Exposure Indices and Target Values in Radiography: What Are They and How Can You Use Them

Rethinking Action Limits Based On Findings of TG151 Multi-site Survey

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Disclosures and Potential Conflict of Interest

- Member of X-Ray Medical Advisory Board GEMS

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

"too strict and did not accurately reflect clinical practice" (TG-232)

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?*

Efforts to establish "practical" DI recommendations

- AAPM Task Group #232
- Co-chairs: *Kyle Jones and Jaydev Dave*
- Task group charge:

  "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. The products of this task group will be a brief report and an updated version of Table 2 from AAPM Report #116."

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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

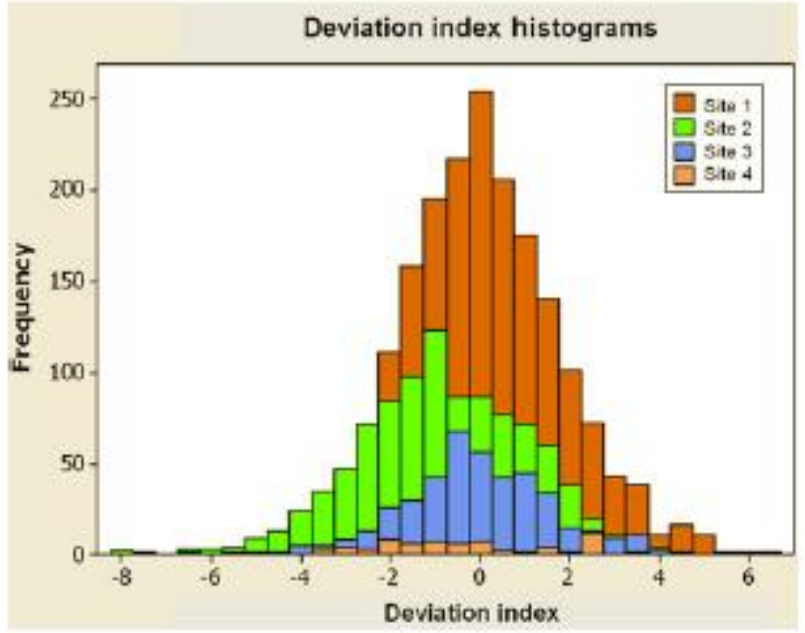


Fig. 1 Graph shows the distribution of the deviation index at each hospital

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

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%

TG 232 collected data from 11 sites

- Academic medical centers, large healthcare organizations, community clinics, and pediatric imaging departments.
- For adult and pediatric patients
- For a variety of body parts and views
  - PA, AP, LAT, and Decub Chest
  - AP Abdomen (KUB), upright and Decub abdomen
  - AP Pelvis
  - Extremity

TG 232 included data from

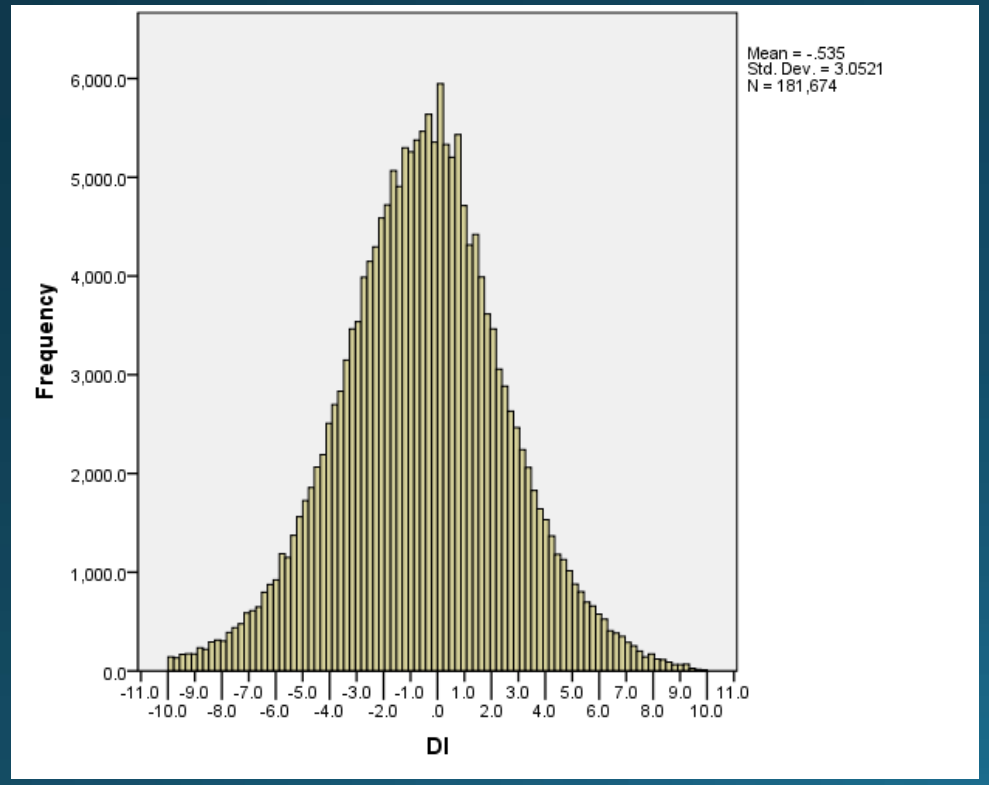
- Scanned-pixel (“CR”)
  - Agfa
  - Fujifilm
- Fixed-pixel (“DR”)
  - Agfa
  - Carestream
  - GE
  - Philips
  - Siemens

TG 232 analyzed 505,930 views with -9.9 ≤ DI ≤ +9.9

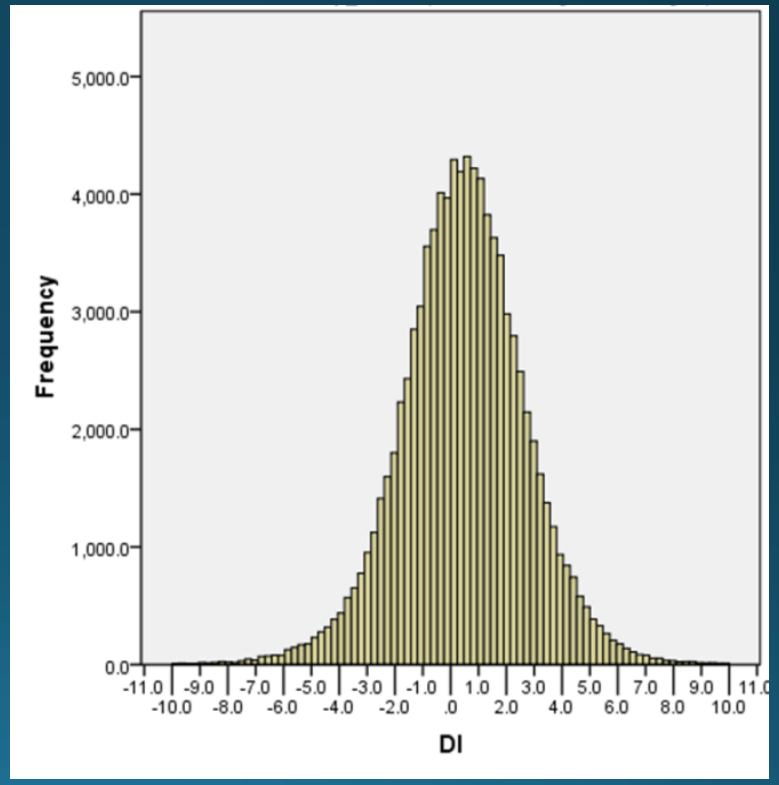
Body Part	Adult/pediatric	View	Number of views	% of total views
Abdomen	Adult	KUB	34803	6.9%
		Upright	5858	1.2%
		Decubitus	9182	1.8%
	Pediatric	KUB/Babygram	2648	0.5%
		Upright	307	0.1%
		Decubitus	208	<0.1%
Chest	Adult	AP	91756	18.1%
		PA	59906	11.8%
		Lateral	65511	12.9%
		Decubitus	258	0.1%
	Pediatric	AP	8609	1.7%
		PA	3410	0.7%
		Lateral	5195	1.0%
		Decubitus	15	<0.1%
Pelvis	Adult	AP	14300	2.8%
	Pediatric	AP	1285	0.3%
Extremity	Adult	Included views	181674	35.9%
	Pediatric	Included views	21005	4.2%

TG232 DI distributions were normally distributed

Distribution of DI data for adult extremity views

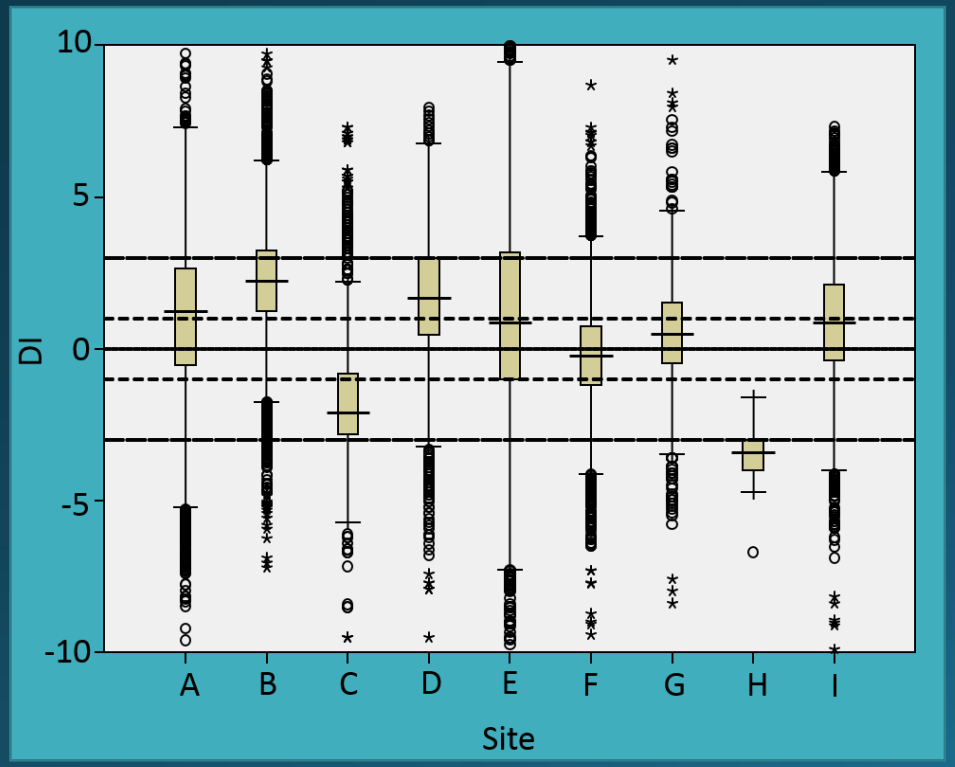


Distribution of DI data for adult AP Chest views

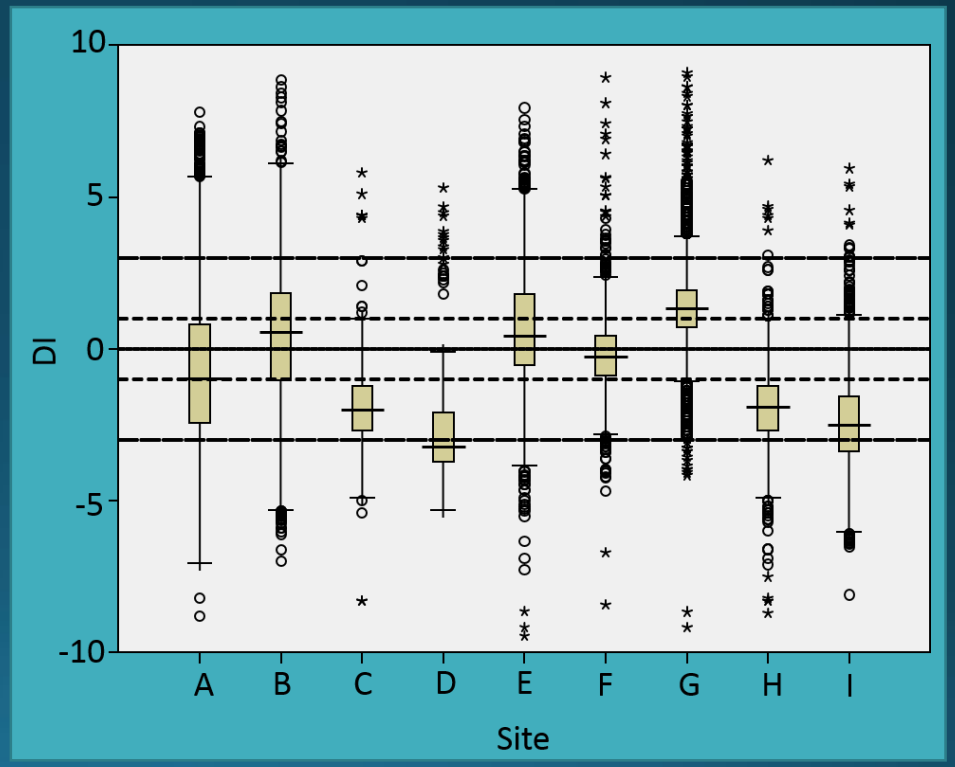


TG 232 analyzed all data for descriptive statistics and extreme values

Boxplot for Adult AP Abdomen



Boxplot for Adult PA Chest

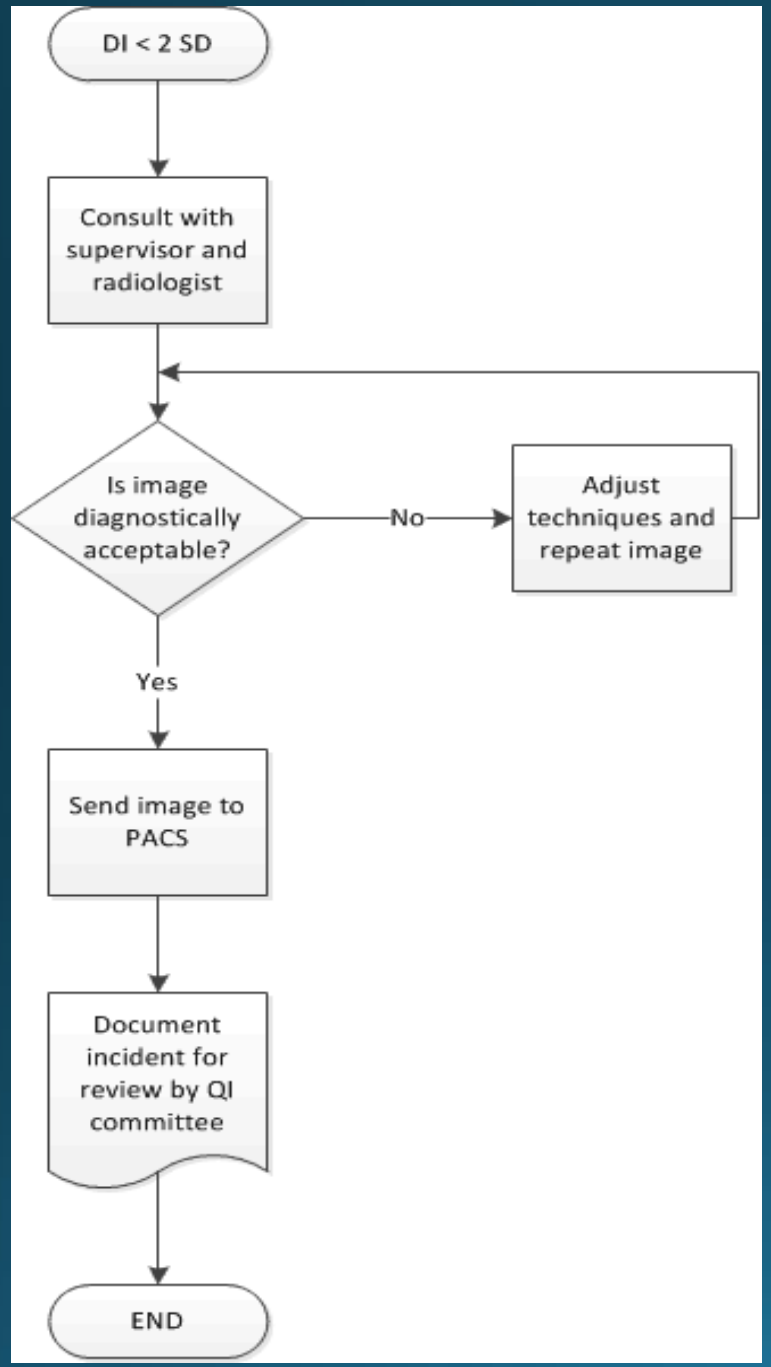


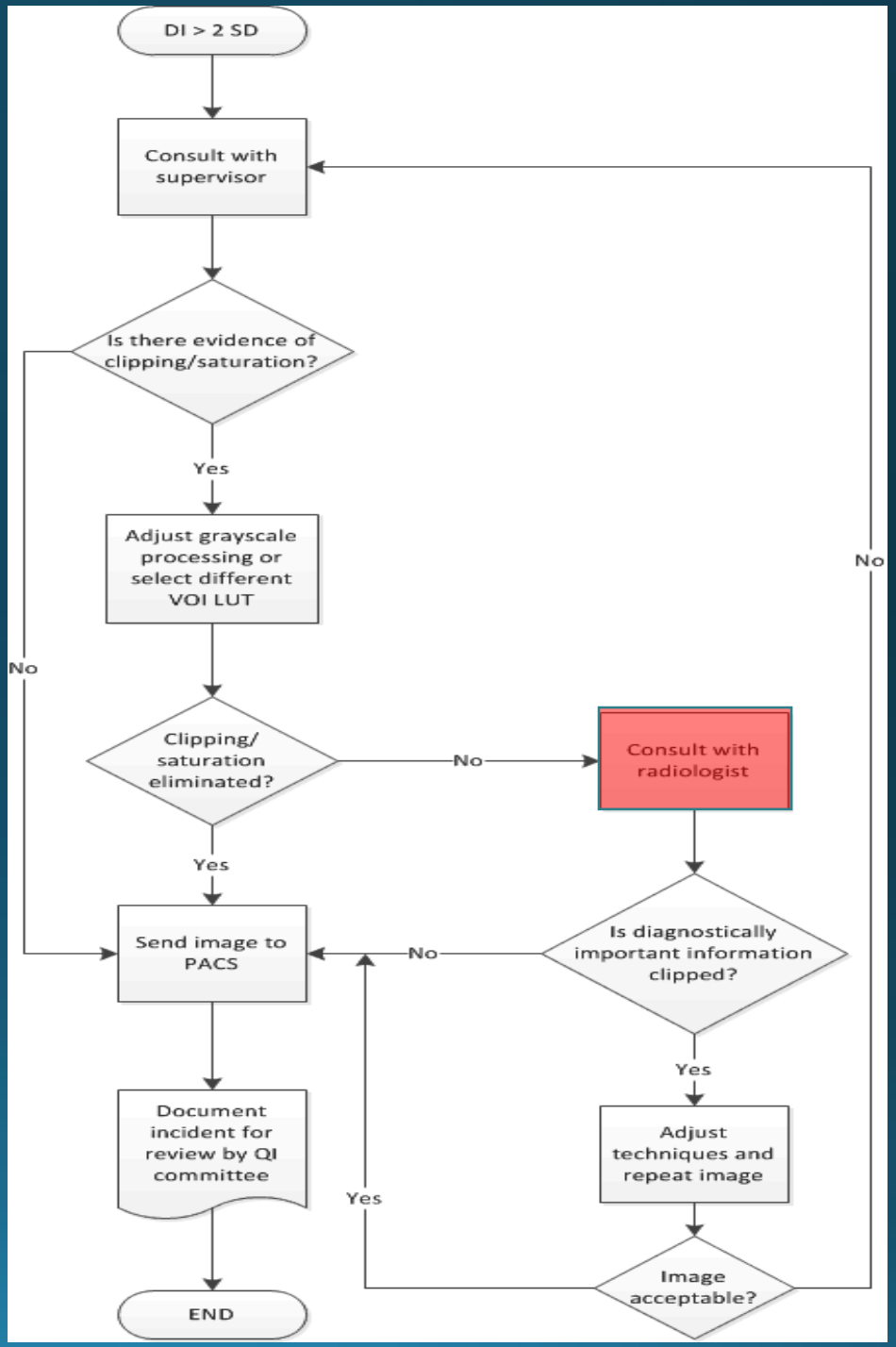
TG232 recommends action limits based on the standard deviation of DI rather than fixed values of DI

- ± 3 DI was only ±1 SD for abdomen and extremity data
  - *34% of exams would be rejected under these limits*
- Radiologists who reviewed selected images with DI of -5.0 ± 0.5 and +5.0 ± 0.5 rated them *"acceptable".*
- The SD of DI varied
  - *among sites for the same views*
    - 1.9 to 3.8 for AP Chest
  - *at each site for different views*

Action limits based on 2SD of DI distribution as starting point

- Then follow the algorithm for QC process
- Intent to narrow the distribution


DI < 2 SD
Consult with supervisor and radiologist
Is image diagnostically acceptable?
No
Adjust techniques and repeat image
Yes
Send image to PACS
Document incident for review by QI committee
END


DI > 2 SD
Consult with supervisor
Is there evidence of clipping/saturation?
Yes
Adjust grayscale processing or select different VOI LUT
No
Clipping/ saturation eliminated?
No
Consult with radiologist
Yes
Send image to PACS
No
Is diagnostically important information clipped?
Yes
Adjust techniques and repeat image
Yes
Image acceptable?
No
Document incident for review by QI committee
END

Computed Radiography X-Ray Exposure Trends

J. Anthony Seibert, PhD, David K. Shelton, MD, Elizabeth H. Moore, MD

Acad Radiol (1996) 3: 313-318

Before intervention

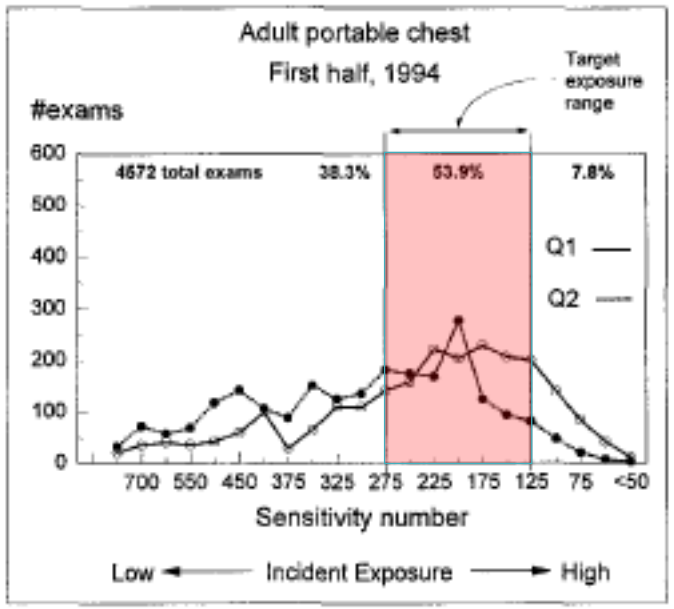


FIGURE 2. Adult portable chest examinations for the first half of 1994 are consolidated by quarter (January through March = quarter 1 [Q1] and April through June = quarter 2 [Q2]). The total number of films and percentages within each exposure range are listed at the inside top of the plot.

After intervention

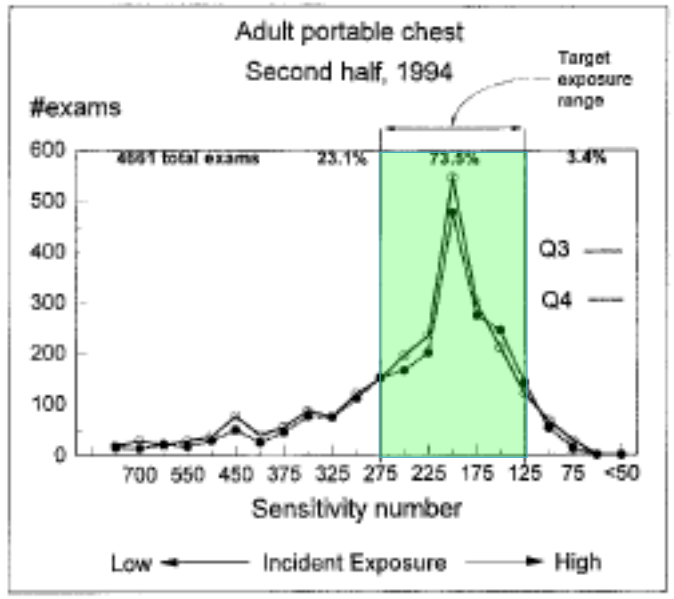


FIGURE 3. Adult portable chest examinations for the second half of 1994 are consolidated by quarter (July through September = quarter 3 [Q3] and October through December = quarter 4 [Q4]). The total number of films and percentages within each exposure range are listed at the inside top of the plot.

Note: -1.4 ≤ DI ≤ +2.0

What was the “intervention”?

- Quality Control audit
- Educational feedback

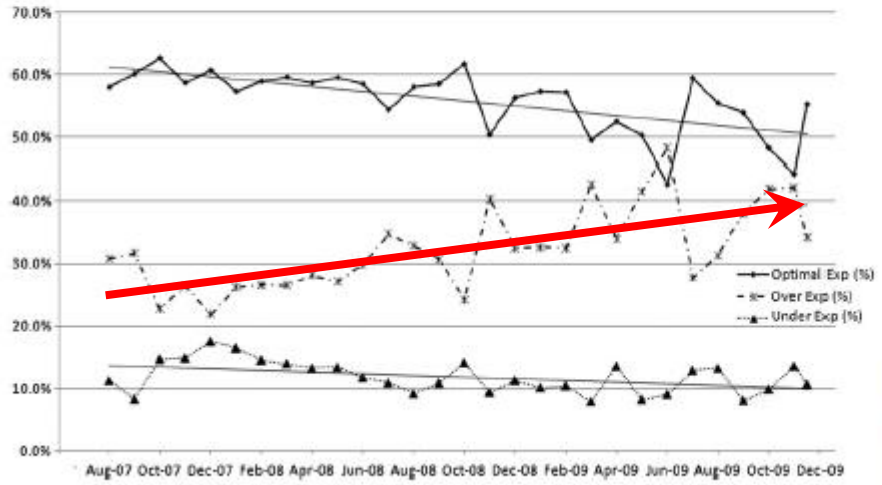


Figure 1. Plot of intensive and critical care unit chest x-ray indicating optimal, over-, and underexposed exposure indexes percentages between August 2007 and December 2009.

Note: -2 ≤ DI ≤ +2

Before intervention

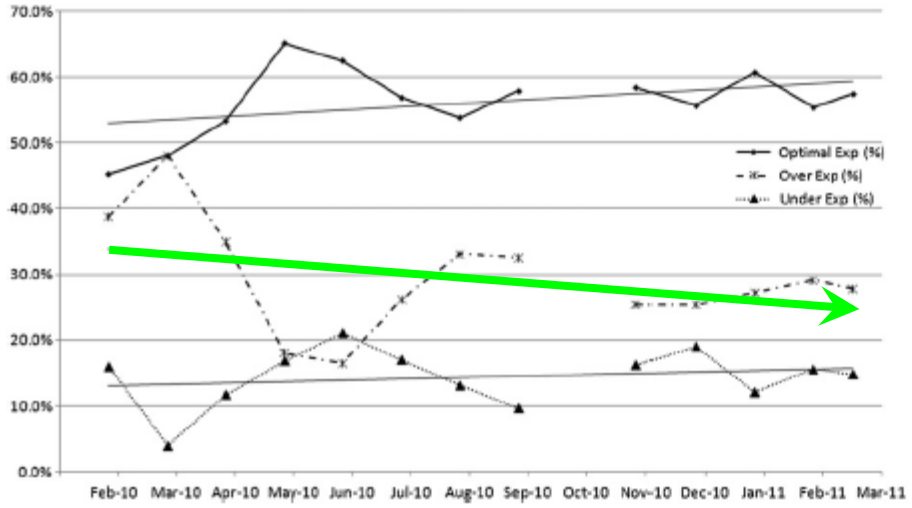


Figure 3. Plot of ICCU CXR indicating optimal, over-, and underexposed exposure index percentages between February 2010 and March 2011.

After intervention

What was the “intervention”?

- Individual exposure factors were recorded
  - kVp, mAs, SID, grid/nongrid, pt position, EI/DI
- Subsequent radiographs on same patient
  - mAs was scaled to achieve DI ≈ 0

Willis CE (1999) Computed Radiography: QA/QC. In: AAPM Monograph No. 25.

Table 2. QC evaluation based on exposure index.					Added
[1]FUJI (S Number)	AGFA (lgM Value)	KODAK (Exposure Index)	[2]*Detector Exposure Estimate (mR)*	INDICATION *and Action*	***Δ DI***
>1000	<1.45	<1250	*<0.20*	Underexposed - repeat view	*DI <-7.5 (DI <-7)*
601-1000	1.45-1.74	1250-1549	*0.3-0.2*	Underexposed - QC exception required	3.0 (2.2)
301-600	1.75-2.04	1550-1849	*0.7-0.3*	Underexposed - QC approval required	3.0
150-300	2.05-2.35	1850-2150	*1.3-0.7*	Acceptable range	3.0
75-149	2.36-2.65	2151-2450	*2.7-1.3*	Overexposed - QC approval required	3.0
50-74	2.66-2.95	2451-2750	*4.0-2.7*	Overexposed - QC exception required	3.0 (1.7)
<50	>2.95	>2750	*>4.0*	Overexposed - repeat view	*DI > 7.5 (DI > 6)*
Note 1: Willis, Mercier, Patel (1996) Modification of QA procedures to accommodate CR. SCAR. 275-281.					
Note 2: Appendix B. ACR-AAPM-SIIM Practice Guideline for Digital Radiography (2007 and 2009 but *not* 2012)					

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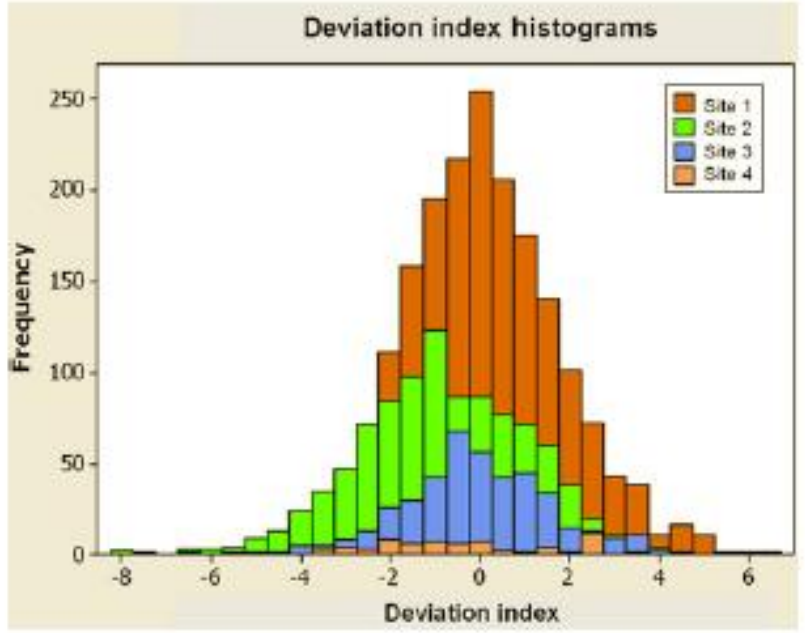

Fig. 1 Graph shows the distribution of the deviation index at each hospital

According to ± 3 DI guideline, ~ 90% of these images would be acceptable!

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%
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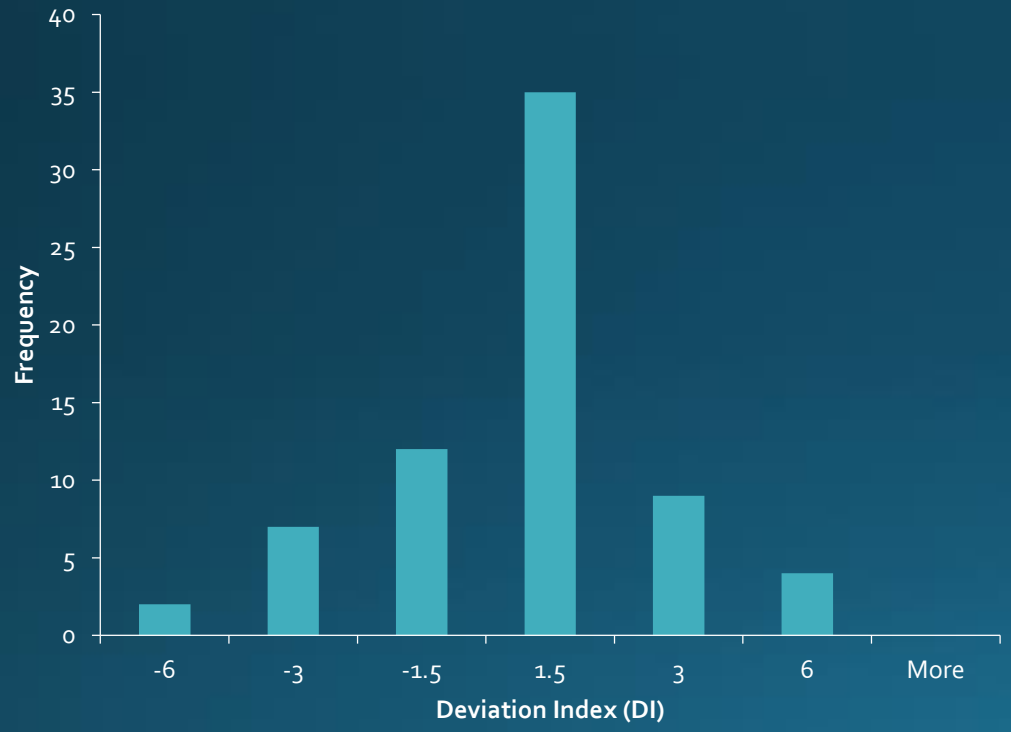
Site 3	−0.07	1.67	49%	79%	91%	98%
Site 4	−0.48	1.94	31%	58%	92%	98%
Combined normalized results	0	1.75	45%	76%	92%	98%

69 Bedside AP Chest Exams

(note: x-axes indicate top of bin)

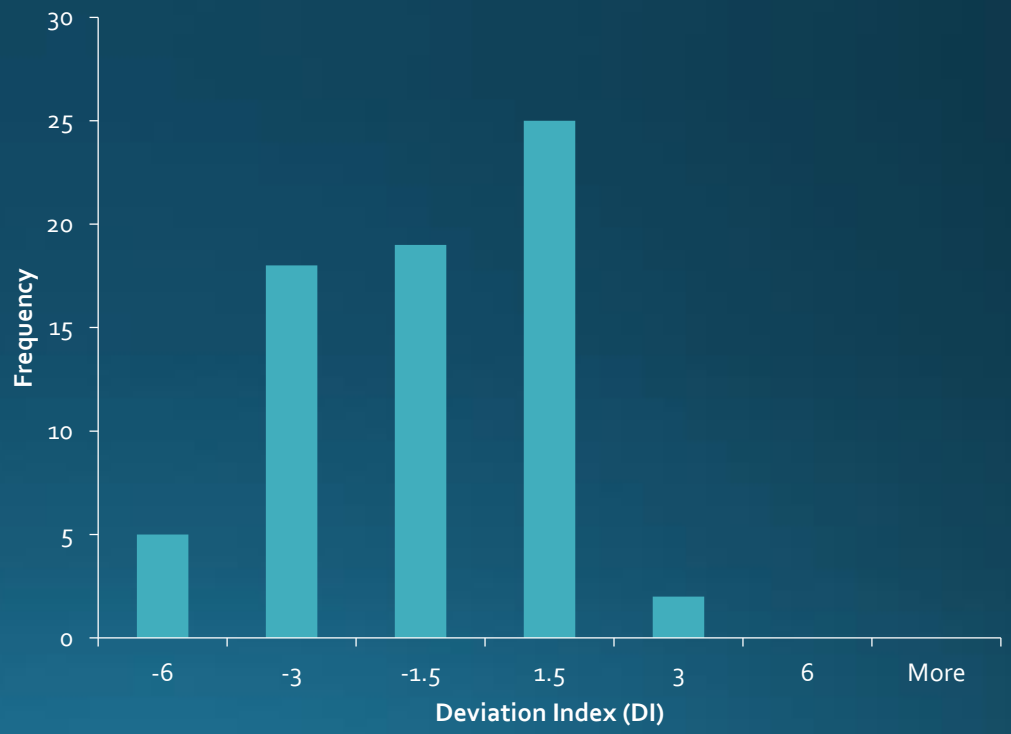
Deviation Index (EI_{TGT}=562)

AP Chest - Carestream



Histogram DI (EI_{TGT}=850)

AP Chest - Carestream



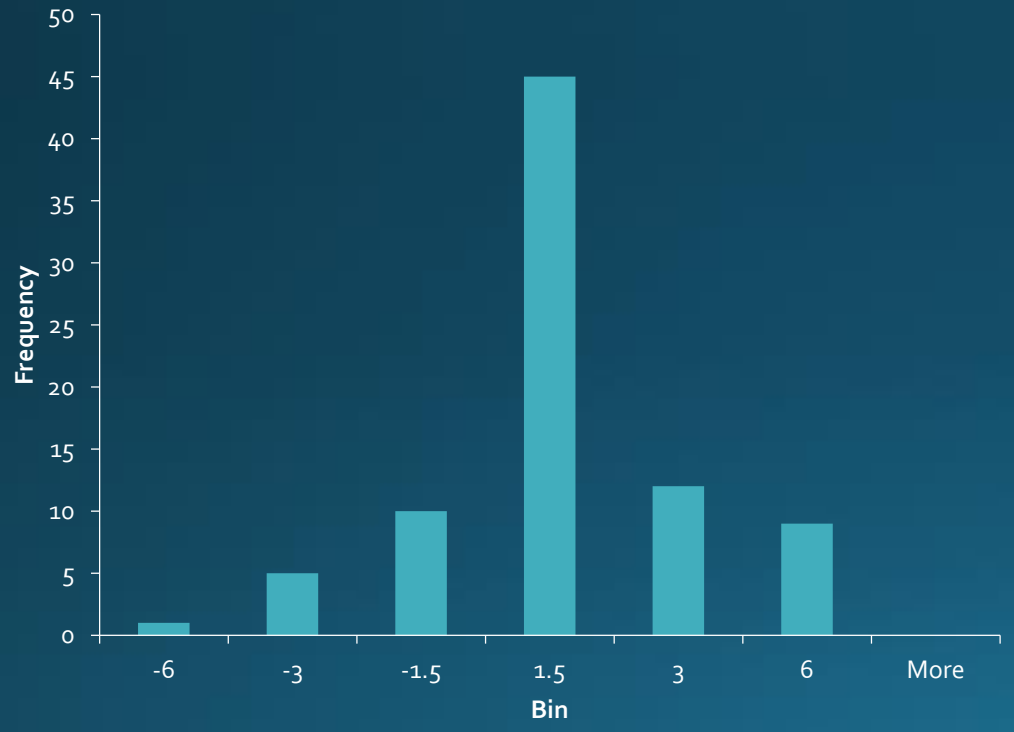
51% within ± 1.5 ; 81% within ± 3 ; 97% within ± 6

82 Bedside AP Chest Exams

(note: x-axes indicate top of bin)

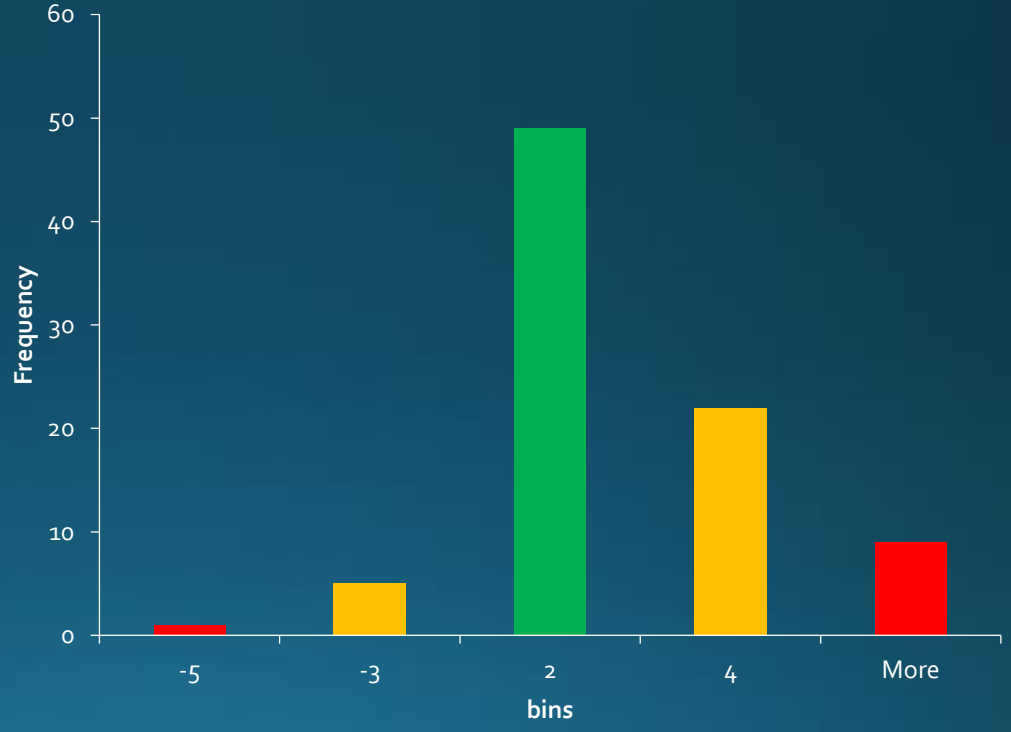
Histogram DI (EI_{TGT}=786)

AP Chest – GE XR220



Same data re-binned using GE default limits

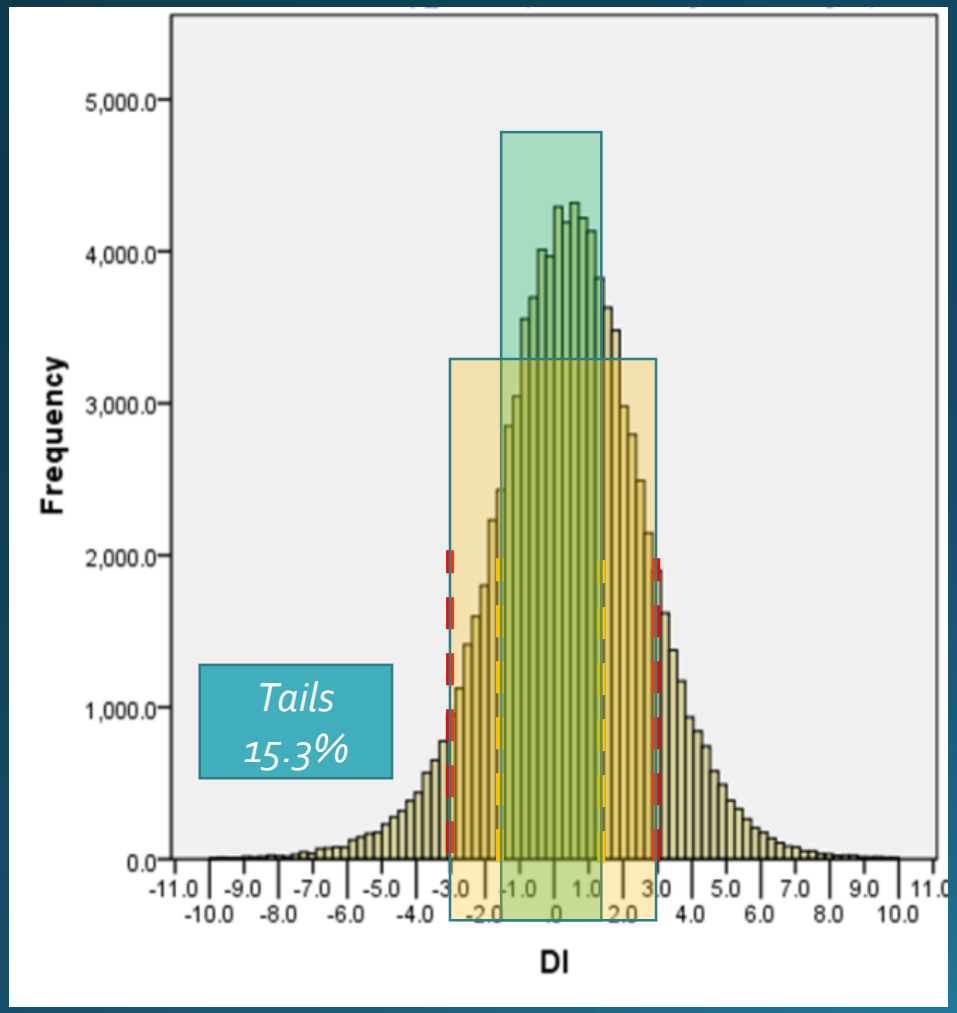
(-5, -3, +2, +4)



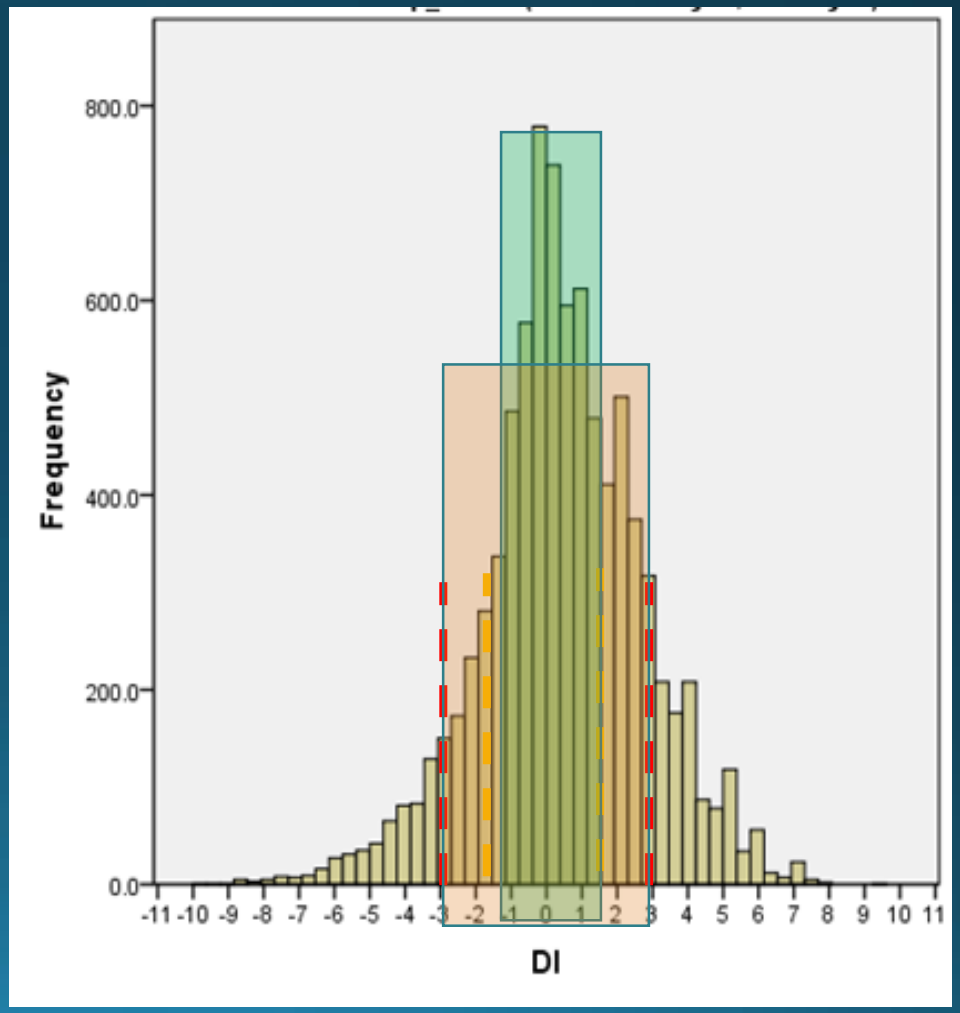
If targets seem high to you, we deliberately shoot 250 speed class

How do the alternative limits relate to TG 232 data?

Adult AP Chest

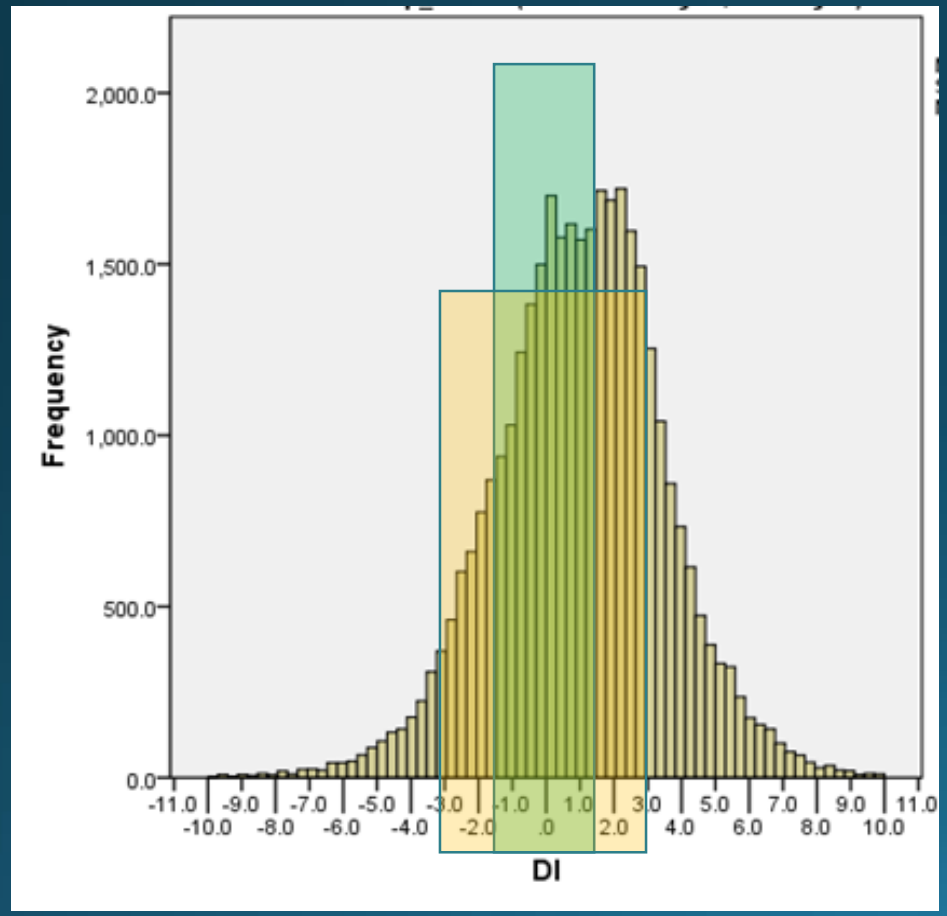


Pediatric AP Chest

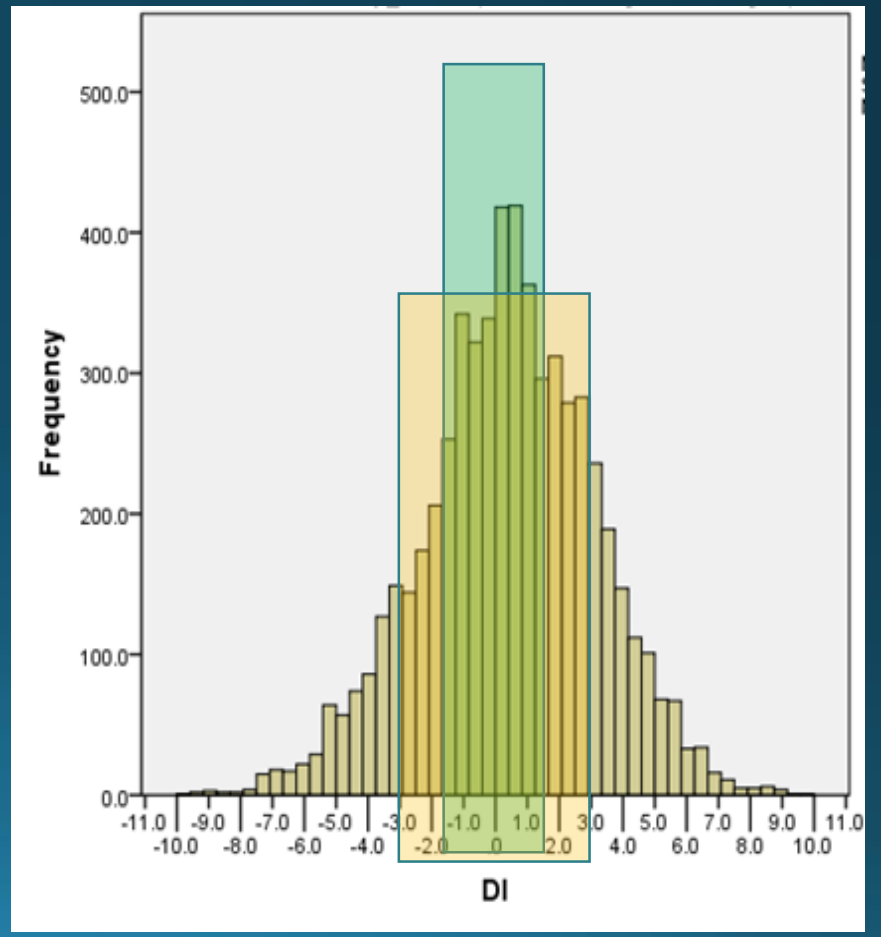


TG232 Data where alternative limits were problematic – large Standard Deviation of DI

Adult KUB



Adult Upright Abdomen



Conclusions

- Thanks to TG116, IEC, and the vendors, the standardization of EI and DI have finally provided a vehicle for objective assessment and quality improvement in digital radiography.
- TG232 provided an exceptional description of the state of practice which only remains to be published.
- TG232 recommends using ± 2SD of the DI for a given view as the starting point for a QI algorithm.
- An alternative set of limits based on factors of two in the exposure domain has been proven to be useful in clinical practice.
- The primary purpose of this effort is to improve consistency; the secondary purpose is to manage radiation exposure to the patient.
- QC based on DI can only be meaningful when EI_{tgt} is properly selected, machines are properly calibrated, and segmentation is successful, along with other potential interferences.