Clinical Utilization Strategies and Challenges
with Exposure and Deviation Indices

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No disclosures of support or conflict of interest

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Outline

- Clinical Utilization Overview
- Getting to Meaningful EI data
- Developing EI Targets
- Clinical Feedback Loop
  - Practice oversight
  - Tech education
- Summary

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EI and DI
Clinical Utilization Overview

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Need for Exposure Feedback
practice oversight

Metrics are needed:

- To define a “proper” exposure
- For evaluation of outlier images
  - that may indicate areas for tech education, improved acquisition strategies, or problems with equipment settings

Exposure feedback can alert us to system default issues, problem techniques, or problems in following the techniques

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Need for Exposure Feedback *for techs*

- Guidance is needed for achieving a “proper” exposure
  - Educational reinforcement to move away from film-based imaging strategies
  - Avoiding dose creep
- Challenging imaging situations occur and things don’t always go perfectly
  - Direction for how to adjust technique when retakes are needed

Exposure feedback can alert techs to the possibility of an image quality issue and how to approach fixing it

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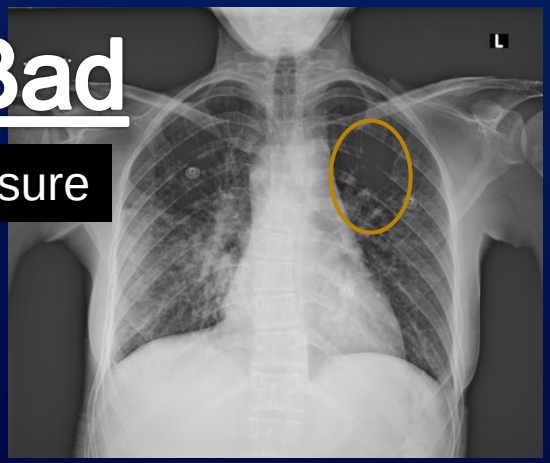
The Good, the Bad and the Ugly

The Good

- *Radiologist-specified*
- *Diagnostic value not compromised by noise*
- *Exposure isn't excessive to what is needed*

The Bad

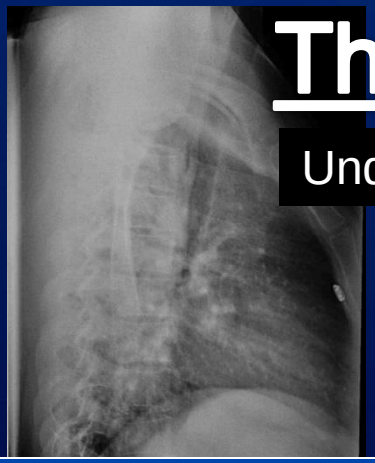
Over-Exposure



- Significantly more mAs than needed for "good"
- *May be clipping if extreme*
- Patient receives excess exposure

The Ugly

Under-Exposure



- Less mAs than is desired for "good"
- *Too noisy*
- Excess patient dose with retakes

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This is Not Film

Over-exposures are not generally obvious

Same patient

A. Lat

B. Ext Lat

Which image has 3 times the air kerma to the detector at L3?

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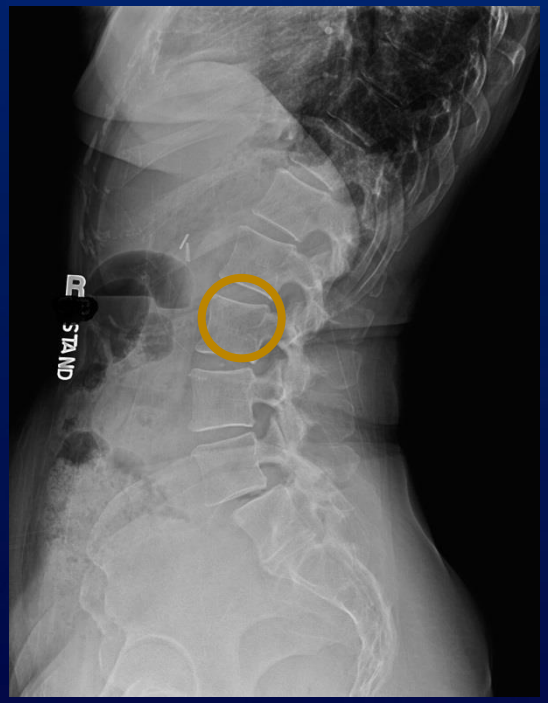
Unlike for Film

Image brightness or contrast in a digital image doesn't tell us how well an image was exposed



"raw" pixel value:

500

1550 hmm

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Concern for Exposure Creep

Because images may look better when they are overexposed :

- Technologists may feel pressured to increase exposures over time (to improve image quality)

If people are following technique charts, creep shouldn't happen ☺

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Exposure feedback
Using incident air kerma (IAK) to the patient?

70kVp, **22 mAs**

70 kVp, **65 mAs**

No.

Different patients need different exposures to achieve the same image quality

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Exposure feedback
With EI, DI?

EI = 350, DI = -0.4

EI = 398, DI = 0.2

Yes.

Better relation to image properties.

Different patients need different exposures to achieve the same quality of exam.

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EI and DI for Exposure Feedback

- Standard based
- A metric that has the potential to relate to both
  - Consistency in image quality
  - Patient exposure
- **Currently available** *(on many radiography systems)*

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EI for Image Quality Consistency

Questions to ask about EI

1. How well robustly does it track image quality?
   - For what constraints or granularity?
   - Vendor system variation?
   - Where might it fail?
2. Strategy to define “proper” exposure (EI target)?
3. How can a practice use this information for optimization?
4. How can technologists use this information for quality standardization?

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Getting to meaningful EI data-
Challenges

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Elements of EI
sources of variability in calculation

As defined in IEC (2008) and AAPM (2009),

EI is a:

- Measure of detector response to incident radiation in a **relevant image region**
- Described by a value of interest which is a function of the image receptor air kerma
- Defined by a function that is valid **for a standard beam**
  - EI $= \frac{100}{\mu Gy} K_{CAL}$, where K_{CAL} is the image receptor air kerma at calibration

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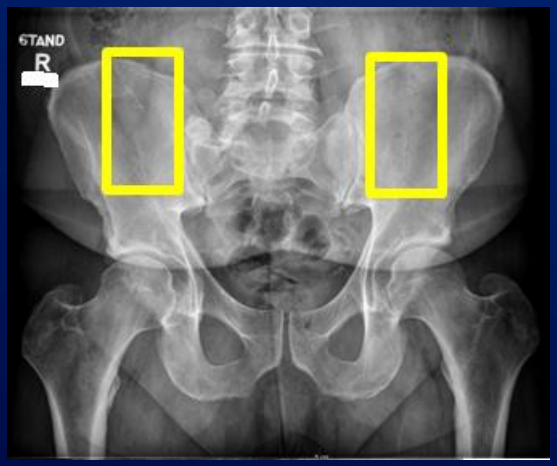
EI dependence on the **relevant image region**

Different systems may calculate EI differently because they choose different parts of the image as *relevant*.

This complicates comparison between systems

Segmenting to the anatomy



AEC: looks at region under selected cells
Manual: segments to the anatomy

Other segmentation scheme,
looks at “green snow”

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Sources of EI Calculation Complications

- Inconsistent selection of diagnostically relevant region
    - Positioning
    - Collimation
    - Shuttering failure
- Variations in x-ray beam energies (kVp, beam hardening)

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EI Data Files

Vendor-provided EI data may include anatomical view and kVp

Recepto	Anatom	View	Exposu	Exposu	uAs	kVp	SID(mm	Grid	EI
TABLE	SHOULDE	antero-pos	AUTOMA	CENTRAL	12706	70	1220	IN	402.252
TABLE	SHOULDE	antero-pos	AUTOMA	CENTRAL	12942	70	1220	IN	413.82
DIGITALCA	SHOULDE	axial	FIXED	NO_ION_(	40037	75	1000	IN	973.3431
WALLSTA	KNEE	antero-pos	FIXED	NO_ION_(	16031	65	1220	IN	391.7517
DIGITALCA	PATELLA	tangential	FIXED	NO_ION_(	12523	70	1000	OUT	206.5485
TABLE	SHOULDE	antero-pos	AUTOMA	CENTRAL	22234	70	1219	IN	308.1303
TABLE	SHOULDE	antero-pos	FIXED	NO_ION_(	31977	70	1219	IN	389.1065
TABLE	SHOULDE	antero-pos	AUTOMA	CENTRAL	81389	70	1219	IN	302.3463
DIGITALCA	SHOULDE	axial	FIXED	NO_ION_(	19966	70	1000	IN	564.746
DIGITALCA	SHOULDE	axial	FIXED	NO_ION_(	19970	70	1000	IN	267.7481
DIGITALCA	ANKLE	antero-pos	FIXED	NO_ION_(	8049	65	1000	OUT	386.3208

EI analysis is done separately for specific anatomical view and kVp (range).

NOTE: no information provided to tie data to images

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Analytics Needs –tools we use in addition to EI and DI

- Anatomical view
- Patient data (for compares –size measurement)
- All acquisition details (grid, AEC, kVp, SID, mAs, mA)
- RAW IMAGE DATA!
- Reject images and data
- Access to a table of EI targets
  - And how they vary with “speed”, kVp
- Offline protocol and processing databases

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Reconciling EI Data by View

- Technologists may acquire different views under the same view settings.
- Variations in positioning may be included under one view label.

Source images tied to data must viewable to see problems

Both run as "AP" Shoulder

"proper" exposures of these views have different EI targets

If technique or processing doesn't vary much between views, techs may not think they need to pick the correctly labeled view. This can undermine EI analysis.

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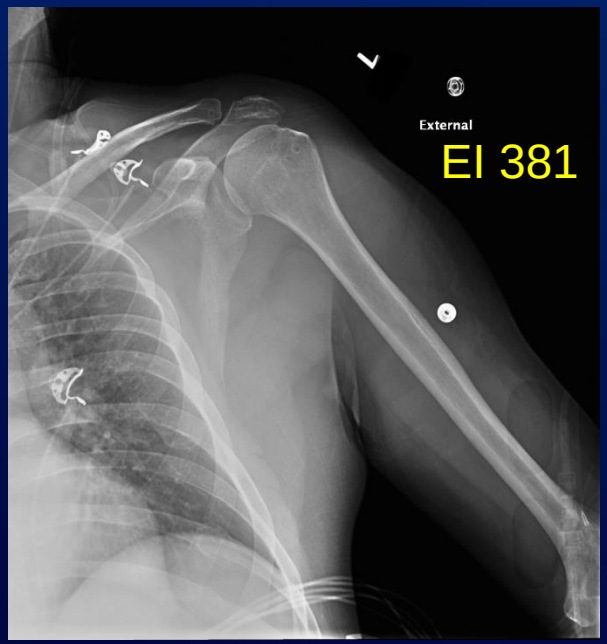
EI Dependence on the **Positioning**

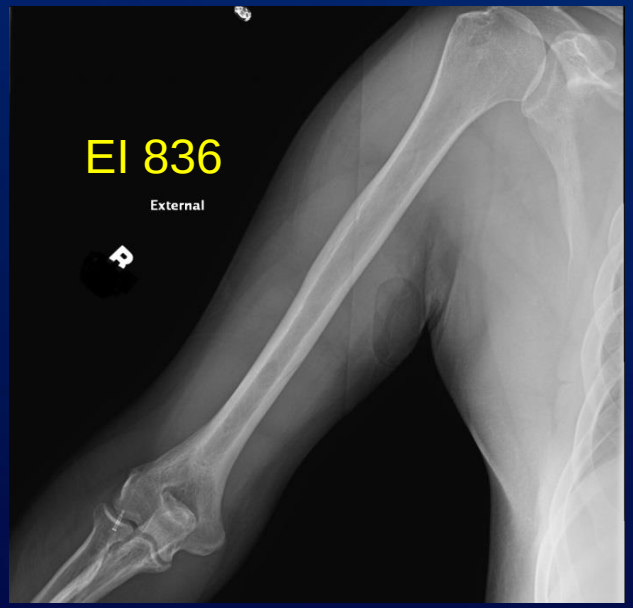
For segmentation that includes all anatomy in the collimated area:

Consistent positioning and collimation is crucial to meaningful EI

Same patient
Both “humerus” images

Same technique





Other segmentation strategies have their own challenges for robustness

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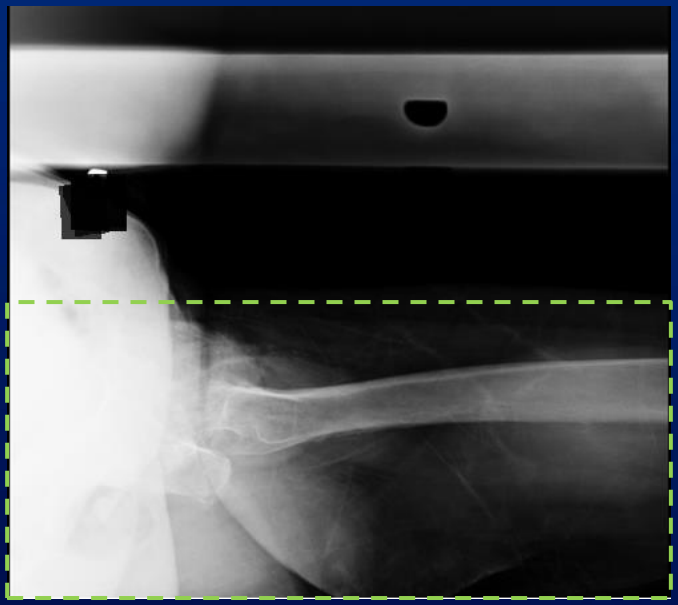
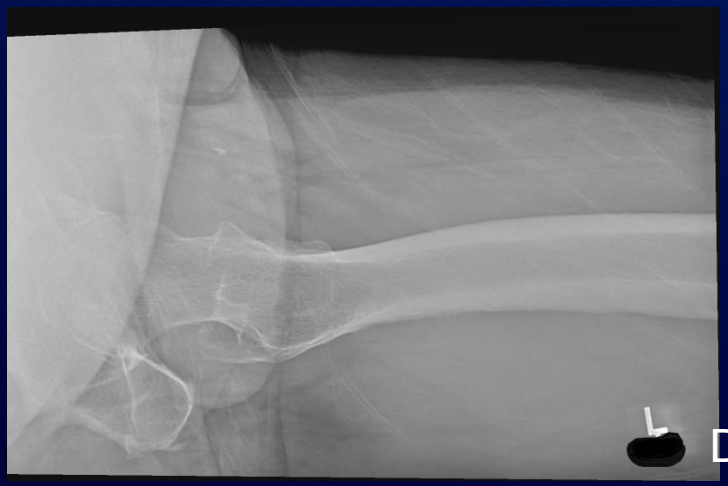
EI dependence on shuttering to the *relevant* image region



Impact of shutter failure

Before shutter and reprocess
EI =1647, DI =3.5



After shutter and reprocess
EI= 805, DI = .4
Target = 728

Desired image

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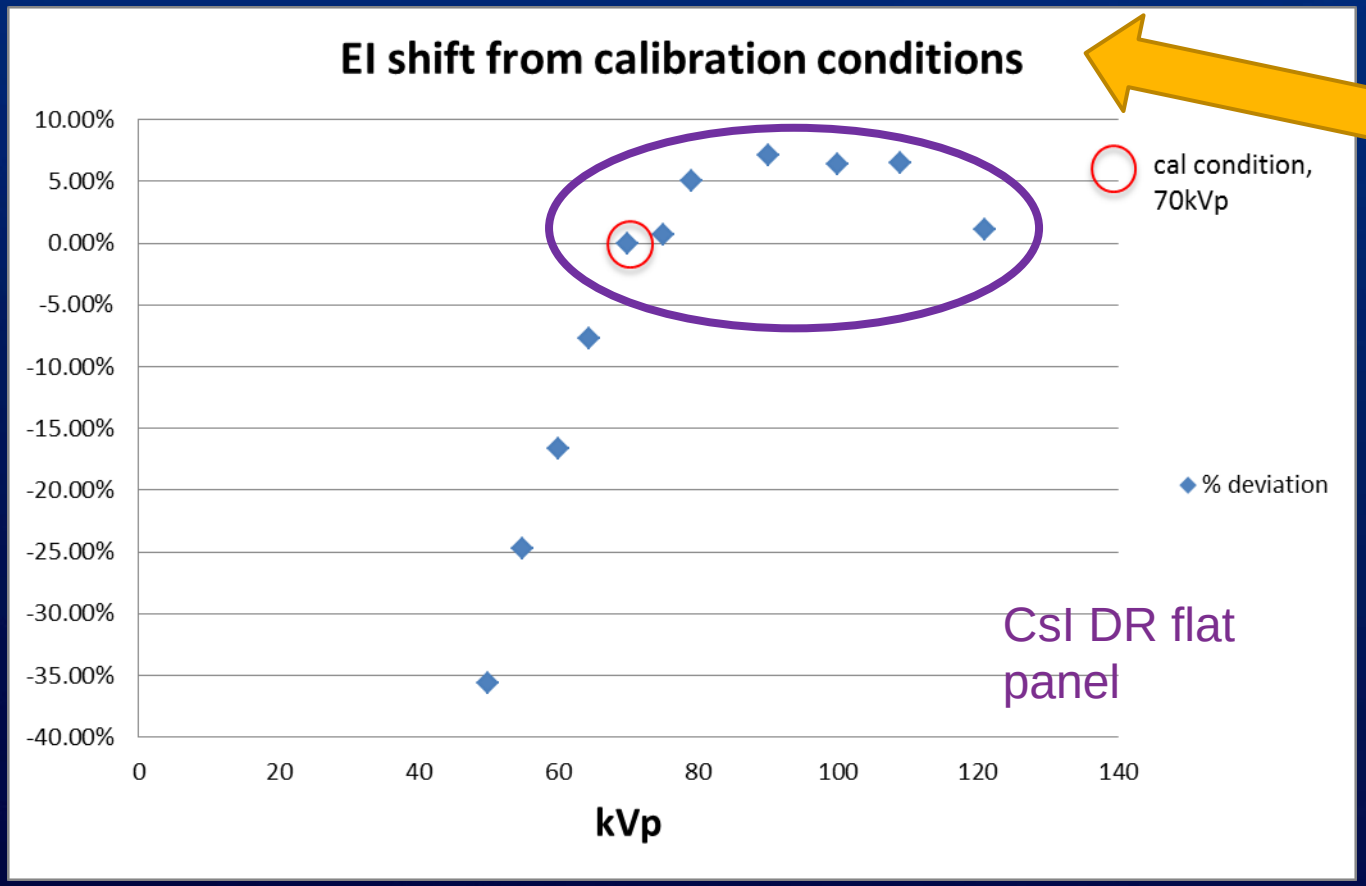
EI variation with kVp for the same image receptor air kerma



How much EI deviates from calibration definition:

$$\frac{EI - EI_{DEF}}{EI_{DEF}}\%$$

$$EI_{DEF} = \frac{100 * IRAK}{\mu Gy}$$

Data collected with 21 mm Al phantom on Siemens DR

Between 60 to 120 kVp the maximum deviation in EI from calibration conditions was ~7%.

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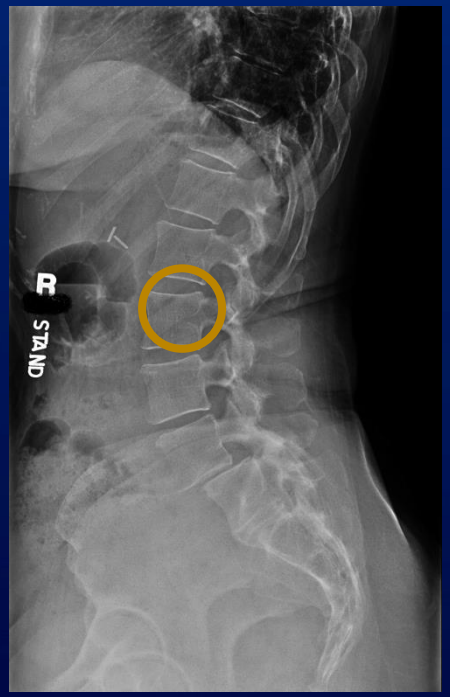
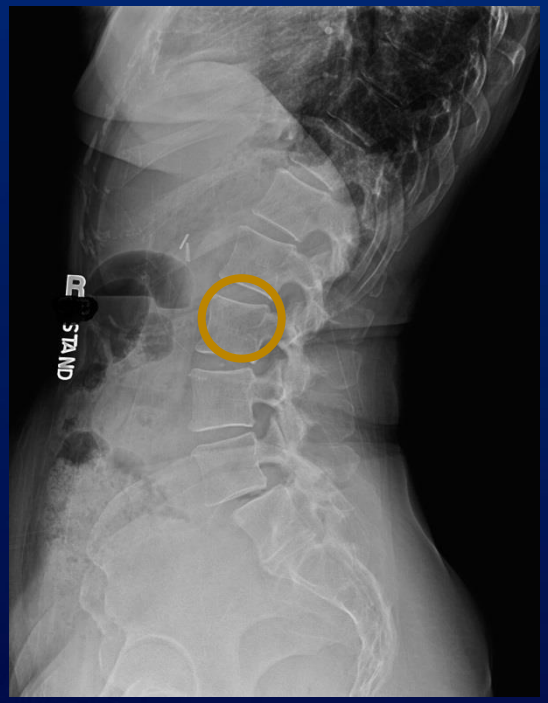
Check for EI robustness in images

How well does EI track with a feature of interest or diagnostically limiting feature?

EI 229





EI 1091

"raw" pixel value: 500 1550

THIS REQUIRES ACCESS TO RAW IMAGES!

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Developing EI Targets

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EI Targets

Deviation indices (DI) provide techs with feedback on how close an EI is to a target

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

Only works if you set a good target!

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Setting EI Targets

1. Determine Granularity of Target
   - Anatomical view
   - Patient size cohort? May have different detector exposure needs for consistent image quality
2. Pick a target strategy, i.e. Average DI = 0
3. Analyze your images
   - Select images that use a prescribed technique
     - Check grid, kVp, AEC, manual as charted?
   - Get good EI data
     - look at images

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Check your target!

- Review images with radiologist(s), having
  - $EI \sim EI_T$

  If EI_T is for average patient, choose average patients. Try several examples that capture patient variability.
- If images are too noisy, techniques may need adjustment
- Consider also reviewing examples with
  - $EI < EI_T$ for dose optimization

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Clinical Feedback Loop with EI and DI
Practice Assessment

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Need for Exposure Feedback
practice oversight

- Good Targets?
- Evaluation of Outlier images
  - areas needing tech education
  - improved acquisition strategies
  - problems with equipment settings

Exposure feedback can alert us to system default issues, problem techniques, or problems in following the techniques

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Team Review

Physics, Techs, and Radiologists

Need to work together for

Image assessment, EI target and technique optimization, and identifying areas needing tech education

Essential support to for practice change.

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Our Team

Reject Analysis ("RAP") Team

Physics Alisa Walz-Flannigan, Ph.D. Jill Lucas, R.T. Holly Meyer, R.T. **Radiologist** Laurel Littrel, M.D.	**Radiography School Faculty** Ann Urban, R.T. Jessica Nachreiner, R.T. **Technologists** Deb Ritten, R.T., lead Jo Dean, R.T., lead Deanna Schmidt, R.T., lead Bob Gilgenbach, R.T., lead Katy Nauman, R.T., supervisor

In addition we have an IQ working group which meets to review reported image quality issues.

RAP team looks for trouble. Trouble is brought to IQWG.

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The RAP SHEET

Team Analysis is summarized in a bimonthly bulletin

Assessment (of EI, other image data, and image review) is labor intensive!

Scope Management

One anatomical view is examined for reject/repeat analysis, EI spread, EI target, overall image quality

Opportunities sought specific to anatomical view for quality improvement.

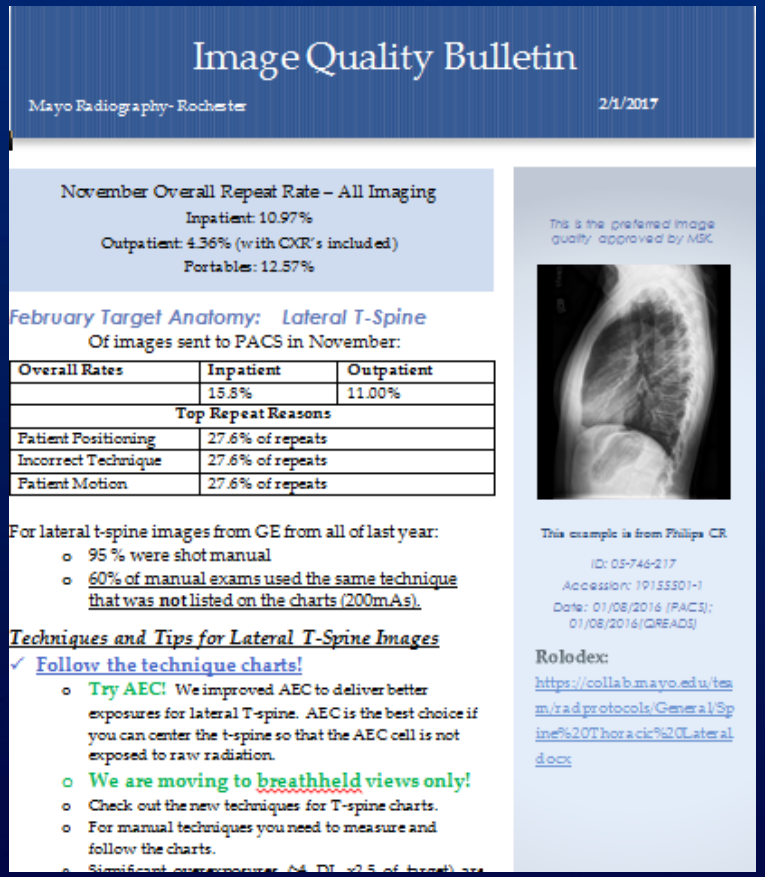

Image Quality Bulletin

Mayo Radiography- Rochester 2/1/2017

November Overall Repeat Rate – All Imaging
Inpatient: 10.97%
Outpatient: 4.36% (with CXR's included)
Portables: 12.57%

February Target Anatomy: Lateral T-Spine
Of images sent to PACS in November:

Overall Rates	Inpatient	Outpatient
	15.8%	11.00%
Top Repeat Reasons		
Patient Positioning	27.6% of repeats	
Incorrect Technique	27.6% of repeats	
Patient Motion	27.6% of repeats	

For lateral t-spine images from GE from all of last year:
- 95 % were shot manual
- 60% of manual exams used the same technique that was not listed on the charts (200mAs).

Techniques and Tips for Lateral T-Spine Images
- ✓ Follow the technique charts!
  - Try AEC! We improved AEC to deliver better exposures for lateral T-spine. AEC is the best choice if you can center the t-spine so that the AEC cell is not exposed to raw radiation.
  - We are moving to breathheld views only!
  - Check out the new techniques for T-spine charts.
  - For manual techniques you need to measure and follow the charts.

This is the preferred image quality approved by MSK

This example is from Philips CR

ID: 05-746-217
Accession: 19155501-1
Date: 01/08/2016 (PACS); 01/08/2016(QREADS)

Rolodex:
https://collab.mayo.edu/team/radprotocols/General/Spine%20Thoracic%20Lateral.docx

From Assessment to Feedback

- IQ bulletin reports
  - Repeat rate
  - Target image quality
  - Positioning guide
  - Problems found
  - Technique changes for optimization
  - Suggestions for Techs for standardization
- Nuggets are pulled out and presented by lead techs at daily huddles (5 x)

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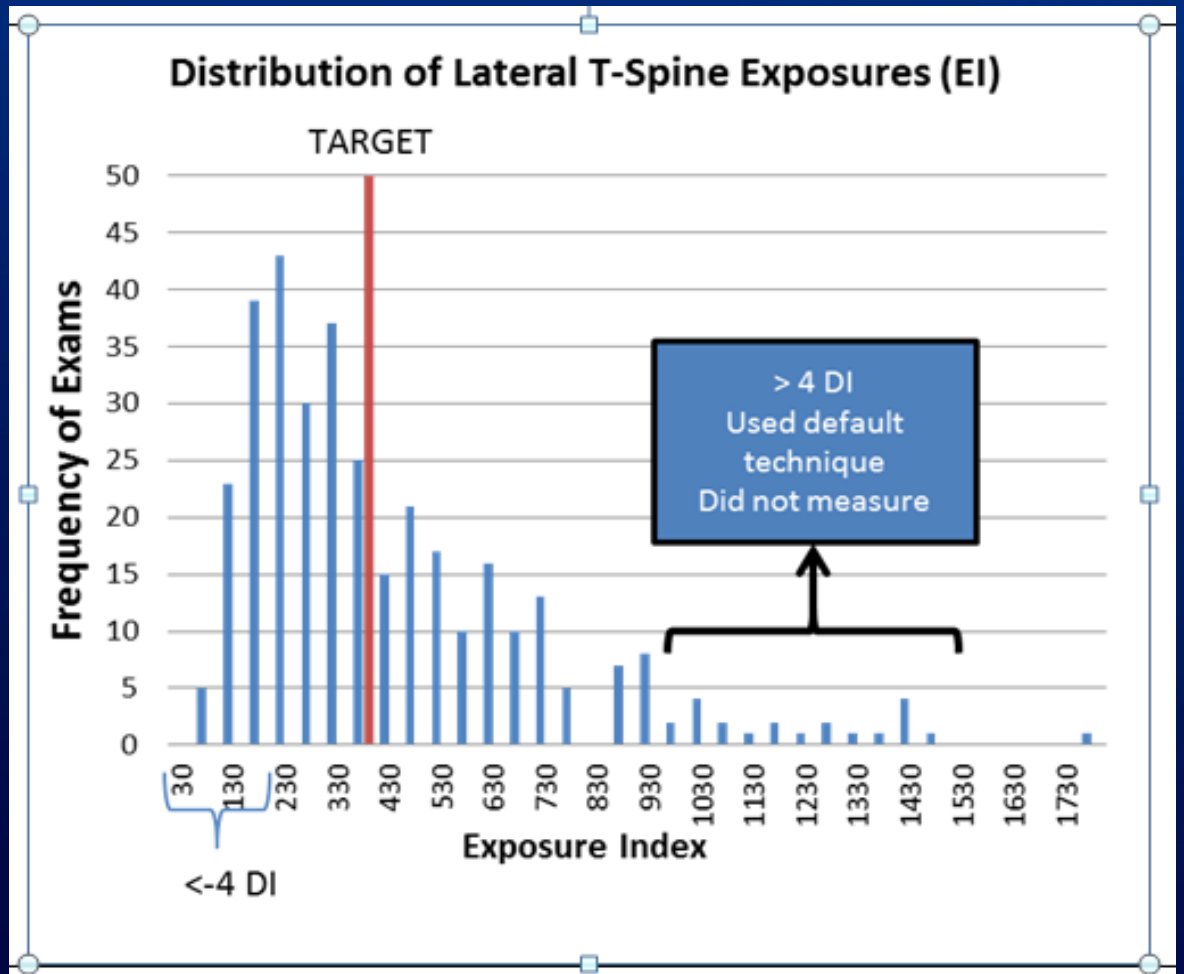
Example Findings

IQ Bulletin Excerpt



Distribution of lateral t-spine EI

EI target is 390

Example Findings

IQ Bulletin Excerpt

Techniques and Tips for Lateral T-Spine Images

- ✓ **Follow the technique charts!**
  - **Try AEC!** We improved AEC to deliver better exposures for lateral T-spine. AEC is the best choice if you can center the t-spine so that the AEC cell is not exposed to raw radiation.
  - **We are moving to breathheld views only!**
  - Check out the new techniques for T-spine charts.
  - For manual techniques you need to measure and follow the charts.
  - Significant overexposures (>4 DI, x2.5 of target) are attributable to techs selecting the default technique without measuring.
  - 63% of significant underexposures (< -4 DI, < 1/3 of target) did not appear to use a measured chart technique.

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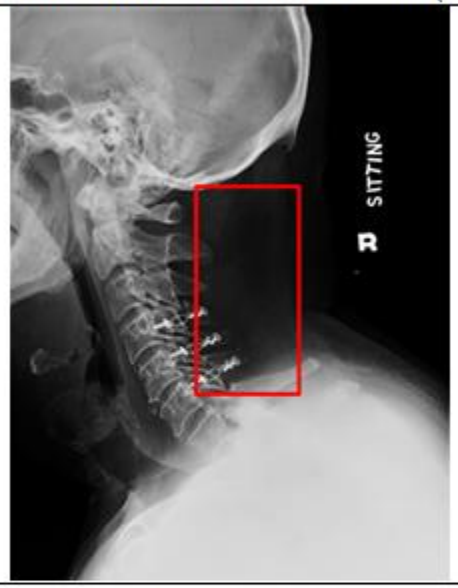
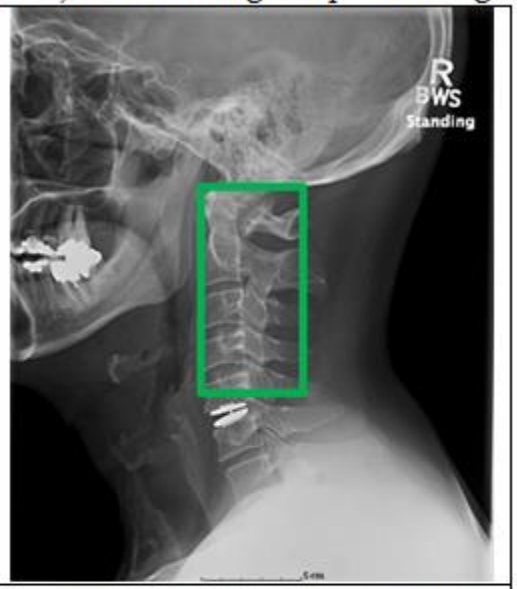
Showing Opportunities for Improvement

IQ Bulletin Excerpt

AEC is working well for neutral lateral c-spines.

The poorest exposures are when AEC is used when it shouldn't be (i.e. Flex), or without good positioning.

		
EI=45, DI =-6, image is very noisy **Do not use AEC for flex views. Flex/Ext should use the same mAs that you obtained for the neutral lateral view. (If no neutral lateral view is acquired, use AEC for Ext and then use that mAs for Flex)**	EI=93, DI= -2.8 noisier than desired. The spine was not well-centered to the AEC cell.	EI= 263, DI = 1.6, very nice cell centering!

Each anatomical view is followed up on after a period of intervention

IQ Bulletin Excerpt

Follow up Anatomy: Lateral C-Spine

Well Done! Our repeat % went down!
Our AEC images are really looking good.
Great improvement in centering to the cell!

September: 11.6%	**November: 7.9%**
Noisy Image % of repeats: 19%	Noisy Image % of repeats: 0%

REFLECTIONS

Manual exposures are **too high** (on average much higher than our target).

- Ensure you are measuring in the correct location (at C5 above the base of the neck)
- Take note of a new chart meant to improve our exposures.

AEC exposures are right on target.

- 39% of low DI (< -2 DI) were because AEC was used for flexion.
- Other low DI images were positioned with the spine not centered to the AEC cell.

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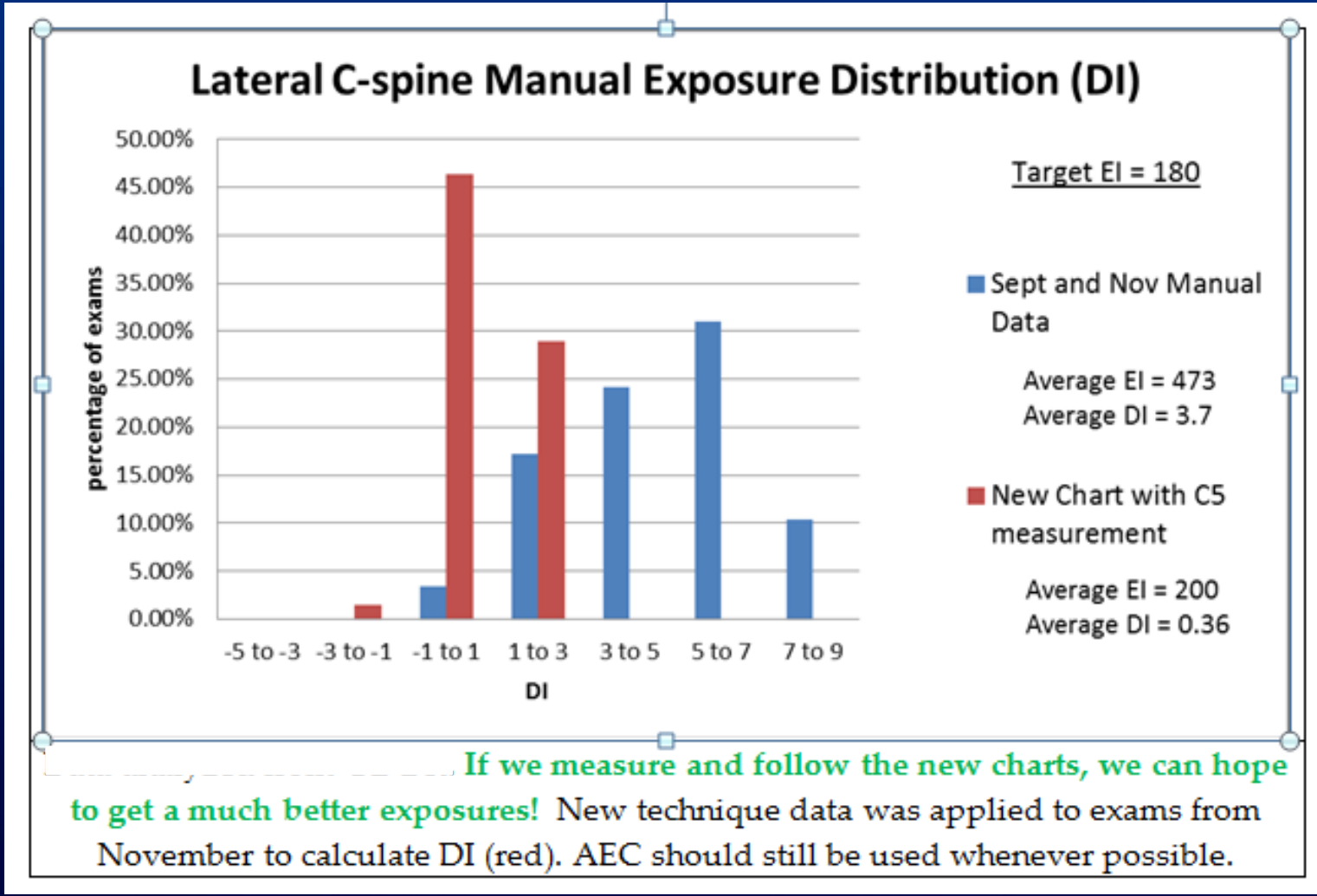
Using EI to Optimize Manual Charts

IQ Bulletin Excerpt



If patient measurement can be found, scale mAs for different size bins to achieve a tighter EI distribution

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Clinical Feedback Loop with EI and DI
At Acquisition

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Need for Exposure Feedback *for techs*

- Guidance is needed for achieving a “proper” exposure
  - Educational reinforcement to move away from film-based imaging strategies
  - Avoiding dose creep
- Challenging imaging situations occur and things don’t always go perfectly
  - Direction for how to adjust technique when retakes are needed

Exposure feedback can alert techs to the possibility of an image quality issue and how to approach fixing it

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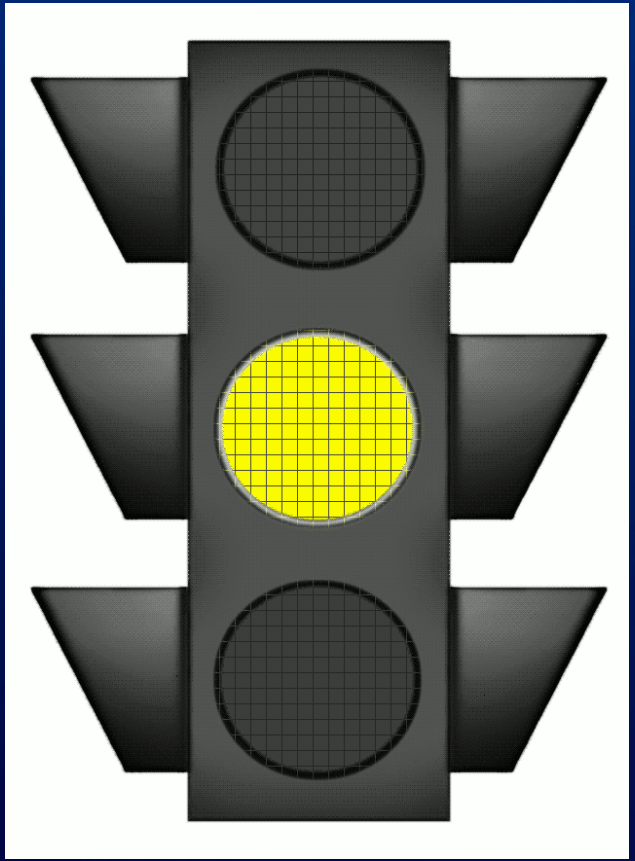
Techs: What if you see a bad EI or DI?

NO DI-BASED REPEATS!!



Bad DI = “out of desired range”

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What to do if you see a bad EI or DI?

1) Does it make sense?

   Did the calculation fail?

Is EI calculated from regions outside the anatomy?

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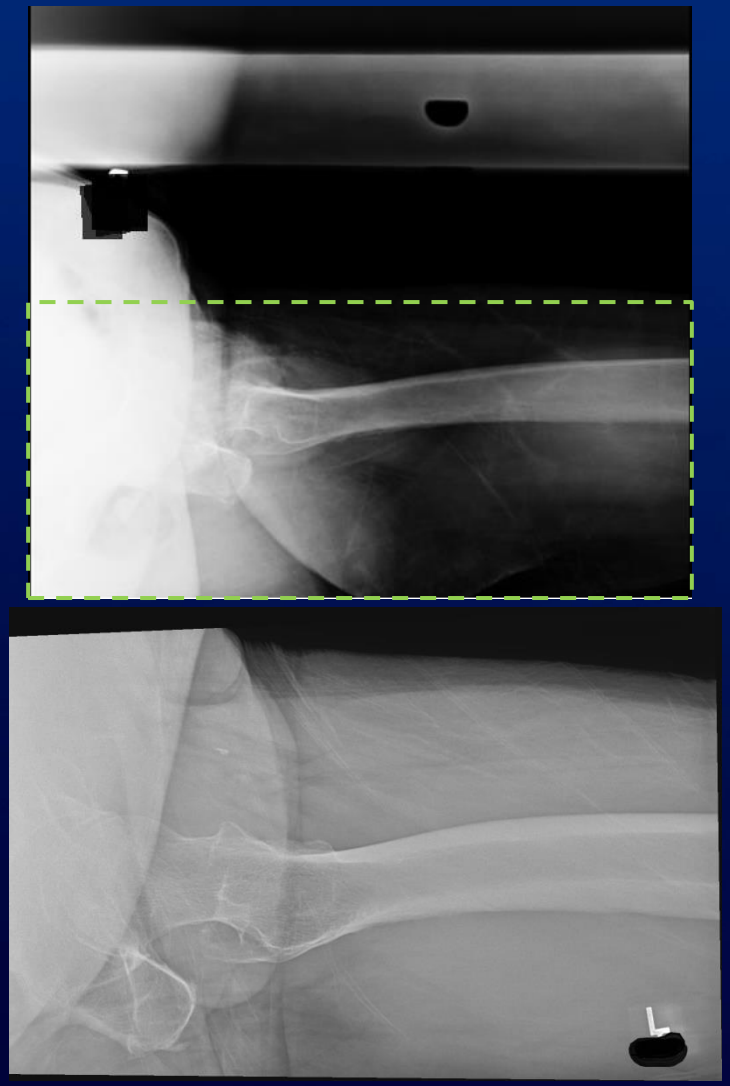
Fixing a bad EI –shutter and reprocess



Before shutter and reprocess
EI =1647, DI =3.5

After shutter and reprocess
EI= 805, DI = .4

Target = 728

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What to do if you see a bad EI or DI?

2) Check what you did

- Did you follow the charts?
- Grid ? SID? mAs? Right protocol selected?
- <u>Report if you follow the chart and get bad DIs</u>

- EI = 1508
- DI =5.9
- Target = 587

Desirable technique: 65 kVp, 50 mAs
Used: 70kVp, 200 mAs

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What to do if you see a bad EI or DI?

3) **Look at the image**: magnify to look at noise

- Really ***high*** DI : is there image clipping? Blackholes?
  - Can you fix by reprocessing?
  - If not, consult with lead or radiologist for retake. Adjust technique for retake
- Really ***low*** DI: is the image too noisy to be diagnostic?
  - Consult as needed. Adjust technique and retake

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If you need to retake

How to use DI to adjust your technique
an example

For Renard-step scaled mAs on GE DR

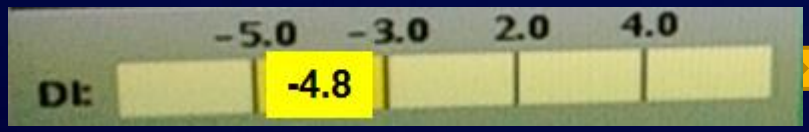
Tech tips:
Round DI to Nearest Integer.
That is how many mAs stations to move.

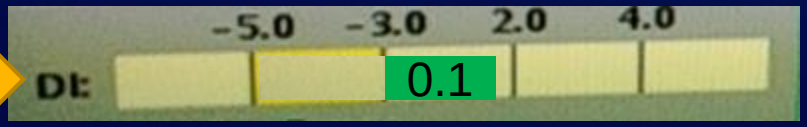
Example: DI = -4.8
This round to 5.
Go 5 mAs stations up.

If first image was 24 mAs you'd increase to 80 mAs

EI 103, mAs 24
Too noisy

EI 312, mAs 80
good





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If you need to retake

How to use DI to adjust your technique for a retake

Deviation Index	% off target mAs
3	~100% too high
2	~58% too high
1	~26% too high
0	Correct
-1	~21% too low
-2	~37% too low
-3	~50% too low

X 2 target mAs

X ½ mAs

If your retake technique has a mAs that is too high (long time), then kVp needs to be increased.

Things you don't want to see

DI of 8 = mAs over 6 x too high
DI of 5 ~ mAs 300% (3 x) too high
DI of -5 ~ 1/3 of target mAs
DI of -8 ~ 1/6 of target mAs

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Summary - EI Opportunities

EI is

- **Possibly** a very useful tool to monitor standardization and optimization of radiographic image quality.
  - **Utility depends** on the ability to robustly link EI to image quality related “proper exposures”
- A **needed** exposure feedback for acquisition support
  - Requires EI, DI validation and setup and tech training or can lead to ignoring EI/DI or influencing inappropriate retakes

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Summary- EI Challenges

Challenges to robustly link EI to "proper exposure"

- **Vendor segmentation algorithm**
  - Can do better to tie EI to regions that limit diagnostic value with exposure
- **Lack of practice standardization** in positioning and collimation
- **Anatomical View**: some views more susceptible to patient variability influences that don't track image quality (TG232)

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Summary- Room for Improvement

- Better, robust segmentation algorithms for ‘relevant region’
- Tools for analysis!
  - Easy viewing of settings (targets)
  - Anatomical-view specific data for EI spread and target setting
  - Tie EI/DI to images and other image data for
    - quality check of EI, DI data
    - quality improvement feedback

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Summary

Good clinical utilization of EI/DI and working through challenges depends on

TEAM WORK !

radiologist, technologists, educators, and physicists

MAYO CLINIC

Questions & Discussion