Exposing the Numbers behind Exposure Indicators

RT 1

Introduction

Radiographers have a professional and ethical obligation to minimize patient radiation exposure while producing high quality, diagnostic images.[1,2] The chemical processing of film-based radiography provided visual cues of inadequate technique settings through varying density levels of resultant films.[3] However, visual cues are lost on digital images due to computer processing and larger dynamic range capabilities resulting in wider exposure latitudes.[4-6] Due to automatic rescaling, images acquired with insufficient or extreme techniques may still initially appear acceptable.[5,7] **(See Figures 1-5)** Only significant underexposure and extreme overexposure may result in quantum mottle and saturation on the image, respectively.[5] Images with quantum mottle need to be repeated, leading to higher patient dose due to additional exposure while overexposure results in a greater patient dose than necessary.[5,8]

Exposure Indices measure the exposure exiting the patient and received by the image receptor, not patient radiation dose.[5-7] By determining the exposure at the image receptor, technologists can determine if the correct technique was used in acquiring the image.[5-7] Exposure indicators (EI) are the radiographer's only means for determining if an acceptable technique was used to obtain a digital image.[5]

The mission of every radiographer is…

"to produce images of the highest diagnostic quality possible while keeping patient exposure to a minimum."[5]

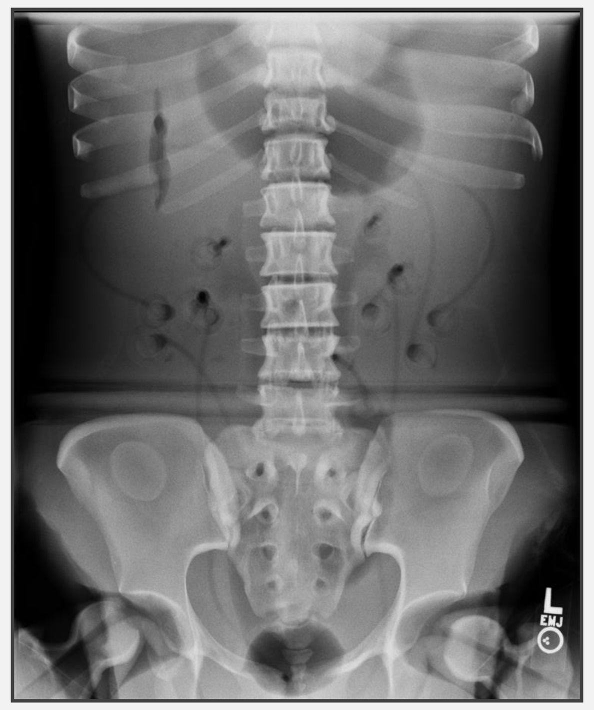

Figure 1.
Technique: 80 kVp @ 2 mAs
(~38% of ideal exposure used)
Deviation Index: -5.16
Proportional Scale: 87.4
Inversely Proportional Scale: 550
Logarithmic Scale: 924[9]

Figure 2.
Technique: 80 kVp @ 3.2 mAs
(~60% of ideal exposure used)
Deviation Index: -2.86
Proportional Scale: 138
Inversely Proportional Scale: 300
Logarithmic Scale: 1130[9]

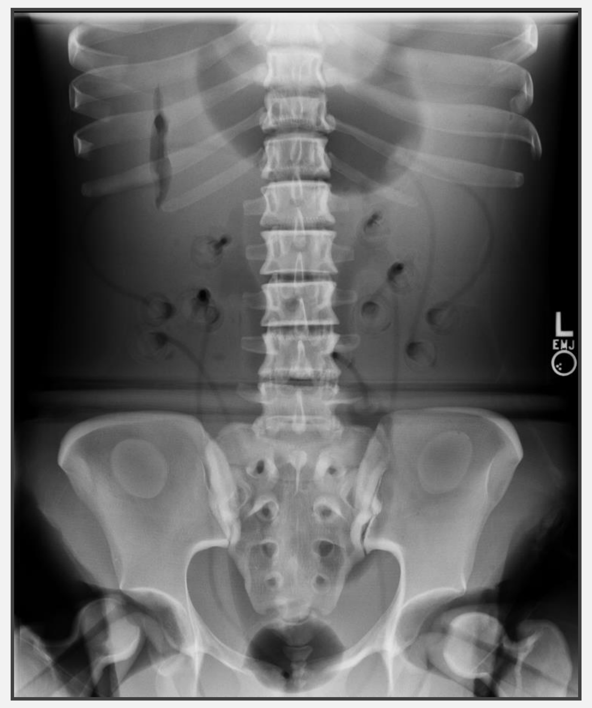

Figure 3.
Technique: 80 kVp @ 5.2 mAs
(properly exposed image)
Deviation Index: -0.29
Proportional Scale: 230
Inversely Proportional Scale: 200
Logarithmic Scale: 1379[9]

Figure 4.
Technique: 80 kVp @ 12.8 mAs
(~2.5 x overexposed from ideal)
Deviation Index: +3.46
Proportional Scale: 575
Inversely Proportional Scale: 75
Logarithmic Scale: 1758[9]

Figure 5.
Technique: 80 kVp @ 160 mAs
(~30 x overexposed from ideal)
Deviation Index: +12.64
Proportional Scale: 6900
Inversely Proportional Scale: 7
Logarithmic Scale: 2771[9]

Deviation Index as a Response to Lack of Standardization

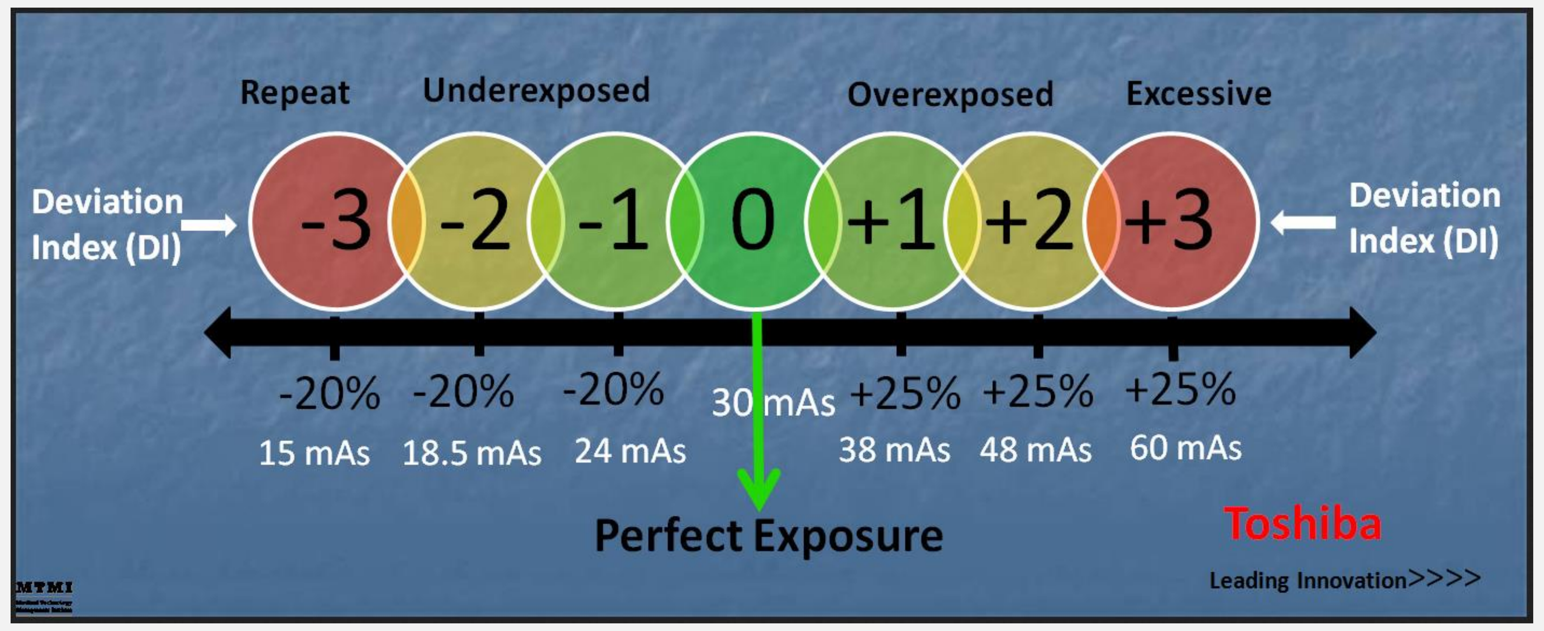

Figure 10. Image demonstrating navigation of the deviation index with mAs examples.[12]

Lack of standardization of exposure indicator scales among vendors has led to confusion among radiologists and technologists.[5,8,13] In 2009, the deviation index (DI) was proposed by the American Association of Physicists in Medicine (AAPM) as a solution to the lack of standardization through providing the radiographer with immediate visual feedback about the appropriateness of the selected technique.[13] The DI is determined by logarithmically comparing the exposure index of the acquired image (EI) to the ideal exposure which balances appropriate signal to the image receptor and patient dose, termed the target exposure index (EI_T):[5,13]

$$DI = 10\log_{10}(EI/EI_T)$$

An ideal exposure would have an equal EI and EI_T, leading to a DI of zero.[13] Positive numbers indicate overexposure and each step represents an approximate 25% increase in exposure.[7,8] Negative numbers indicate underexposure and each step represents an approximate 20% decrease in exposure.[7,8] Steps are successive and build upon the previous step. A DI of -3 correlates to 50% of the ideal exposure resulting in probable quantum mottle.[8] A DI of +3 correlates to 100% of the ideal exposure, or twice the necessary radiation resulting in excessive patient exposure.[8] **(See Figure 10)**[12] Overexposed images should only be repeated if pertinent anatomy is clipped or the image is saturated or "burned out".[5,8] **(See Figure 9)**[9]

Proportional Scales

Proportional EI scales measure increased image receptor exposure as increased EI.[5] Higher numbers represent more exposure has reached the image receptor while lower numbers represent less exposure has reached the image receptor.[5]

87.4 * 2 = 174 EI
2 mAs * 2 = 4 mAs

Figure 6. Mathematical explanation of the relationship between EI and mAs values in proportional scales.

$$\frac{87.4}{230} = \frac{X}{100}$$
X = 38%

Figure 7. Mathematical explanation of the ratio relationship between exposures in Figure 1 and Figure 3.

An example of a proportional scale has a target range for abdomen exams set at 100-300. **Figure 1**[9] is underexposed with an EI of 87.4. Technologists can double the EI until the desired numerical target range is achieved. The initial mAs read-out needs to double in relation to the doubling of the EI. **(See Figure 6)**

Technologists can also calculate the ratio between two dose values by dividing the EI of each image. Figure 1[9] was exposed at 38% of Figure 3[9]. **(See Figure 7)**

Inversely Proportional Scales

Inversely proportional scale relationships are based off the speed classes of film/screen imaging, resulting in an inverted relationship to actual exposure.[5] Low EI represent overexposure and high EI represent underexposure.[5]

75 * 2 = 150 EI
12.8 mAs / 2 = 6.2 mAs

Figure 8. Mathematical explanation of the inverted relationship between EI and mAs values in inversely proportional scales.

The oldest exposure indicator used by Fuji's CR system suggests an appropriate 'S Number' range of 100-400 for abdominal imaging.[10] The abdominal image in **Figure 4**[9] is exposed by 2.5 times of the properly exposed **Figure 3**[9]. Doubling the EI and correspondingly halving the mAs of **Figure 4**[9] would place the exposure in a more acceptable range. **(See Figure 8)** However, note that this image would _not_ warrant a repeat and additional patient exposure due to the lack of image saturation.[5,8]

Logarithmic Scales

In a logarithmic scale, every change of a set number results in a corresponding exposure change of a factor of two.[5] In the logarithmic scale of the figures above, each step is set at 300.[5,11] The target range for an abdominal image 1280-1380.[11] The properly exposed image has an appropriate logarithmic EI of 1379, reflecting an ideal exposure. **(See Figure 3)**[9] A decrease of 300 would represent 50% of the ideal exposure and an increase of 300 would represent a doubling of ideal exposure.[5]

The grossly overexposed image has a logarithmic EI of 2771 which is almost five logarithmic steps of 300 from the ideal exposure. **(See Figure 5)**[9] This image is approximately 2^5 times overexposed, or 32 times overexposed. When windowed, this image demonstrates a loss of data called saturation or burn-out. **(See Figure 9)**[9] Because diagnostic information is missing, this image would need to be repeated.[5,8]

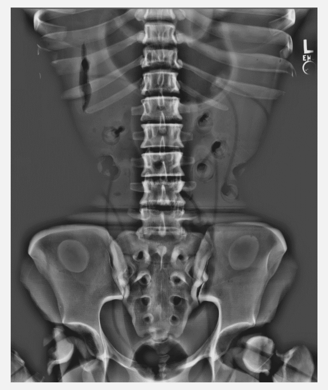

Figure 9. Windowed image of Figure 5 demonstrating a loss of recorded data due to gross overexposure.[9]

Conclusion

Technologists must be able to navigate the exposure indices used in their facility's department. However, these indices lack standardization among scale classifications and across different manufacturers which leads to confusion. Technologists also need to be aware of exposure indices' limitations and errors – realizing these numbers act as a guideline and that final image assessment is the responsibility of the technologist.[6] Radiology departments can support technologists by providing specific training to each exposure index utilized in the department and ensuring charts specific to each manufacturer are conveniently posted within the exam room. By following these best practices, radiology departments can ensure quality diagnostic images while protecting patients from excessive and unnecessary radiation dose.

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