Cleveland Clinic

Practical Medical Physics
Session: TG-151
Dose Monitoring

August 5, 2013
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Digital Imaging and ‘Dose Creep’

Images courtesy of Agfa Healthcare©

Under-Exposed

Over-Exposed

Freedman et al., *The potential for unnecessary patient exposure from the use of storage phosphor imaging systems*, SPIE Medical Imaging, SPIE Proceedings 1897, 472-479 (1993)

Gur et al., *Natural migration to a higher dose in CR imaging, Proceedings of the Eight European congress of Radiology*, 154 (1993)

Dose Tracking – Annual (Physicist)

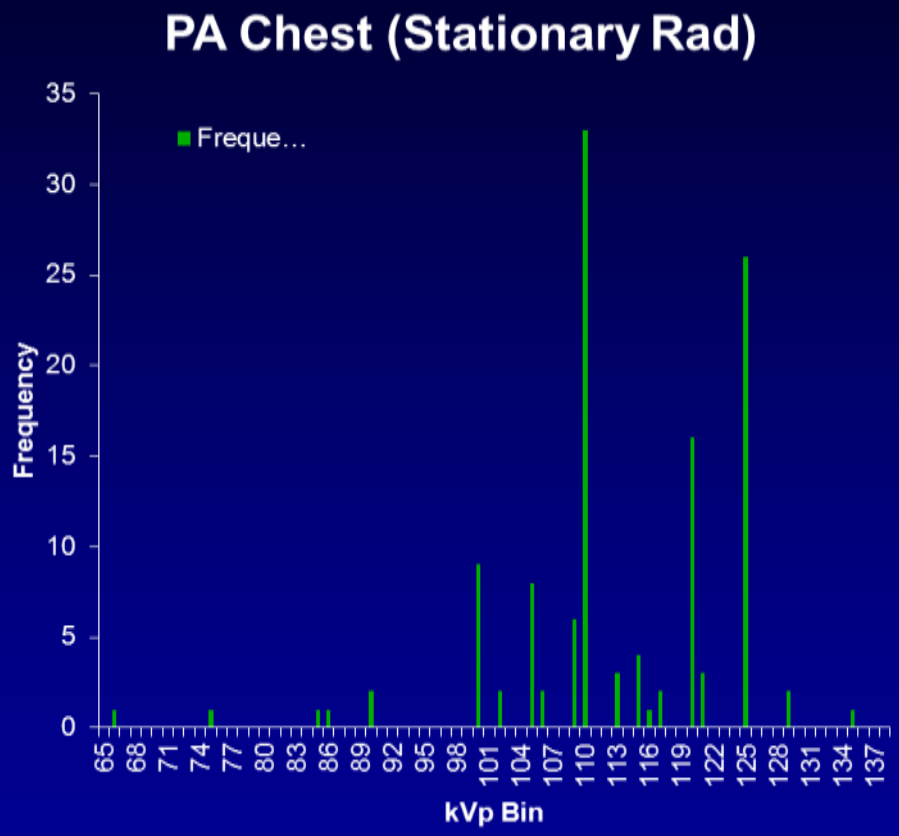
- Tube Output, HVL
- Incident Air Kerma ($K_{a,i}$) Measurements
  - 'typical' doses
  - references for limits / reference levels:
    - NCRP 172
    - NEXT Surveys
    - State regulations
- AEC evaluation
  - EI is useful for this as well!
  - TEIs will be correlated w/ cutoff dose
- Accuracy of metric used for ongoing QC
  - DAP, EI, etc.

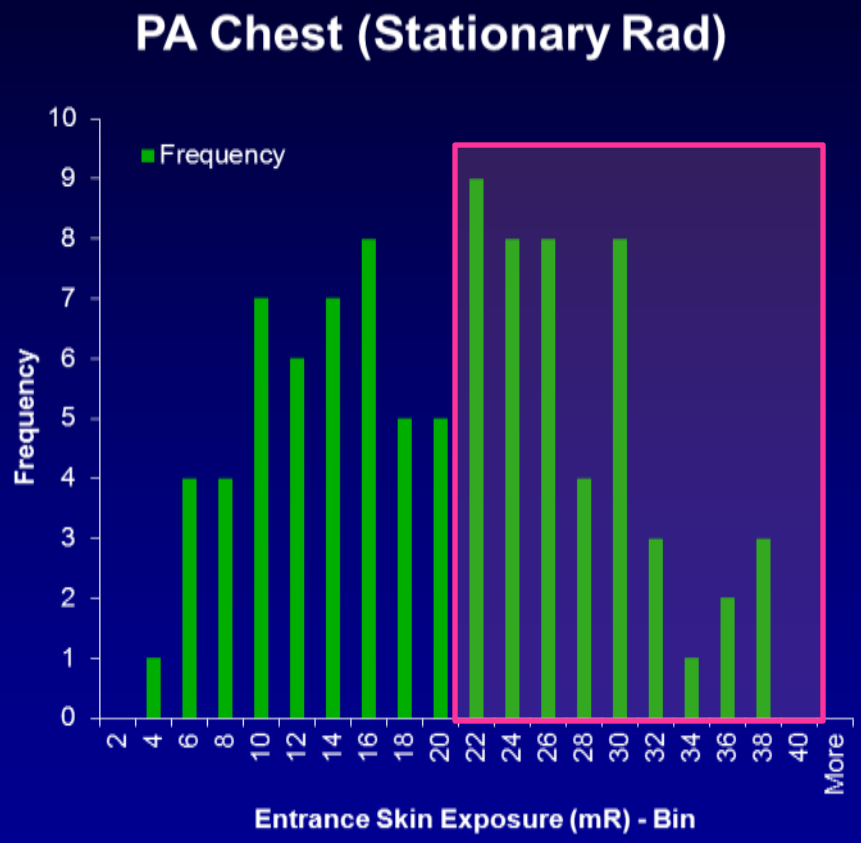
CCF Patient Incident Air Kerma (IAK)

- **GOAL:**
  - **to reduce patient doses for common radiographic exams to below 3rd quartile NEXT* data for ALL sites**

**NEXT = National Evaluation of X-Ray Trends(CRCPD Pub. No. E. 03-2)*

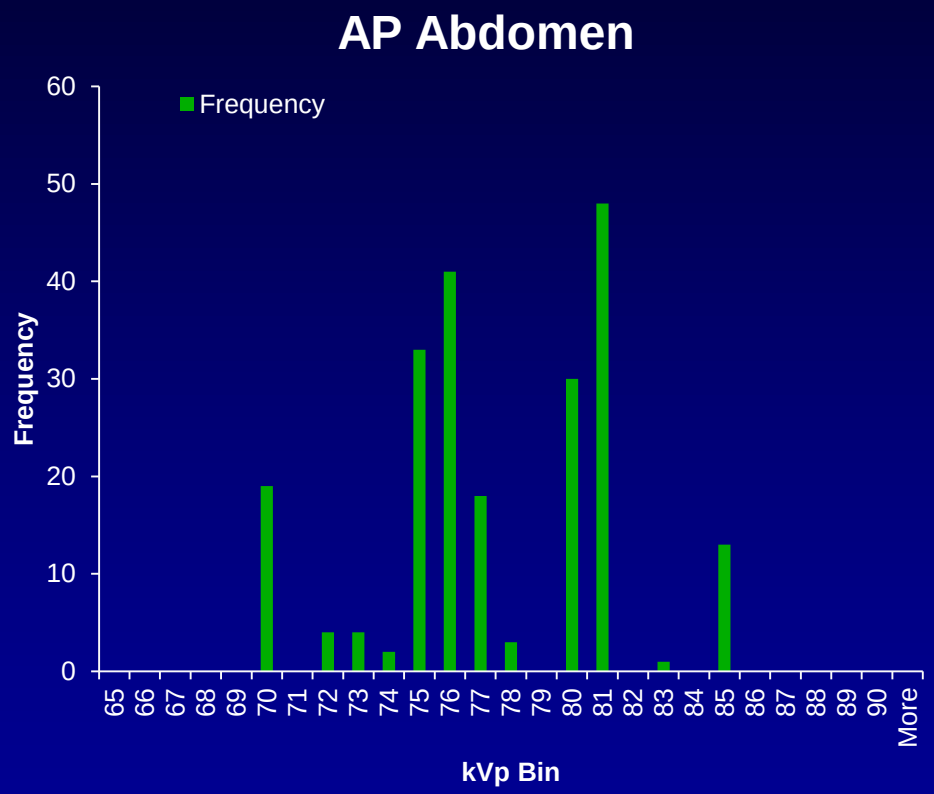
Where we were…

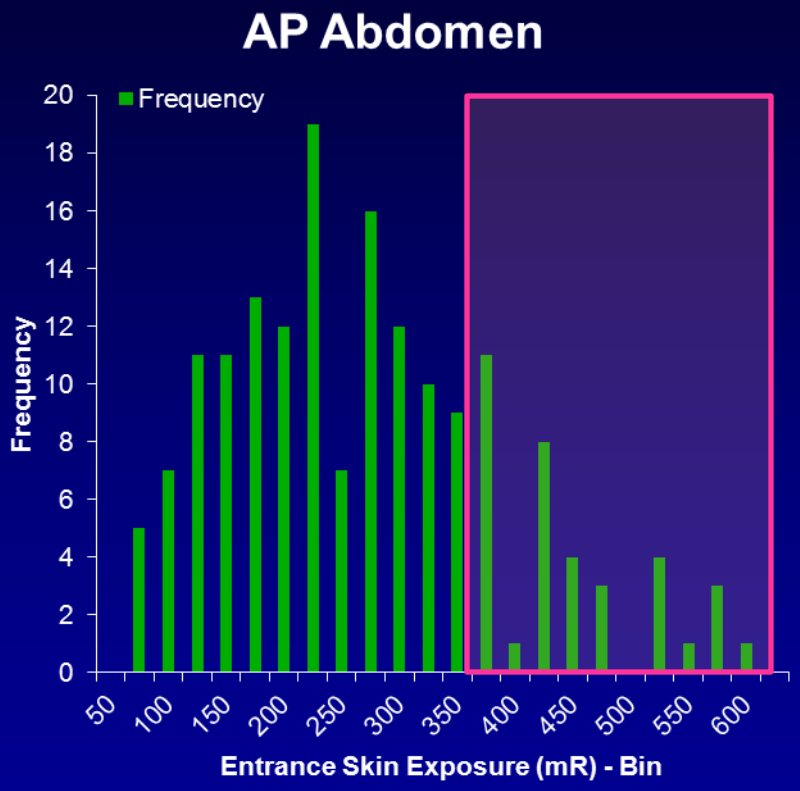




EXCEEDING NEXT 3rd QUARTILE

Where we were…





EXCEEDING NEXT 3rd QUARTILE

CCF Patient Incident Air Kerma (IAK)

- **HOW:**
  - **kVp standardization for select exams**
    - Enables comparison of IAKs between sites with *same* system
  - **Development and documentation of image-based methodology for in-house AEC evaluation and calibration**
  - **Instituted new CCF limit for IAK**
    - Identify outliers during annual testing

**NEXT = National Evaluation of X-Ray Trends(CRCPD Pub. No. E. 03-2)*

CCF IAK Limits

	Grid Y/N	SID (cm)	AEC cell(s)	Dens	kVp	mAs	Patient Size (cm)	Measured Air Kerma Measured @ SCD (mGy)	Incident Air Kerma $K_{a,i}$ $K_{a,i}$ @ SSD (mGy)	ODH Limit (mGy)	CCF Limit (mGy)
AP Abdomen	Y	102	LRC	0	80		23			5.26	3.40
AP Lumbar	Y	102	C	0	80		23			6.13	4.20
AP Thoracic	Y	102	C	0	75		23			3.50	2.27
AP Cervical	Y	102	C	0	74		13			1.75	1.75
LAT Skull	Y	102	C	0	76		15			1.75	1.75
DP Foot	Y	102	C	0	60		8			0.88	0.31
PA-AP Chest*	Y	102					23			0.35	0.26
PA-AP Chest*	N	102					23			0.26	0.18
PA-AP Chest	Y	182	LR	0	120		23			0.35	0.26

* Measure for portables ONLY

CCF IAK Limits

	ODH Limit		CCF ESE Standard		ESE Range quoted by ODH		CRCPD, Pub No. E-03-2, Table 4				TX Limit (mR)
							NEXT Data		NEXT Data		
	(mGy)	(mR)	(mGy)	(mR)	Min (mR)	Max (mR)	Q3 (mGy)	Q3 (mR)	Av (mGy)	Av (mR)	
AP Abdomen	5.26	600	3.40	388	300	490	3.469	396	2.374	271	450
AP Lumbar	6.13	700	4.20	479			4.179	477	2.996	342	550
AP Thoracic	3.50	400	2.27	325							325
AP Cervical	1.75	200	1.75	200					1.183	135	120
LAT Skull	1.75	200	1.75	200					1.270	145	150
DP Foot	0.88	100	0.31	35	8	35					50
PA-AP Chest w/ Gr	0.35	40	0.26	30	10	15	0.158	18	0.114	13	30
PA-AP Chest woo Gr	0.26	30	0.18	20			0.123	14	0.079	9	20
PA-AP Chest w/ Gr	0.35	40	0.26	30	10	15	0.158	18	0.114	13	30

NEXT = National Evaluation of X-Ray Trends
CRCPD = Conference of Radiation Control Program Directors

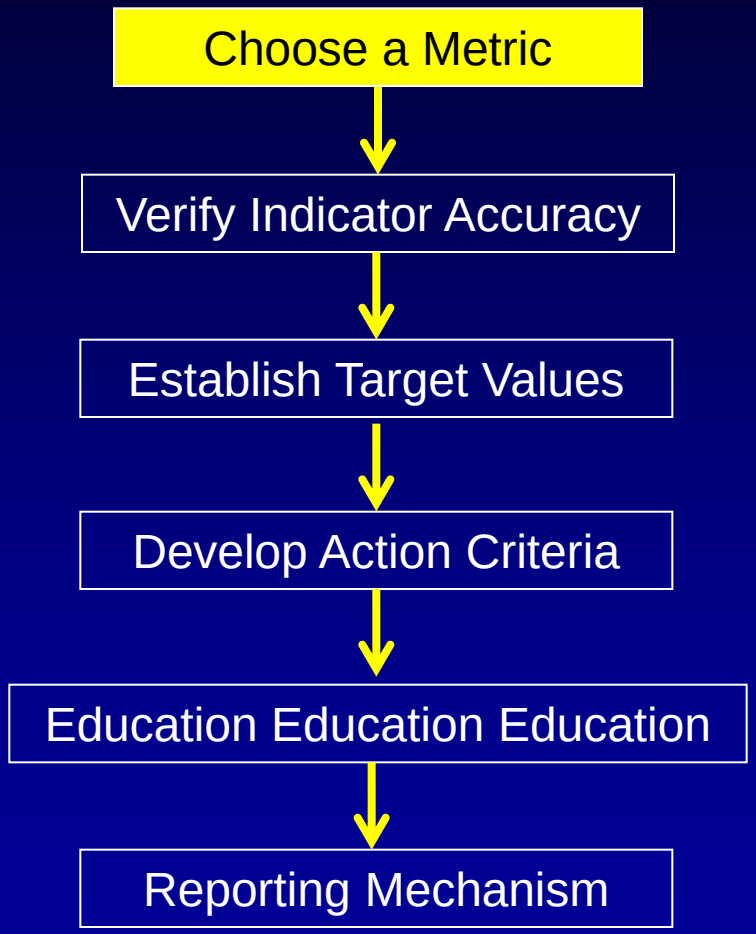
References: *Diagnostic Reference Levels (DRLs)*

- NCRP Report No. 172, *Reference levels and achievable doses in medical and dental imaging: recommendations for the United States*. (2012)
- ACR Practice Guideline for Diagnostic Reference Levels in Medical X-Ray Imaging. (Revised 2008, Resolution 3).
- Gray et al., Reference Values for Diagnostic Radiology: Application and Impact, *Radiology* Vol 235 (2):p354-358, 2005.
- Nationwide Evaluation of X-ray Trends (NEXT): Tabulation and Graphical Summary of 2002 Abdomen/Lumbosacral Spine Survey. CRCPD Publication E-06-2b (2006).
- Nationwide Evaluation of X-ray Trends (NEXT) : Tabulation and Graphical Summary of 2001 Survey of Adult Chest Radiography. CRCPD Publication E-05-2 (2005).
- Nationwide Evaluation of X-ray Trends (NEXT) : Tabulation and Graphical Summary of 1998 Pediatric Chest Survey. CRCPD Publication E-04-5 (2004).

$K_{a,i}$ - Limitations

- 'Average' patient doses do not necessarily reflect actual patient dose or the distribution in patient doses
  - Measurements do not indicate adherence to technique charts (manual)
- Phantoms represent a limited range of exam types and body parts
- Metrics are not suitable for ONGOING QC
  - Require a level of expertise (and equipment) to measure

Dose Tracking – Ongoing



Dose Tracking – Ongoing

WHAT INFORMATION IS AVAILABLE TO YOU??

- **Exposure Index**
  - **DICOM tags*: EI(0018,1411), TEI (0018,1412), DI (0018,1413)**
  - **Available for all systems that have adopted IEC standard**
- **Entrance Dose**
  - **DICOM tags:**
    - **Entrance Dose (0040,0302)**
    - **Entrance Dose in mGy (0040,8302)**
  - **Available on systems with integrated generator**
- **Area Dose Product**
  - **DICOM tag:**
    - **Image and Fluoroscopy Area Dose Product (0018,115E)**
  - **Available on systems with integrated generator**

**DICOM Correction item 1024 – 'Exposure Index Macro'*

Exposure Index *(IEC 62494-1)*

$$EI = c_0 \cdot g(V)$$

- **Where**
  - **V is the *Value of Interest***
  - **g(V) is the inverse calibration function**
  - **C_0 = 100 µGy^{-1}**

Exposure Index

- **Advantages**
  - Reflects receptor dose
  - Not as dependent on patient size/distribution
  - Standardized metric
- **Disadvantages**
  - Indirectly related to patient dose
  - Depends on beam quality, exam/view, as well as vendor-defined VOI
  - Collimation, prosthetics, etc. can affect calculated value

Entrance Dose

- Incident air kerma ($K_{a,i}$) at a fixed location
  - Reference point varies among vendors
- Typically derived from exam parameters
  - kVp / mAs
  - not measured on a patient by patient basis

Entrance Dose

- **Advantages**
  - **Can be used to estimate patient dose**
- **Disadvantages**
  - **No standard reference point or method for normalization**
  - **Entrance surface of patient may deviate from reference point**
  - **Does not represent size of the x-ray field**
- **Most data from Europe**
  - **But often limited to certain body habitus range**
    - i.e. 65-75 kg, Hart 2003
  - **Most US data currently w/ respect to phantoms**

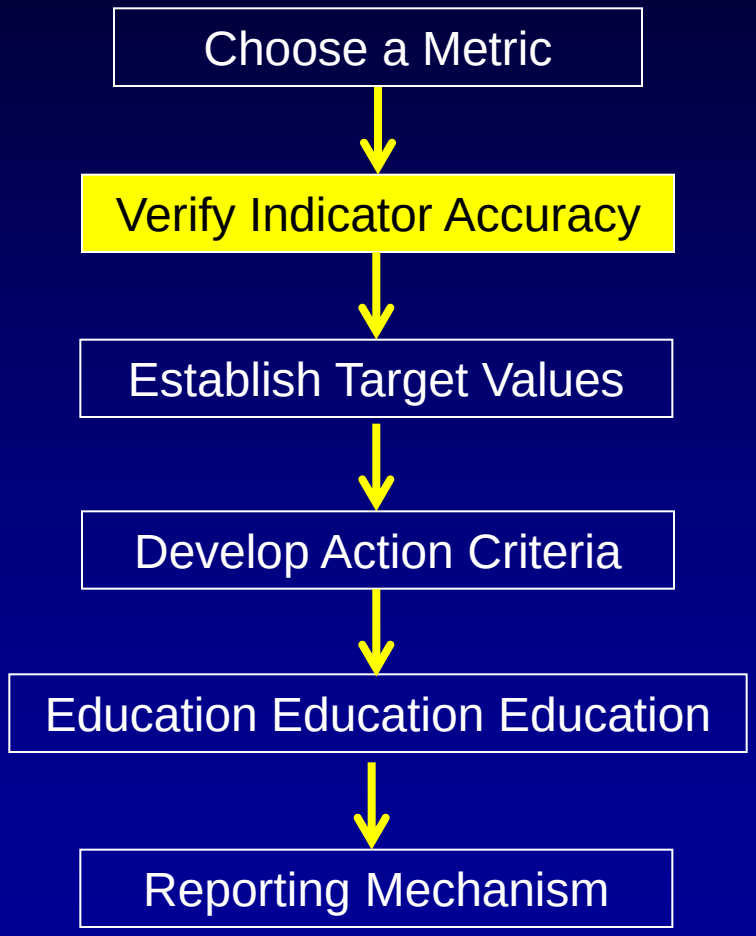
Image and Fluoroscopy Area Dose Product

- Product of the x-ray field size and air kerma
  - Dose Area Product (DAP)
  - Kerma Area Product (KAP)
  - Air Kerma-Area-Product (P_{KA})
  - Unit DICOM field: dGy-cm^2
- Often measured using a P_{KA} meter installed on the collimator

P_{KA}

- Advantages
  - Contains information about $K_{a,i}$ AND field size
    - Enables assessment of both patient dose and collimation
  - Field size can be derived if $K_{a,i}$ is known (or estimated)
- Disadvantages
  - DAP meter option may have to be purchased separately
  - Difficult to isolate impact of collimation without knowledge of $K_{a,i}$

Dose Tracking – Ongoing



Exposure Index *(IEC 62494-1)*

- **IEC 62494-1 standard states that the EI shall be calibrated such that:**

$$EI = C_0 \cdot K_{CAL}$$

- **Where**
  - **K_{CAL} is the receptor air kerma (in µGy) under calibration conditions**
  - **C_0 = 100 μGy^{-1}**

Exposure Index *(IEC 62494-1)*

- **Inverse calibration function is defined as:**

$$K_{CAL} = g(V_{CAL}) = f^{-1}(V_{CAL})$$

- **Inverse calibration function should have an uncertainty of *less than 20%***

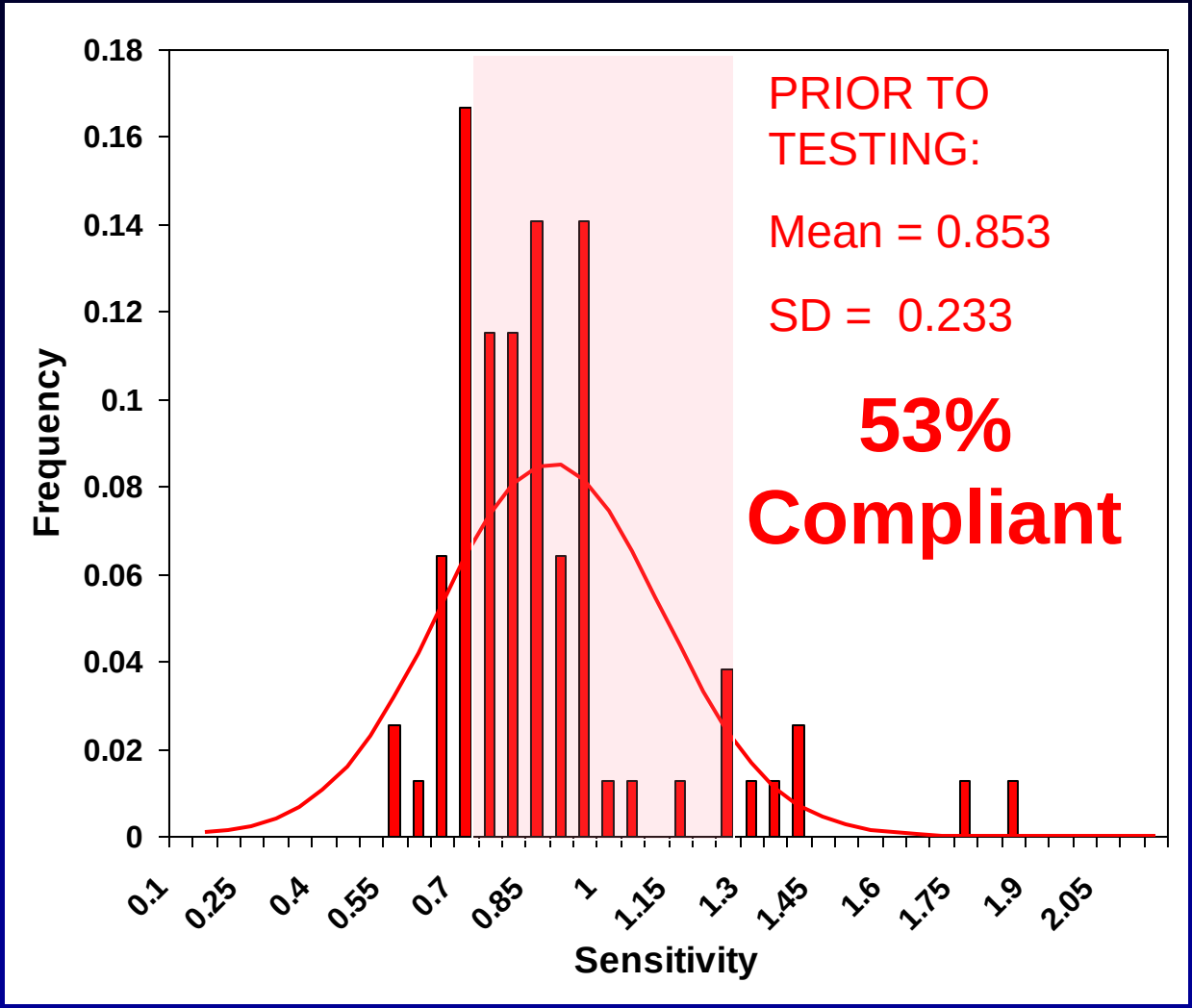
Calibration Conditions *(IEC 62494-1)*

- Fixed radiation quality
  - RQA5
- Homogenous irradiation of image receptor
- Measurement of incident air kerma (free in air, no backscatter)
- Value of Interest (VOI) calculated from central 10% of image area for flat field images

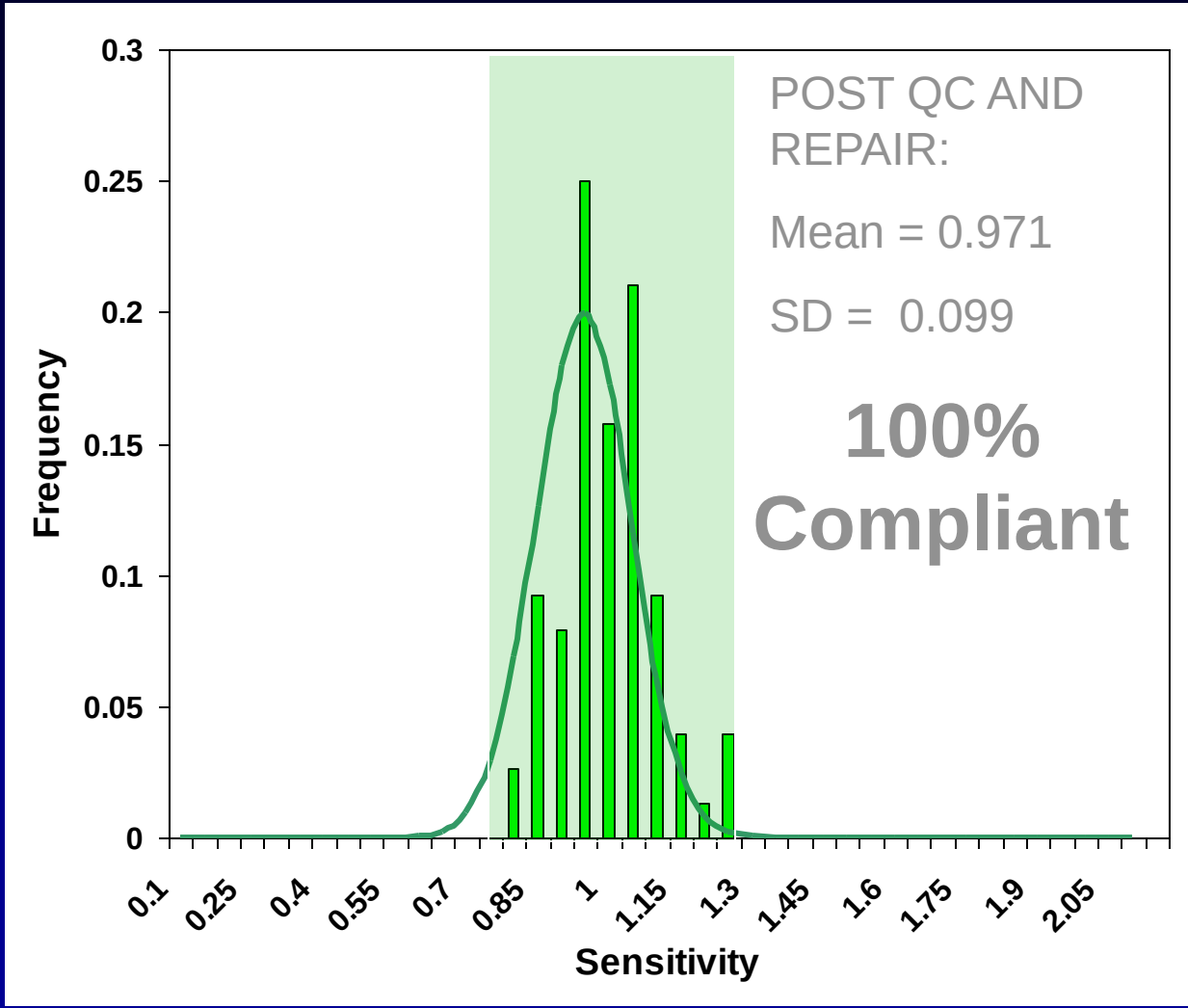
Clinical Experience….

- 80 CR readers (Agfa)
- 38 units required PMT replacement (~50%)

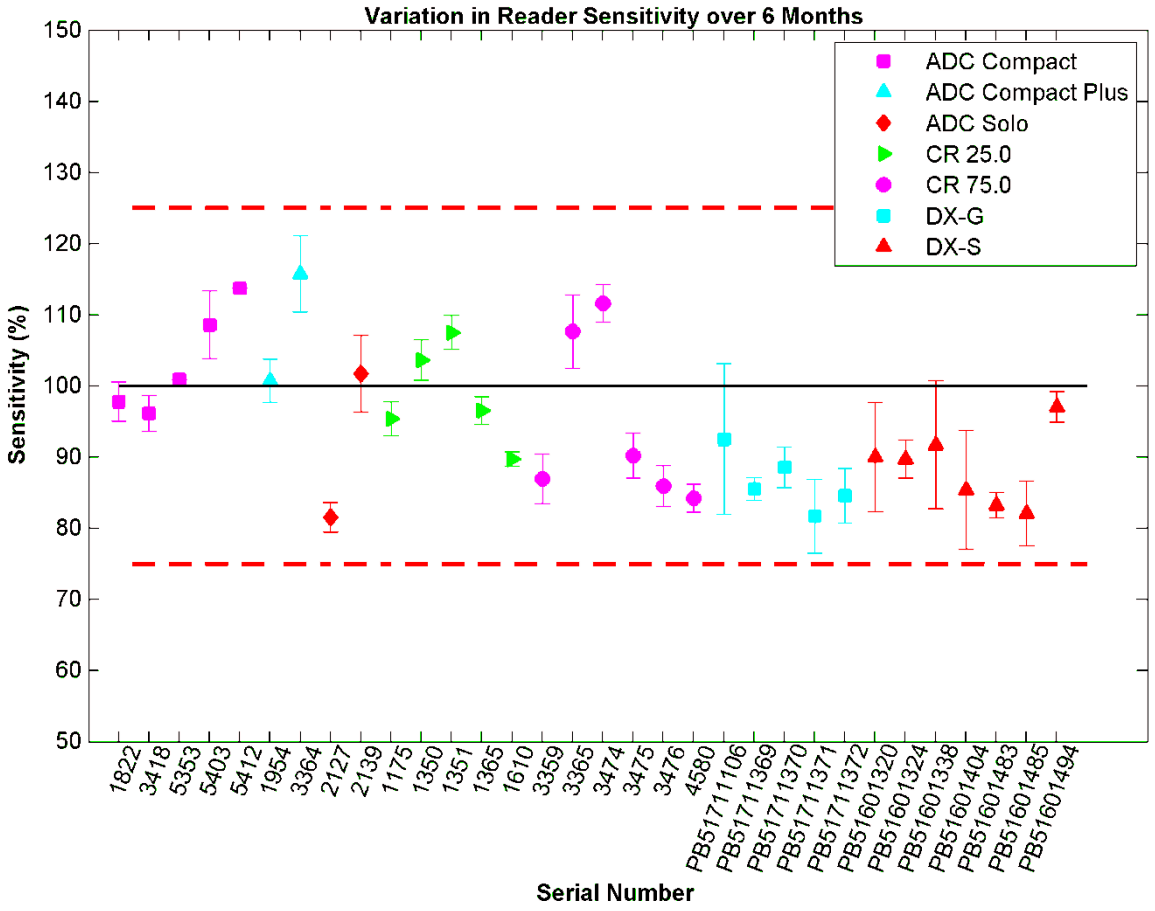
Prior to testing:



Post QC and Repair:



Variation in Sensitivity



Exposure Index Verification and Uniformity

Exam Tag	Delay	Filtration	SID	kVp	mAs	µGy (IP)*
FFPI	0 min	21 mm Al	150.0	75.0	10	20.3

* Value for double exposure w/ reported technique

						Artifacts (mark 1 if present, 2 if significant, 3 if unacceptable)								
Plate Label	Plate ID	Size	IS/ OOS	EI	P/F	Halo	Cleaning Streaks	Suction Cup Marks	Smudge / Watermarks	Scratches or Cracks	Other	Comments	Total Score	*
	QC1	14" x 17"	IS	2150	P							QC plate	0	E
	1	14" x 17"	IS	2091	P	2						FLFS	2	OK
	3	14" x 17"	IS	2255	P			1				FLFS	1	G
	5	14" x 17"	IS	2148	P							FLFS	0	E
	7	14" x 17"	IS	2046	P								0	E
	8	14" x 17"	IS	2177	P								0	E
	24	14" x 17"	IS	2076	P			2		1			3	RFS
	26	14" x 17"	IS	2336	P				1				1	G

* E = Excellent condition (score of 0), G = Good (1), OK = Adequate (2), RFS = Remove from service (score ≥3)

Expected EI:	2028			
Plate Average:	2103			**Tolerance Criteria:**
Tolerance Criteria (Single Plate) EI:	Min: 1682.7		Max: 2524	±20% of plate average
SD in Sensitivity:	109.0	**COV:**	5.2%	COV<±10% across all plates

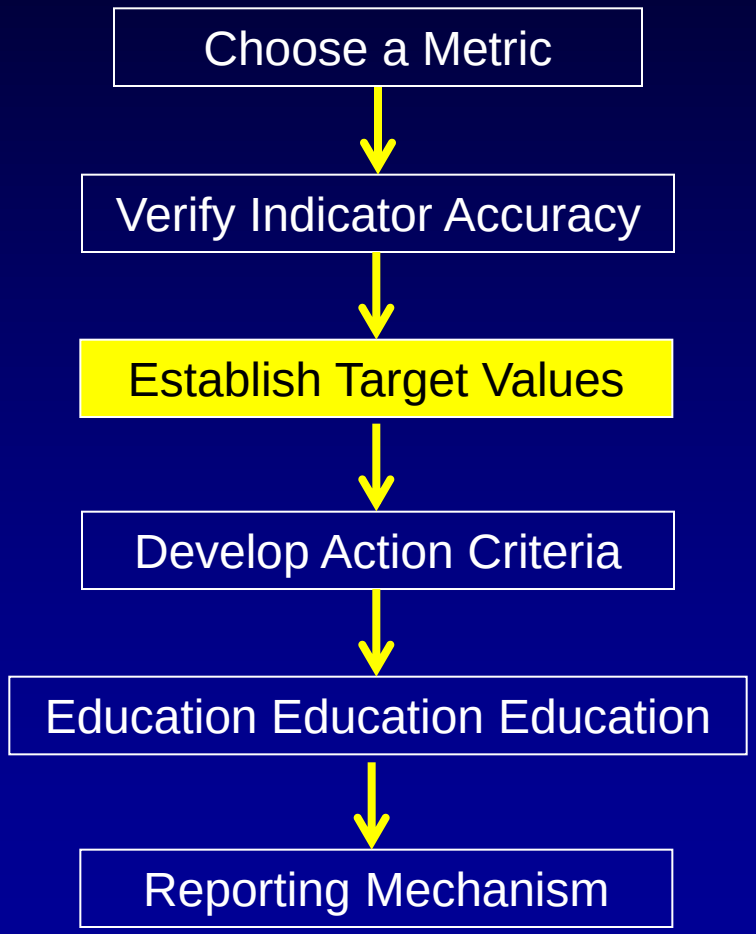
Exposure Indicator Accuracy (computed radiography)

- How well matched should my readers be?
  - ±25% should be achievable
  - TG-10 recommends readers be matched within ±10%
  - Can adjust the high-voltage settings on some units
  - In other cases have to replace the PMT

Indicator Accuracy

- **EI**
  - **± 20% - *IEC 62494-1***
- **P_{KA}**
  - **± 35% - *IEC 60601-2-43***
  - **For P_{KA} > 2.5 Gy-cm^2**
- **$K_{a,i}$**
  - **Vendor-defined**

Dose Tracking – Ongoing



Establishing TEI Values

- DI is only useful if you have selected a reasonable TEI
- Some vendors will provide recommended TEI values

DR MANUFACTURERS
AEC Sensitivity Calibration

	kVp	Grid?	Phantom	Target K_a (μGy)
GE Flashpad (CsI)	80	No	20 mm Al	2.5
Siemens (CsI)	70	No	0.6 mm Cu	2.5
Agfa DX-D (CsI)	70	No	25 mm Al	2.5
Philips	70	No	25 mm Al	2.5
Carestream DRX1-C	80	--	0.5 mm Cu + 1.0 mm Al	2.5
Canon CXDI-70C	80	Yes	20 cm PMMA	2.5

- Can calculate expected EI or PV for target K_a under AEC calibration conditions

AEC Calibration and EI

- VOI can matter
  - Make sure to use the appropriate exam tag
  - Know the VOI used for EI calculation
- If using a target EI:
  - Must verify accuracy of exposure indicator and account for it
  - For CR
    - Time between image and readout must be kept consistent
    - Use QC plate or plate of median sensitivity

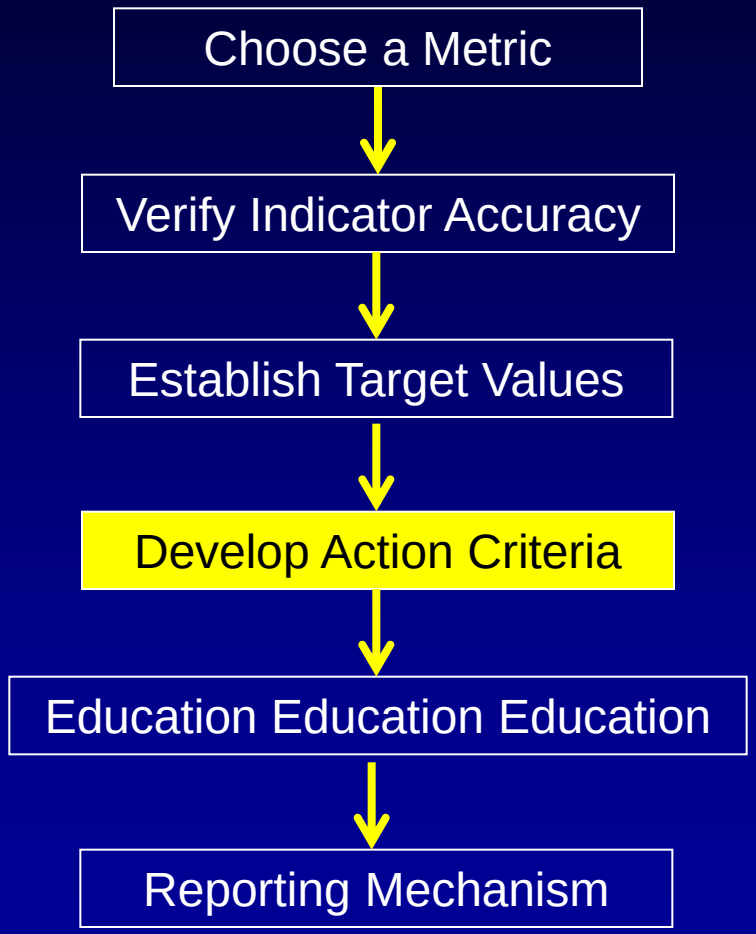
Establishing TEI Values

- The fewer sub-groups you have, the easier your TEI values are to implement…
- Our Agfa CR systems currently set up with three TEI sub-groups
- But are these right?
  - Chest (TEI – 350)
  - Non-Extremity (TEI – 400)
  - Extremity (TEI – 1000)

Entrance Air Kerma

- Still requires establishing a target value for it to be useful for ongoing QC
  - Individual values extremely dependent on patient size
  - No standardized method for normalization
  - Sample mean/ median < a DRL
    - DRL specific to Exam
    - DRL should be adjusted to account for patient distribution OR
    - DRL evaluation should be limited to specific weight category (difficult to automate this!)

Dose Tracking – Ongoing

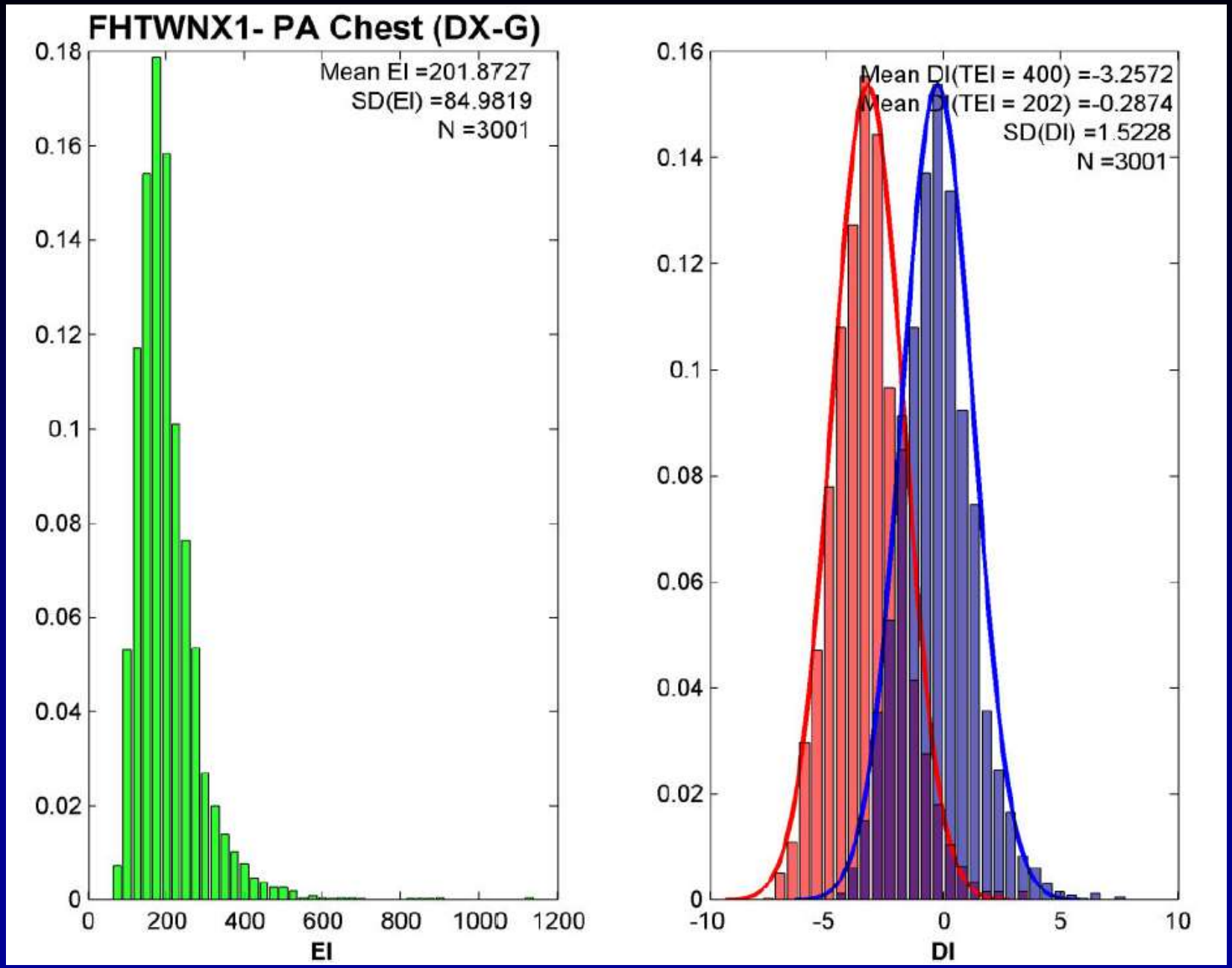


Setting Action Criteria

- Shape of distribution
- Expected variation

EI - Patterns

- Typically, 95% within +/- 2 DI
- SD in EI increases when manual techniques are used
- Log-normal distribution of EI
- Normal distribution of DI
  - SD in DI is independent of TEI
- Guidelines yet to be published
- Questions still to be answered:
  - What is a typical (acceptable) level of variation in the EI and DI
  - Are recommended TEI values optimized?



Hulme et al, *A Method for Deriving Exam-Specific Target Exposure Indices (TEI) in Computed Radiography as a Function of a Reference TEI,* TU-A-116-4

Color Coded Exposure Bar Ranges

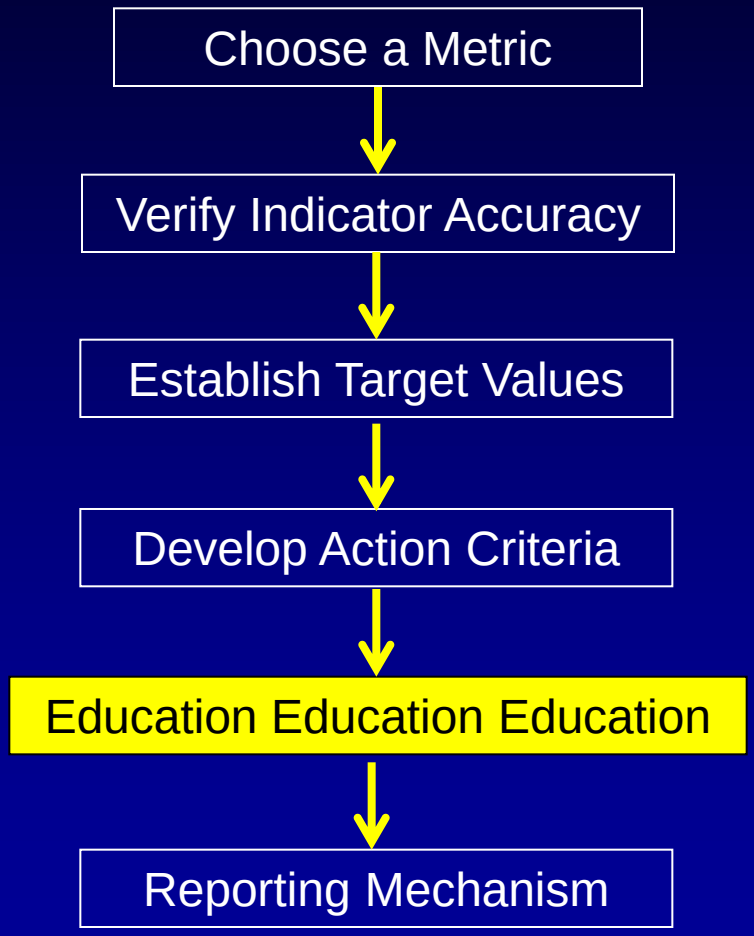
- Green (Go)
  - DI between -3 to +3 deviation units (aim 0)
  - Represents less than a 2x change (±) in exposure index from target
  - Images should be acceptable for exposure (no additional review required)

- Yellow (Caution)
  - DI between -6 and -3 or +3 and +6 Deviation Units
  - Represents a 2x to 4x change (±) in exposure index from target
  - Images may be under or overexposed, but could still be acceptable for use
  - Further review with supervision may be required to determine if repeat is needed

- Red (Alert)
  - DI < -6 or > + 6 deviation units
  - Represents a greater than 4x change (±) in exposure index from target
  - Images are probably significantly under or overexposed and are not acceptable
    - Technique settings and targets should be checked
    - Images should be reviewed with supervision and repeated (as needed)

Table provided courtesy of Agfa HealthCare.

Dose Tracking – Ongoing



IEC Exposure Index

- EI = Exposure Index
  - Approximate exposure to the plate
  - LINEAR with exposure
    - Double the mAs, EI doubles
- TEI = Target Exposure Index
  - ‘Ideal’ exposure to the plate
- DI = Deviation Index
  - How far above/below the TEI you are

Deviation Index *(IEC 62494-1)*

$$DI = 10 \cdot \log\left[\frac{EI}{EI_T}\right]$$

- A DI of 0 indicates the exposure was at the target value
- ±1 DI = ~ ±25% difference in exposure, or +1/-1 density on a phototimer
- +3 DI = 2x the target exposure
- -3 DI = ½ the target exposure

TG-116 Recommendations

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: 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

Deviation Index

Exposure	Deviation Index - DI	Correction Needed
Over Exposed	**6**	**Repeat if Image Saturated Reduce mAs 0.25x***
	>3	**Caution Decrease mAs 0.5x***
	2	**None**
	1	**None**
Aim	**0**	**None**
	-1	**None**
	-2	**None**
	<-3	**Possible Repeat Increase mAs 2x***
Under Exposed	**-6**	**Repeat Increase mAs 4x***

**If needed based on image quality or dose*

Table provided courtesy of Agfa HealthCare.

Test Dose Agfa (Skull, Sinus & Facial)

Screen shot courtesy of Agfa HealthCare

AGFA

Patient

Full Name : Test Dose Agfa
Patient Identification :
Accession Number :
Gender :
Birth Date :
Comments :

Edit

Image Detail

75 kVp, 6.3 mAs

Exam Group : Skull, Sinus & Facial
Exposure Type : LAT SKULL RIGHT
Accession Number :
Cassette Orientation: Portrait
View Position : RL

Exposure Index — EI : 389
TEI : 400
Deviation Index — DI : -0.1

Cassette ID : C0806050
Acquisition Date a... 2/14/2011 6:03:56 PM

Edit
Stitch Images

L R UPR DECUB SUP SEMI

Image Overview (6/6)

@Target Exposure:

EI = 389 (~ 400)

DI = -0.1 (~ 0)

Reject Image | Print Image | Send Image | ID | Add Image | Close and Send All

Worklist | Examination | Editing | Main Menu

Test Dose Agfa (Skull, Sinus & Facial)

Screen shot courtesy of Agfa HealthCare

AGFA

Patient

Full Name : **Test Dose Agfa**
Birth Date :
Patient Identification :
Accession Number :
Comments :
Gender :

Edit

Image Detail

75 kVp, 3.2 mAs

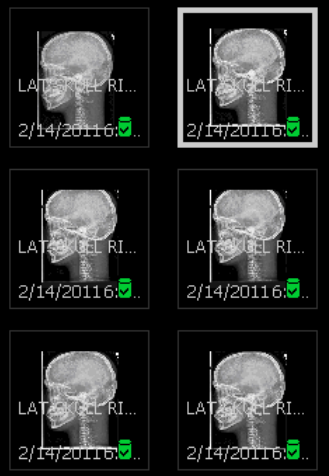
Exposure Index
Deviation Index

Exam Group : **Skull, Sinus & Facial**
Exposure Type : **LAT SKULL RIGHT**
Accession Number :
Cassette Orientation: **Portrait**
View Position : **RL**
EI : **204**
TEI : **400**
DI : **-2.9**
Cassette ID : **C0806047**
Acquisition Date a... **2/14/2011 6:11:13 PM**

Edit
Stitch Images

L R UPR DECUB SUP SEMI

Image Overview (6/6)



½ mAs:

EI = 204 (~ 200)

DI = -2.9 (~ -3)

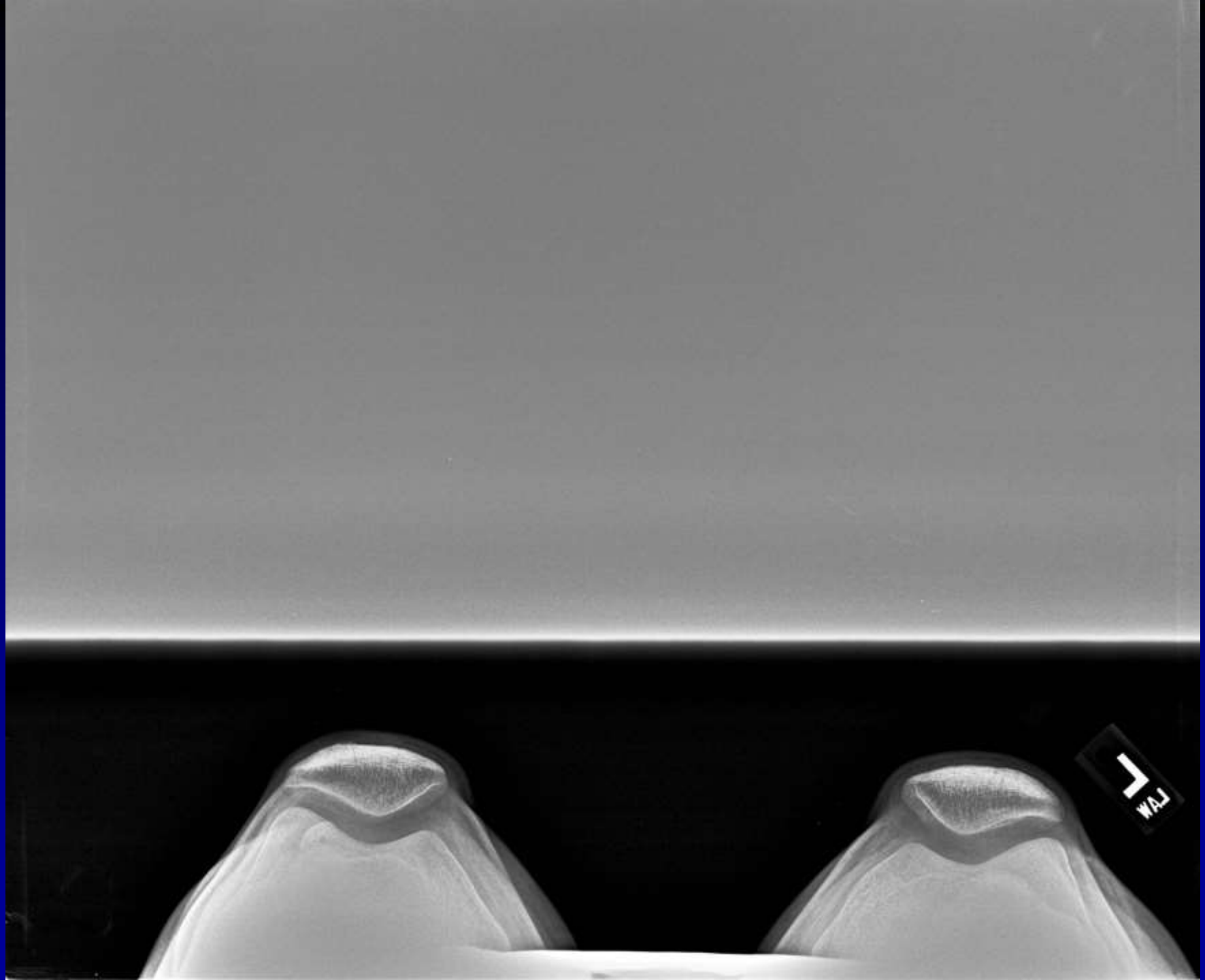
DI > -3 = green

Reject Image | Print Image | Send Image | ID | Add Image | Close and Send All

Worklist | Examination | Editing | Main Menu

Exposure Indices

- Remember, clinical exposure indices will vary with
  - Manufacturer (different VOIs)
  - Anatomical view
  - Collimation
  - Exposure indicator accuracy
- Manual techniques will have larger variation than photo-timed exams
- Errors in detecting collimation borders can result in inaccurate calculation of EI
  - i.e. Merchant view for knees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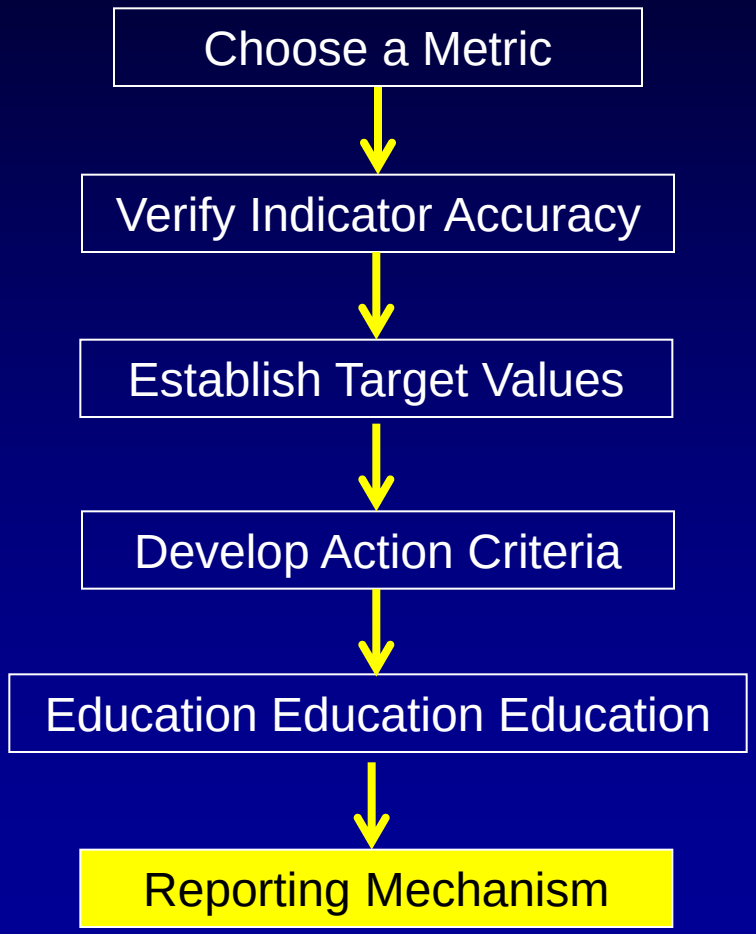
WAJ

Dose Tracking – Ongoing



Data Collection

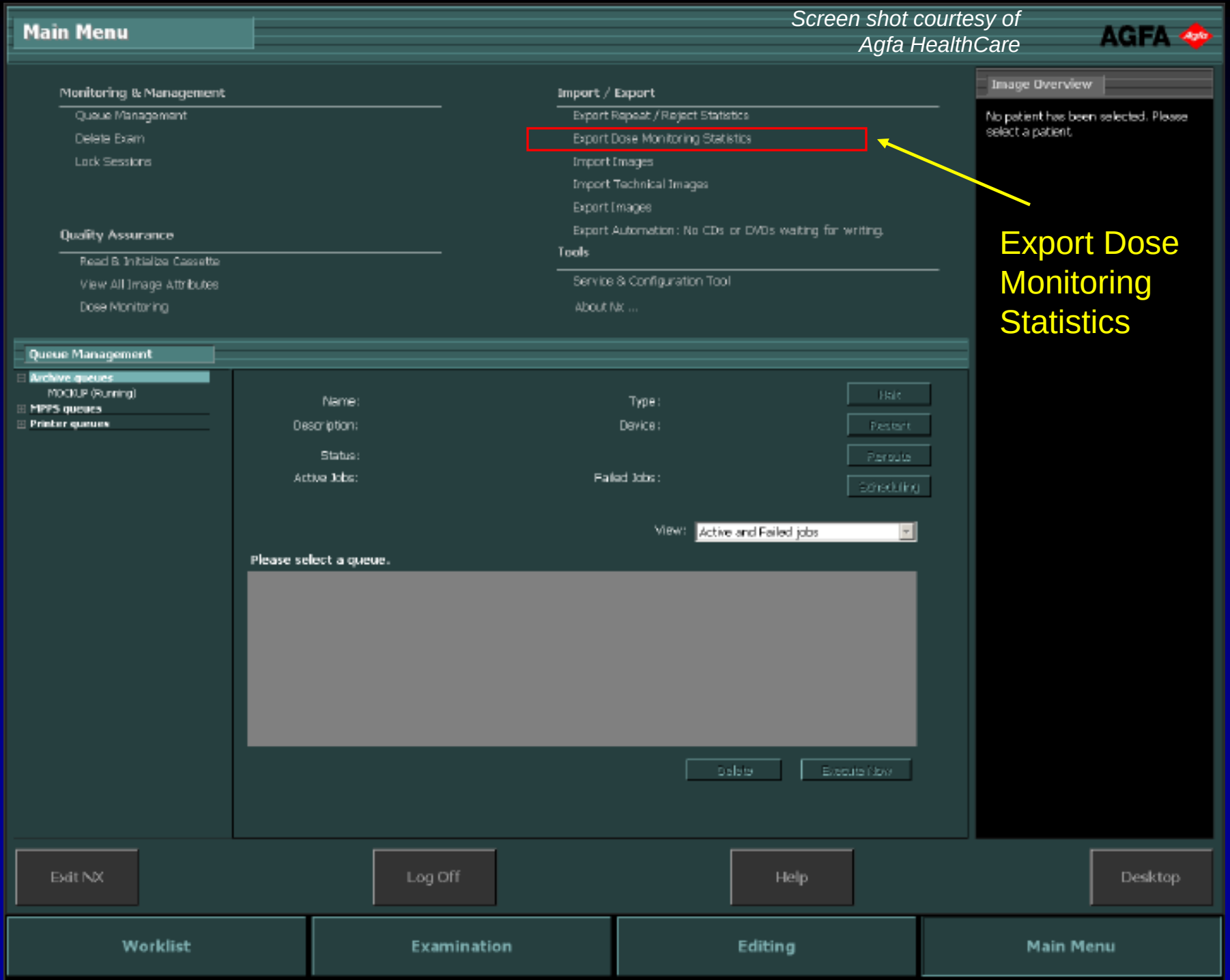
Multiple Options…… (TG-151)

- Paper (single site)
- Modality Performed Procedure Step (MPPS report)
- RIS – extract and archive data (DICOM RDSR or MPPS)
- Send images to a separate server and strip data

Data Collection

Multiple Options…… (TG-151)

- **Export data from workstation**
  - **Easiest option but not always packaged in a manner useful to the technologist**
  - **Need the option to export data in both formats**
    - **xml or csv**
    - **SIMPLE report for routine QC**
  - **Accidental or intentional deletion of data can occur (i.e. during software upgrade by service engineer)**


Main Menu
Screen shot courtesy of
Agfa HealthCare
AGFA
Monitoring & Management
Queue Management
Delete Exam
Lock Sessions
Quality Assurance
Read & Initialize Cassette
View All Image Attributes
Dose Monitoring
Import / Export
Export Repeat / Reject Statistics
Export Dose Monitoring Statistics
Import Images
Import Technical Images
Export Images
Export Automation : No CDs or DVDs waiting for writing.
Tools
Service & Configuration Tool
About NX ...
Image Overview
No patient has been selected. Please select a patient.
Export Dose Monitoring Statistics
Queue Management
Archive queues
MOD1UP (Running)
MPPS queues
Printer queues
Name:
Type:
Description:
Device:
Status:
Active Jobs:
Failed Jobs:
Halt
Restart
Pause
Scheduling
View:
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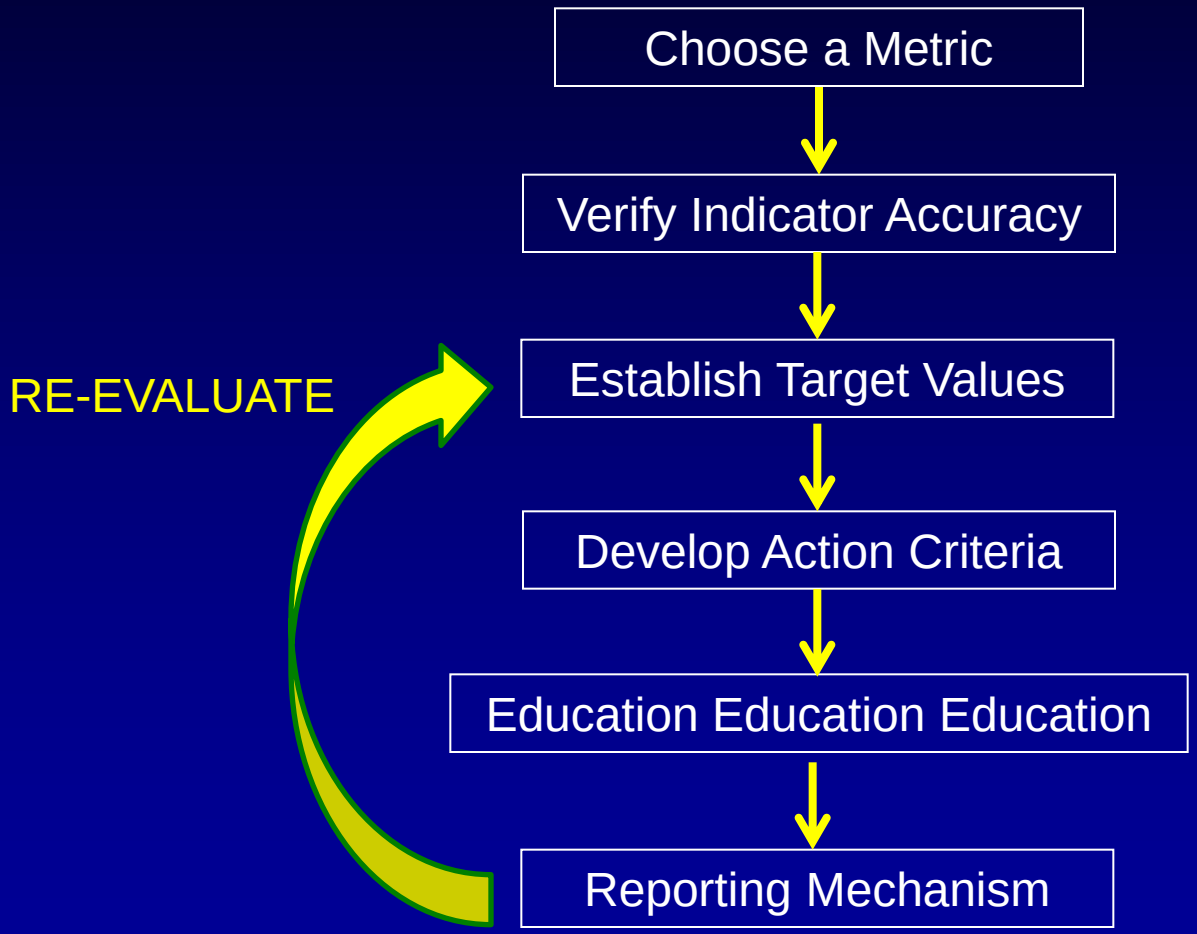
Dose Tracking – Ongoing



TEI vs. Exam Group

Exam Group (k)	N_k	Weighted Average*: $DI_{ref,k}$	Standard Error: $\Delta DI_{ref,k}$	$DI_{ref,k}$ *Sub-Group*	$K_{ref,k}$ *Sub-Group*	TEI_k (TEI_{ref}= 400)	TEI_k (TEI_{ref}= 350)	Weighted Average: $SD(DI_{ref,k})$	95% CI (±DI)
Chest	29078	-1.70	0.01	-2	0.6	252	221	0.79	1.6
Abdomen	3094	-1.30	0.03	-1	0.8	318	278	0.96	1.9
Abdomen GU	548	-1.24	0.03	-1	0.8	318	278	0.81	1.6
Mandible & TMJ	145	-0.76	0.07	-1	0.8	318	278	1.21	2.4
Nasal & Orbits	164	-0.63	0.08	-1	0.8	318	278	1.78	3.5
Spine	270	-0.51	0.05	0	1.0	400	350	2.26	4.4
C-Spine	7558	-0.37	0.01	0	1.0	400	350	1.01	2.0
Abdomen GI	536	-0.05	0.08	0	1.0	400	350	1.58	3.1
Full Leg / Full Spine	2863	0.20	0.01	0	1.0	400	350	1.78	3.5
T-Spine	1792	0.27	0.02	0	1.0	400	350	1.07	2.1
Shoulder	11367	0.38	0.01	0	1.0	400	350	0.95	1.9
Femur Knee Leg	27529	0.59	0.02	1	1.3	504	441	1.02	2.0
Skull, Sinus & Facial	465	0.89	0.06	1	1.3	504	441	0.98	1.9
L/S Spine	13172	0.94	0.02	1	1.3	504	441	0.82	1.6
Pelvis	60	1.05	0.24	1	1.3	504	441	1.87	3.7
Pelvis & Hip	10910	1.07	0.01	1	1.3	504	441	0.88	1.7
Lower Extremity	1124	2.08	0.03	2	1.6	634	555	2.68	5.3
Ankle & Foot	20519	3.26	0.01	3	2.0	798	698	0.83	1.6
Humerus, Elbow & Forearm	4400	4.10	0.03	4	2.5	1005	879	0.83	1.6
Hand & Wrist	11345	4.35	0.01	4	2.5	1005	879	0.75	1.5
Upper Extremity	680	4.43	0.08	4	2.5	1005	879	2.08	4.1

*Assuming an initial TEI of 400 for all exam tags

Hulme et al, *A Method for Deriving Exam-Specific Target Exposure Indices (TEI) in Computed Radiography as a Function of a Reference TEI,* TU-A-116-4

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