***PASS***	

IV. Conclusions and caveats

- Three approaches for setting EI_T
  - *Statistical*
  - *Deterministic*
  - *Experimental*
- Calibration of detectors is critical
- Collimation is critical for segmentation and calibration
- Beam quality, (kVp, HVL) and SPR is critical
- EI is only accurate to ± 20%
- Your mileage may vary