Optimizing the Exposure Indicator as a Dose Management Strategy in Computed Radiography

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Purpose To investigate a technique for optimizing radiation dose and image quality for a computed radiography system.

Methods Entrance skin doses were measured for phantom models of the pelvis and lumbar spine imaged using the vendor's recommended exposure settings (ie, the reference doses) as well as doses above and below the vendor's recommended settings for both body parts. Images were assessed using visual grading analysis (VGA).

Results The phantom dosimetry results revealed strong positive linear relationships between dose and milliampere seconds (mAs), mAs and inverse exposure indicator (EI), and dose and inverse EI for both body parts. The VGA showed that optimized values of 16 mAs/EI = 136 for the anteroposterior (AP) pelvis and 32 mAs/EI = 139 for the AP lumbar spine did not compromise image quality.

Discussion Selecting optimized mAs reduced dose by 36% compared with the vendor's recommended mAs (dose) values.

Conclusion Optimizing the mAs and associated EIs can be an effective dose management strategy.

Keywords | *dose optimization, exposure indicator, visual grading analysis, entrance skin dose*

The exposure indicator (EI) is a numerical parameter used in computed radiography (CR) to inform operators about the amount of exposure to the imaging plate. The EI indicates whether appropriate radiographic techniques were used for an examination,[1] and can help radiologic technologists control and manage radiation dose. In fact, EI can be "used as a surrogate for dose management."[2] Furthermore, EI is "the key to controlling exposure levels" in CR,[3] and optimizing the EI is closely linked with optimizing kilovoltage (kV) and milliampere seconds (mAs).[4] A few years ago, a standardized EI was proposed[5]; however, many existing digital radiography systems still use different EI systems. In this study, EI is used as a general exposure term, as opposed to the S (sensitivity) number used by Fuji CR systems.

Two significant and fundamental problems in CR imaging are exposure creep (ie, using exposures greater than required to produce diagnostic-quality images) and the wide exposure latitude, or dynamic range, of the digital detector. The potential harm associated with exposure creep is unnecessarily high radiation doses to patients,[6] whereas wide exposure latitude can result in images with high noise levels caused by low exposure or increased radiation doses to patients caused by high exposure.[4,7]

Literature Review

The literature is sparse regarding the use of EI as part of an optimization strategy in digital radiography, and further research is needed to understand its relationship to exposure techniques and patient exposure.[1,6,7]

With respect to exposure techniques, "manipulation of the operating kVp cannot stand alone even with digital systems, and concomitant compensation of the applied mAs, together with adequate scatter control are necessary."[7] One concern in digital imaging is the inverse relationship between mAs and image noise. As a

result, optimization must consider image quality along with the dose per image. Increasing the dose per image decreases noise, thus improving image quality.[8]

The purpose of this study was to investigate optimization of the EI of a CR imaging system as a radiation dose management strategy, in keeping with the ALARA (as low as reasonably achievable) principle and to compare the optimized EI with the manufacturer's recommended values for the anteroposterior (AP) pelvis and AP lumbar spine projections.

Methods

The imaging equipment used in this study was a BuckyDiagnost Optimus 50 (Philips Healthcare). To ensure that the x-ray generator performance was within acceptable limits, 3 quality control tests were performed, as outlined by Papp: radiation output, exposure linearity, and exposure reproducibility.[9]

The anthropomorphic phantom used in this study was a transparent pelvis and lumbar spine (L1 to L5) phantom designed to represent an average-sized man approximately 5 ft 9 in (175 cm) tall and weighing 162 lb (73.6 kg) (Radiology Support Devices). The phantom contained human skeletal pelvis and lumbar spine parts embedded in anatomically accurate, tissue-equivalent materials with the same radiation absorption characteristics as living tissue.

Exposure Technique Selection

The pelvis phantom was 20 cm thick, and the lumbar spine was 25 cm thick. For a 20-cm thickness, the manufacturer suggests using exposure factors of 25 mAs and 80 kVp to produce an acceptable AP image of the pelvis. However, the control panel did not allow an operator to select 80 kVp; it defaulted to a setting of 81 kVp when pelvis and lumbar spine were selected on the control panel. Therefore, all entrance surface dose (ESD) measurements for the AP pelvis reflect imaging with 25 mAs and 81 kVp. This is referred to as the *reference exposure technique*. For the AP lumbar spine exposure, technique factors were selected from the manufacturer's technique chart. These factors were listed as 50 mAs and 80 kVp. Again, the kVp setting on the control panel defaulted to 81 kVp. Therefore, 50 mAs and 81 kVp was used as the reference exposure technique for the AP lumbar spine.

Dose Measurement

The ESD measurements were obtained using a ThinX RAD calibrated dosimeter (Unfors Instruments) free-in-air for both the AP pelvis and the AP lumbar spine. These measurements were recorded based on the protocol established by the American Association of Physicists in Medicine and described in its Report No. 31.[10] For the AP pelvis, 4 ESD measurements were recorded for each of the following mAs values: 6.3, 8, 12.5, 16, 20, 25 (the reference mAs), 32, 40, and 50, all with a fixed kVp of 81. For the AP lumbar spine, 4 measurements were recorded for each of the following mAs values: 16, 20, 25, 32, 40, 50 (the reference mAs), 63, 80, and 100. Thirty-six dose measurements were recorded for the AP pelvis (4 measurements for each of the 9 mAs settings) and 36 for the AP lumbar spine (4 measurements for each of the 9 mAs settings for the lumbar spine). The mean milligray per mAs setting was calculated for each of the 9 settings for both the AP pelvis and AP lumbar spine.

Image Acquisition

The images were acquired using a Fuji CR system (FCR XG5000) including a review workstation. The imaging plate used for image acquisition was the Fuji standard 35-cm × 43-cm ST-VI imaging plate for general-purpose radiography. Before acquiring the images used in this study, the EI (ie, the S number) was first calibrated using the calibration procedures outlined by Fuji.[11] For the AP pelvis, 3 images were acquired for each of the following mAs technique settings at 81 kVp: 6.3, 8, 12.5, 16, 20, and 25 mAs (reference mAs) Three images also were acquired using each setting of 81 kVp and mAs of 32, 40, and 50. A total of 27 images were acquired. For the AP lumbar spine, 3 images were then acquired for each of the following mAs technique settings at 81 kVp: 16, 20, 25, 32, 40, and 50 (reference mAs). Three images also were acquired using each setting of 81 kVp and mAs of 63, 80, and 100. A total of 27 images were acquired and processed by the CR reader.

Image Quality Evaluation

Seven volunteer observers independently evaluated 54 images of the AP pelvis and AP lumbar spine. All

of the observers were radiologic technologists with at least 10 years of experience teaching radiographic technique and positioning in classrooms, laboratories, and hospitals. No time limit was imposed for assessment, and observers could pause during the assessments as needed to reduce the potential effects of fatigue on their ability to evaluate the images.

Twenty-seven images of the AP pelvis and 27 images of the AP lumbar spine were displayed for assessment. Each image was obtained with a different ESD. To establish the optimized mAs and EIs for the AP pelvis and AP lumbar spine, observers were asked to indicate whether the image displayed on a computer monitor was acceptable or unacceptable in terms of image mottle (noise). This method of establishing an optimized mAs/EI was described by Peters and Brennan.[12]

To determine the dose-image quality optimization, all observers evaluated all images by comparing the test images with the reference images. Observers used criteria that define the degree of visibility of certain anatomical structures and a visual grading analysis (VGA) method to assess image quality.

Table 1 defines 4 key terms that describe the degree of visibility as established by the Commission of European Communities.[13] The anatomical criteria for evaluating image quality based on the reproduction and visualization of defined structures on AP pelvis and AP lumbar spine images are listed in **Table 2**. VGA is a simple method of subjectively assessing image quality based on the visibility and reproduction of anatomical structures and characterized by "powerful discriminating properties" and applied in a "controlled scientific manner."[14-18] Sund et al noted that an assumption of visual grading is that "the visibility of normal anatomy is strongly correlated to the detectability of pathological structures."[14] VGA is a well-established, valid, and popular tool for image assessment.

Table 1

The Commission of European Communities Definitions of the Degree of Visibility for Anatomical Structures in an Image[13]

Term	Definition
Visualization	Characteristic features are detectable but details are not fully reproduced; features are just visible.
Reproduction	Details of anatomical structures are visible but not necessarily clearly defined; detail is emerging.
Visually sharp reproduction	Anatomical details are clearly defined; details are clear.
Important image details	These define the minimum limiting dimensions in the image at which specific or abnormal anatomical details should be recognized.

Table 2

Commission of European Communities Anatomical Criteria for Images[13]

Part and Projection	Image Criteria
AP pelvis	Visually sharp reproduction of the: ■ Sacrum and its intervertebral foramina. ■ Pubic and ischial rami. ■ Sacroiliac joints. ■ Necks of the femora (no foreshortening or rotation). ■ Greater trochanters. ■ Cortex/trabecular patterns.
AP lumbar spine	Visually sharp reproduction of the: ■ Upper and lower end plate surfaces. ■ Pedicles. ■ Intervertebral joints. ■ Spinous and transverse processes. ■ Cortex/trabecular patterns.

Abbreviation: AP, anteroposterior.

Statistical Analysis

Descriptive statistics, such as sample size, mean, standard deviation, and range, were computed for the dosimetry data, the EI data, and the VGA image quality scores. In addition, the Pearson correlation was applied to examine the correlation between the ESD and the EI and dose and mAs.[15,16] The VGA study results for visualization of anatomical structures in the images, specifically the mean criteria and the mean total image scores, were examined with the hypothesis that images produced with the different mAs values could not show differences with respect to image quality. Statistical

Table 3

Dose Measurement Results[a]

Pelvis		Lumbar Spine	
mAs	Mean mGy[b]	mAs	Mean mGy[b]
50	6.45	100	13
40	5.17	80	10
32	4.14	63	7.98
25[c]	3.24	50[c]	6.36
20	2.60	40	5.09
16	2.09	32	4.07
12.5	1.63	25	3.19
8	1.06	20	2.56
6.3	0.83	16	2.05

Abbreviations: mAs, milliampere seconds; mGy, milligray.

[a]*All images were obtained at 81 kVp.*

[b]*Free-in-air measurements.*

[c]*Reference exposure techniques.*

significance was assessed using analysis of variance.[17,18] Interobserver agreement in the VGA study was assessed using Cohen kappa analysis.[17,19] Furthermore, a *P* value of less than 5% ($P < .05$) was used to determine statistical significance.[20,21] All statistical analysis was performed using the Statistical Analysis Software (SAS) system (SAS Institute).[22]

Results

Dosimetry

The results of dosimetric measurements for the AP pelvis and the AP lumbar spine are shown in **Table 3**. Graphs of the mean dose in milligray for the AP pelvis and the AP lumbar spine were plotted as a function of mAs, the inverse EI and the mAs, and the dose and the inverse EI (see **Figure 1**). This shows a strong positive linear relationship ($r = 0.999$) for both the AP pelvis and the AP lumbar spine.

Image Acquisition

Images of both phantoms were acquired at the reference mAs settings as well as mAs settings above and below the reference values, which are referred to as *test*

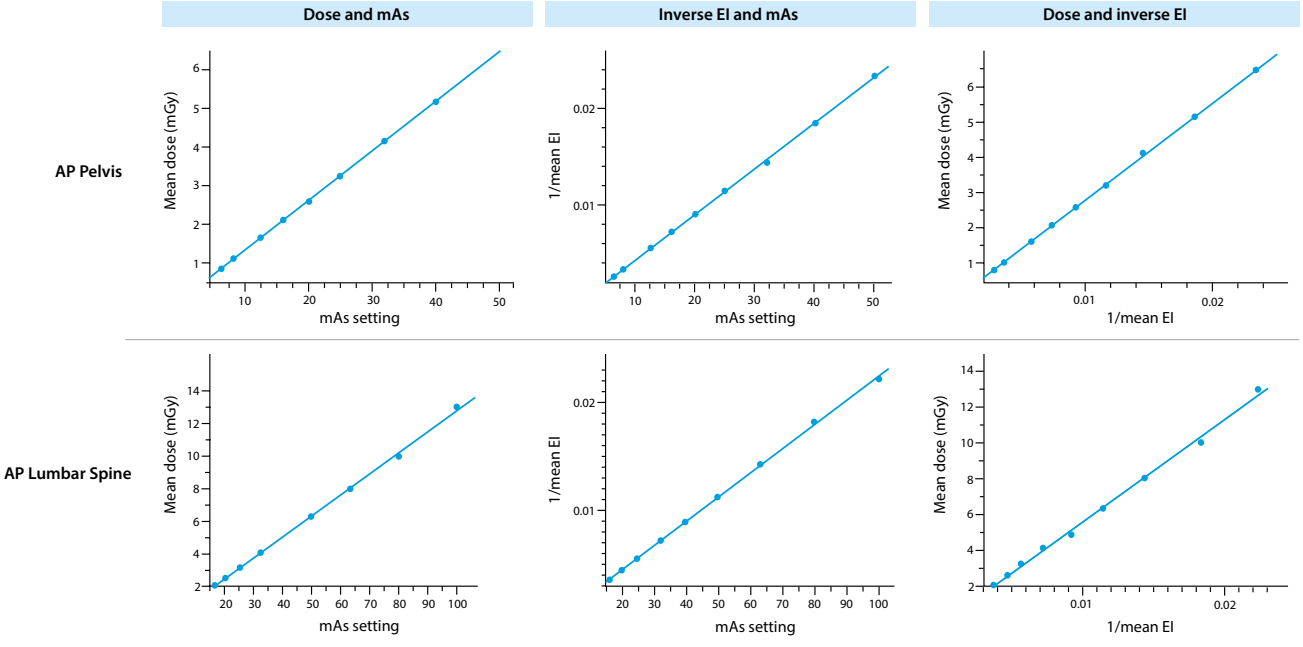

Figure 1. *Graphs of the mean dose in mGy plotted as a function of mAs, the inverse exposure index (EI) and the mAs, and the dose and the inverse EI for the AP pelvis and the AP lumbar spine.*

mAs values. The EIs associated with the mAs settings are reported as well. Image acquisition results for the AP pelvis and AP lumbar spine are shown in **Table 4**. For each mAs setting, 3 images were obtained and the associated EIs recorded. The images produced with the lowest mAs and selected as acceptable by all observers were chosen as the optimum mAs (see **Table 5**). Image number 3 for the AP pelvis (obtained with 16 mAs) and image number 23 for the AP lumbar spine (obtained with 20 mAs) were identified as the optimized mAs setting. The optimized mAs and corresponding optimized EI, together with reference mAs and the manufacturer's recommended EI range for the AP pelvis and AP lumbar spine, are shown in **Table 6**.

The manufacturer's recommended EI ranges do not provide mAs settings for the body parts studied. The manufacturer's mAs used in this study for the AP pelvis (25 mAs for a thickness of 20 cm) and for the AP lumbar spine (50 mAs for a thickness of 25 cm) were provided in a separate document from Fuji. The images for the reference mAs and the optimized mAs for the AP pelvis and the AP lumbar spine are shown in **Figures 2** and **3**.

Image Quality Assessment

The overall results of the VGA study for the pelvis images are shown in **Table 7**, and a graph of the VGA scores plotted as a function of mean dose is shown in **Figure 4**, which demonstrates that the VGA scores increase (ie, image quality increases) as the dose increases. Furthermore, a positive linear relationship appears as the dose increases from 1.63 mGy to 6.45 mGy (12.5-50 mAs, respectively). There also is a sharp decrease in the VGA scores as the dose decreases from

Table 4

AP Pelvis and AP Lumbar Spine Image Acquisition Results[a]

AP Pelvis					AP Lumbar Spine				
mAs	Mean mGy	EIs (S No.)	Mean mGy (S No.)	Inverse Mean EI[b]	mAs	Mean mGy	EIs (S No.)	Mean EI (S No.)	Inverse Mean EI[b]
50	6.45	43 44 44	43	0.023	100	13	45 45 45	45	0.022
40	5.17	54 55 54	54	0.018	80	10	57 55 55	55	0.018
32	4.14	71 68 68	69	0.014	63	7.98	71 71 70	70	0.014
25[c]	3.24	88 86 84	86	0.011	50[c]	6.36	88 90 88	88	0.011
20	2.60	108 108 108	108	0.009	40	5.09	110 110 110	110	0.009
16	2.09	136 136 136	136	0.007	32	4.07	139 139 139	139	0.007
12.5	1.63	175 175 175	175	0.005	25	3.19	179 179 179	179	0.005
8	1.06	277 277 277	277	0.003	20	2.56	220 220 220	220	0.004
6.3	0.83	357 357 357	357	0.002	16	2.05	277 277 277	277	0.003

[a] *All images were obtained at 81 kVp.*
[b] *The mean exposure index (EI) for 3 images obtained at each mAs setting.*
[c] *Reference exposure techniques.*

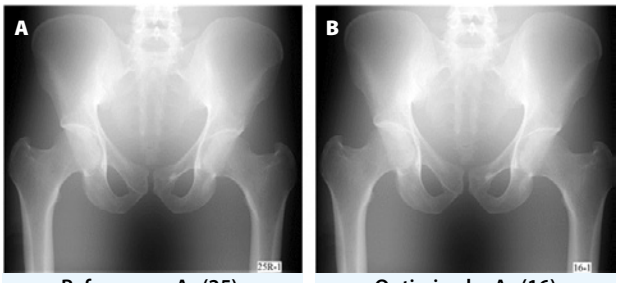

Figure 2. *A comparison of image quality between the reference image of the AP pelvis obtained at 25 mAs (A) and the optimized image recorded at 16 mAs, or approximately one-third the reference dose (B). Images courtesy of the authors.*

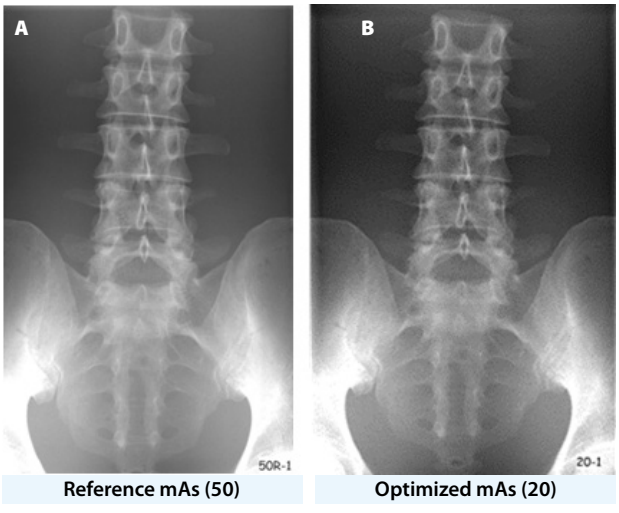

Figure 3. *A comparison of the image quality between the reference image of the AP lumbar spine obtained at 50 mAs (A) and the optimized image recorded at 20 mAs, or approximately one-third the reference dose (B). Images courtesy of the authors.*

1.63 mGy to 0.83 mGy (12.5-6.3 mAs, respectively). **Figure 5** shows the VGA scores plotted as a function of the mean EI and demonstrates that as the EI increases, the VGA scores decrease. This is to be expected because for the Fuji CR system, the EI is inversely proportional to the dose, meaning that the EI increases as the dose decreases.

The overall results of the VGA study for the lumbar spine images are shown in **Table 8**, and **Figure 6** shows the VGA scores plotted as a function of the mean dose, which demonstrates that the VGA scores increase as the dose increases. There is a sharp decrease in VGA scores as the dose decreases from 2.56 mGy to 2.05 mGy (20-16 mAs). **Figure 7** shows the mean VGA scores plotted as a function of the mean EI. As the EI increases, the VGA scores decrease. Again, this is to be expected because for the Fuji CR system, the EI is inversely proportional to the dose, meaning that as the EI increases, the dose decreases.

Discussion

The overall goal of this study was to determine the lowest possible dose to the pelvis and lumbar spine of an anthropomorphic phantom without compromising the diagnostic quality of the images. To accomplish this goal, 3 sets of data were collected: dosimetry data, images, and image quality assessments.

Dose is directly proportional to the mAs, meaning that if the mAs is doubled, the dose doubles. For the Fuji CR system, the EI (ie, the S number) is inversely proportional to the dose[1]: as the dose increases, the EI decreases proportionally. Thus, at 5 μGy, 10 μGy, and 20 μGy, the Fuji CR EIs are 400, 200, and 100, respectively.[1] When the inverse EI is plotted as a function of mAs and the dose is plotted as a function of the inverse EI, the results show a strong positive linear relationship in both cases ($r = 0.999$).

The notion of an inverse EI (1/S for the Fuji CR system) is interesting, and perhaps instead of displaying the S number on an image, the inverse S number should be displayed. If this were the case, technologists might better understand the relationship between dose to the patient (as opposed to the image plate) and the S number because as dose increases, the inverse S number (1/S) increases proportionally.

To establish an optimum mAs and associated EI for the pelvis and lumbar spine, it was important to first produce images using the vendor's recommended mAs values. For a 20-cm thick AP pelvis, the recommended or reference mAs was 25, which produced an EI of 86. The mAs recommended by the vendor for a 25-cm thick AP lumbar spine was 50, and this produced an EI of 88. The optimized mAs selected by 7 expert observers for the AP pelvis was 16 mAs and 20 mAs for the AP lumbar spine. These 2 mAs settings, the reference and the optimized mAs, produced EI values of 136 for the AP pelvis and 220 for the AP lumbar spine (see Table 4). Unlike the vendor's EI recommended ranges,

Table 5

AP Pelvis and AP Lumbar Spine Image Acquisition Results

Body Part	Observers 1	2	3	4	5	6	7	Optimized mAs	Dose Reduction (%)
Pelvis Image number selected (reference mAs = 25)	3	3	3	3	3	3	3	16	36
Lumbar Spine Image number selected (reference mAs = 50)	23	23	23	23	23	23	23	20	60

Table 6

AP Pelvis and AP Lumbar Spine Dose Measurement Results

Body Part	Reference mAs (AP diameter)	EI for Reference mAs	Optimized mAs	EI for Optimized mAs	Manufacturer's Recommended EI Range
Pelvis	25 mAs (20 cm)	86	16	136	250-600
Lumbar spine	50 mAs (25 cm)	88	20	220	250-600

Table 7

Visual Grading Analysis (VGA) Scores for Images of an Anthropomorphic AP Pelvis Phantom Compared With a Reference Image at 25 mAs[a]

mAs Setting	Mean Dose (mGy)	Mean EI	Mean VGA Score
50	6.45	43	0.5
40	5.17	54	0.4
32	4.14	69	0.3
25[b]	3.24	86	0.2
20	2.60	108	0.2
16	2.09	136	0
12.5	1.63	175	0
8	1.06	277	−0.2
6.3	0.83	357	−0.5

[a] *There were 7 observers, and 3 images were obtained for each mAs setting at 81 kVp.*

[b] *Reference exposure technique.*

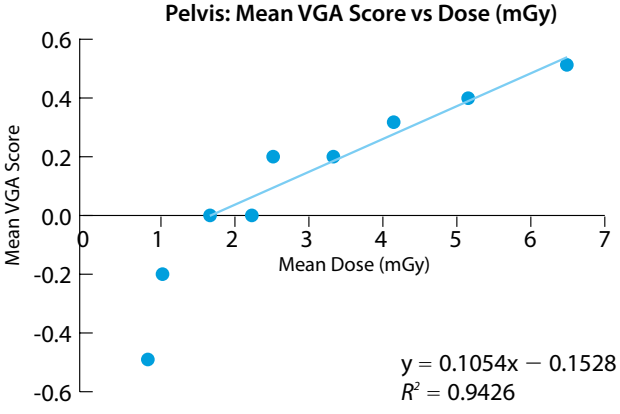

Figure 4. *Visual grading analysis (VGA) scores plotted as a function of mean dose.*

the optimized EI values do not fall within the range of 250 to 600. To fall within this range, the mAs (and associated EI values) would have to be 8 mAs (277) for the pelvis or as low as 6.3 mAs (357) and 16 mAs (277) for the AP lumbar spine.

The optimized mAs values and optimized EI values mean that all observers rated these 2 images as acceptable based on the lowest exposure used to produce them. Images obtained with less than 16 mAs for the pelvis and 20 mAs for the lumbar spine were deemed unacceptable for diagnosis by all observers based on the appearance of image mottle. These findings are consistent with the results of the VGA study findings that image quality is inferior (ie, negative VGA scores)

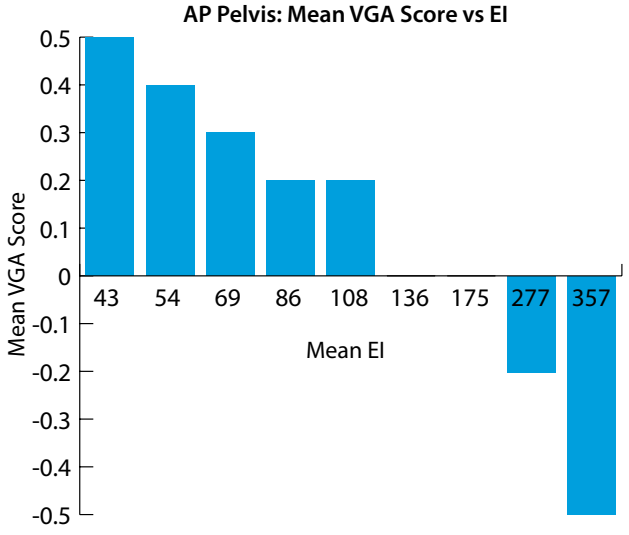

Figure 5. *Graphical display of the VGA scores plotted as a function of the mean EI for the AP pelvis. As the EI increases, the VGA scores (image quality) decrease.*

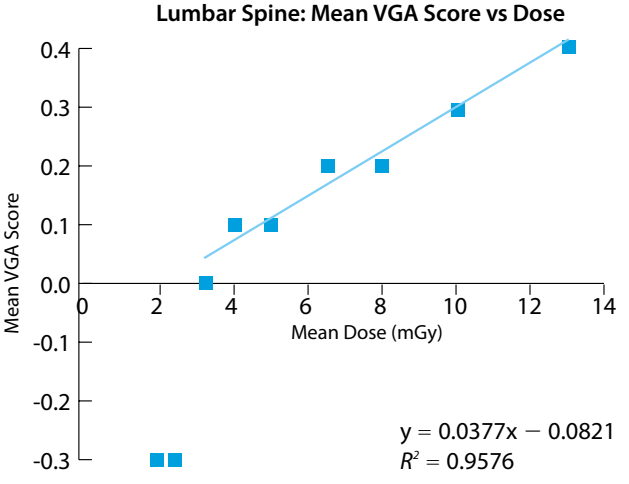

Figure 6. *The VGA scores plotted as a function the mean dose.*

for images of the AP pelvis obtained at 8 mAs and 6.3 mAs compared with the reference mAs of 25 (EI = 86). Image quality also is inferior for the image of the AP lumbar spine obtained at 16 mAs compared with the reference mAs of 50 (EI = 88).

The reference EI values obtained in this study for the AP pelvis and AP lumbar spine and the optimized EI values of 136 for the AP pelvis and 220 for the AP

Table 8

VGA Scores for Images of an Anthropomorphic AP Lumbar Spine Compared With a Reference Image at 50 mAs[a]

mAs Setting	Mean Dose (mGy)	Mean EI	Mean VGA Score
100	13	45	0.4
80	10	55	0.3
63	7.98	70	0.2
50[b]	6.36	88	0.2
40	5.09	110	0.1
32	4.07	139	0.1
25	3.19	179	0
20	2.56	220	−0.3
16	2.05	277	−0.3

[a]*There were 7 observers, and 3 images were obtained for each mAs setting at 81 kVp.*

[b]*Reference exposure technique.*

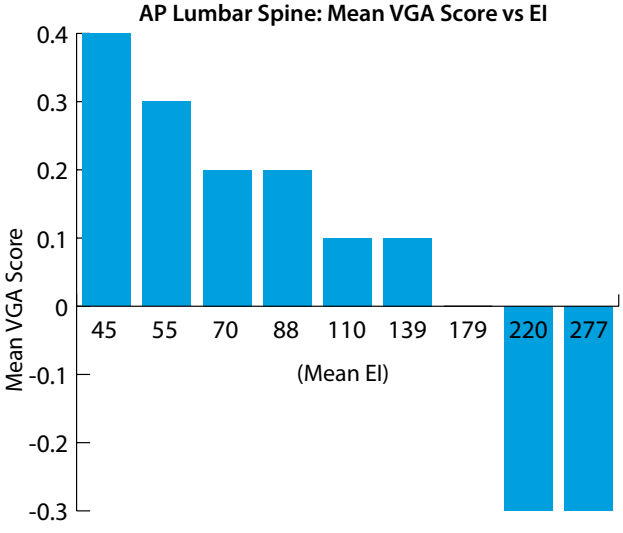

Figure 7. *Graphical display of the VGA scores plotted as a function of the mean EI for the AP lumbar spine. As the EI increases, the VGA scores (image quality) decrease.*

lumbar spine do not fall within the vendor's recommended values. One possible explanation might be that the vendor's recommended values were based on patient exposures rather than on anthropomorphic phantom exposures.

However, the differences in the optimized EI values found in this study and the vendor's recommended EI ranges for the pelvis and lumbar spine are not drastic. Furthermore, Fuji states that the accuracy of EI values falls within ± 20%.[12] With this tolerance limit for the optimized EI value for the AP lumbar spine, that is ± 20% of 220 (176-264), only the upper limit of 264 falls within the vendor's recommended range for the lumbar spine of 250 to 600. Applying this tolerance limit to the optimized EI (136) for the pelvis (± 20% of 136 = 110-163) would mean that the upper limit of 163 does not fall within the vendor's recommended EI range for the pelvis of 250 to 600.

However, these upper tolerance limits of EI values for the pelvis and lumbar spine fall within the recommended limits for general adult imaging described by Seibert based on the Fuji 5000 CR imaging system at the University of California Davis Medical Center.[23] Seibert reported that, assuming proper positioning and using the correct processing algorithm matched to the anatomy being imaged, the recommended S number limits for an acceptable range are 150 to 300. The current study also used the Fuji 5000 CR imaging system, and the optimized EI values obtained for the AP pelvis and AP lumbar spine are closer to those reported by Seibert.[23] Furthermore, the optimized mAs of 16 for the AP pelvis and 20 mAs for the AP lumbar spine resulted in a dose reduction of 36% and 60%, respectively, compared with the doses obtained with the reference mAs.

Several points regarding the expert image assessment using the VGA procedure warrant further discussion. First, the overall VGA scores for the AP pelvis and the AP lumbar spine showed the same general trend: image quality improved with increasing dose (mAs) and increasing inverse EI, using the fixed kVp and variable mAs exposure technique settings. This finding also was more noticeable for the AP pelvis than for the AP lumbar spine, with substantial to almost perfect inter-rater reliability for the criteria numbers at specified mAs settings ranging from low to high. The goal of the image quality assessment was to determine the dose-image quality optimization using the mAs settings and the visualization of specific structures at each of the mAs settings in the range of settings used in this study.

Another important finding in the overall VGA scores is clearly demonstrated in Figures 4 and 6, which show that:

- A threshold dose exists at which the VGA score equals zero and visualization of anatomic structures on test images is equal to visualization of the same structures on the reference images. For the AP pelvis, this threshold dose is 1.63 mGy (12.5 mAs); for the AP lumbar spine, it is 3.19 mGy (25 mAs).
- Below these threshold doses, VGA scores decrease dramatically, meaning that visualization of structures on the test images became more difficult and worsened compared with the visualization of structures on the reference images.

The second outcome of the image quality assessment was related to the VGA scores for the reference and optimized mAs values. For the pelvis, the reference and optimized mAs were 25 and 16, respectively; for the AP lumbar spine, the reference mAs was 50 and the optimized mAs was 20. The reference and optimized VGA scores for the AP pelvis were 0.2 and zero, respectively, and they were 0.2 and −0.3, respectively, for the AP lumbar spine. A positive VGA score meant that the structures on the test images were better visualized and reproduced compared with those on the reference images, whereas a zero and a negative VGA score meant that the structures visualized and reproduced on the test images were equal to and worse than those on the reference images, respectively.

For the AP pelvis, the optimized mAs of 16 resulted in a VGA score of zero, signifying that the visualization and reproduction of structures on an image obtained at 16 mAs were equal to those on the reference image obtained at 25 mAs. The result was a dose reduction that upheld the ALARA principle (ie, image quality was not compromised, and the dose to the patient was reduced by 36%.)

For the AP lumbar spine, the optimized mAs of 20 resulted in a VGA score of −0.3. This meant the visualization and reproduction of anatomical structures on an image obtained at 20 mAs were worse than those on the reference image obtained at 50 mAs. This finding suggests that the optimized 20 mAs is not acceptable for dose-image quality optimization of the AP lumbar spine. Table 8 shows that the dose-image quality in CR imaging of the AP lumbar spine can be optimized and the dose reduced to one-half the reference mAs (25 mAs) because the VGA score at 25 mAs is zero. The dose for the AP lumbar spine reference image obtained at 50 mAs

was 6.36 mGy, whereas it was 3.19 mGy for the image obtained at 25 mAs. A score of zero indicated that visualization and reproduction of the structures on a test image were equal to those seen on the reference image. Negative and positive scores indicated that visualization and reproduction of structures on test images were worse or better compared with those seen on the reference images. At 25 mAs, however, the cortex and trabecular patterns were not reproduced and visualized clearly (ie, visualization and reproduction were compromised).

Therefore, it is reasonable to examine visualization and reproduction of structures at the next higher mAs setting (32 mAs) and compare them with the reference 50 mAs setting. All structures visualized and reproduced on the 32 mAs image were equal to those seen on the 50 mAs reference image. No structure was compromised in terms of visualization and reproduction. Therefore, it is logical to select 32 mAs as the lowest mAs setting in the dose-image quality optimization strategy for the AP lumbar spine. This would result in a dose reduction of 36% without compromising image quality.

The dose can be optimized at 16 mAs for the AP pelvis and at 32 mAs for the AP lumbar spine, resulting in a dose reduction of 36% without compromising image quality. The null hypothesis that there is no difference between the main effects of mAs settings and criteria number on criteria scores was rejected: image quality improves as the dose increases, and a threshold dose was found in which the structures on the test images were equal in visualization and reproduction to the same structures seen on the reference images. Finally, below the threshold dose, image quality degrades.

The explanation for these findings is based on the physics of quantum noise. Bushberg et al noted that imaging in the radiology department with ionizing radiation "uses relatively few quanta to form the image—indeed the numbers of quanta are so low that for most medical images involving x rays…appreciable noise in the image results, and this noise is quantum noise."[24] Noise affects the visualization and reproduction of structures on an image, and the "presence of noise reduces our ability to extract information from an image."[25]

In dose optimization, the relationship between noise in an image and radiation dose to the patient is a significant contributing factor.[4,24-26] In this study, the dose to the patient was influenced by the range of low to high mAs settings. By increasing the mAs, more photons are distributed more uniformly at the detector, resulting in a reduction of image noise.[24,25] This reduction of image noise resulted in better visualization and reproduction of the anatomical structures assessed in the study.

The findings of this study show that the mAs and its associated EI can be used as a radiation dose management strategy in CR imaging. The mAs can be adjusted to an optimum value, resulting in a clinically acceptable noise level that does not compromise image quality. The user must understand how optimum mAs levels can be established for various examinations. **Figures 8** and **9** summarize the main findings of the VGA studies of the AP pelvis and AP lumbar spine.

The results of this study show it is feasible to optimize the dose and image quality in CR imaging using the mAs exposure technique factor and associated EIs for the Fuji CR system. Specifically, the dosimetry phase of this investigation showed a strong positive linear relationship ($r = 0.999$) between mAs and dose, mAs and the inverse EI, and the inverse EI and dose for both the AP pelvis and AP lumbar spine. Under the controlled conditions used in this study for dose optimization, the EI values were stable, unlike the results reported by Butler et al.[1]

Furthermore, reference values of the manufacturer of 25 mAs (EI = 86) for the AP pelvis and 50 mAs (EI = 88) for the AP lumbar spine were optimized to 16 mAs for the AP pelvis (EI = 136) and 32 mAs for the AP lumbar spine (EI = 139).

The third major finding determined by the image quality assessment of 7 expert observers was that the manufacturer's recommended dose can be reduced by 36% for both the AP pelvis and AP lumbar spine without compromising image quality.

Conclusion

This study focused on dose optimization using a relatively new digital imaging technology in clinical practice. This topic warrants continual scholarly inquiry as science and technology for digital imaging systems advance. Based on this study, an important future investigation could be performed on the use of a standardized EI. The wide range of EIs and detector exposures used by different

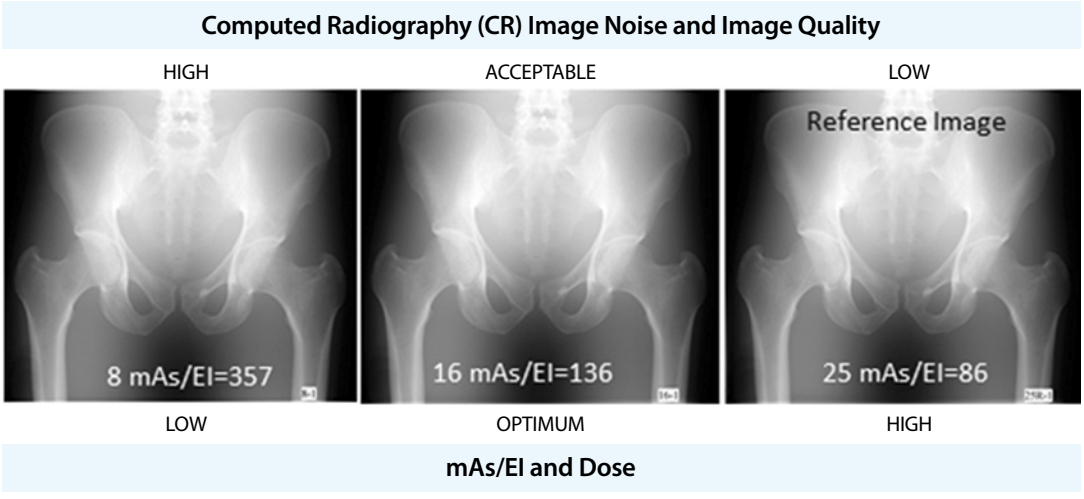

Figure 8. *The main findings of the VGA study demonstrating that the optimum mAs/EI for the AP pelvis is 16 mAs/136 compared with the manufacturer's reference image obtained at 25 mAs and an EI value of 86. Reprinted with permission from Seeram E. The new exposure indicator for digital radiography.* J Med Imaging Radiat Sci. *2014;45(2):144-158.*

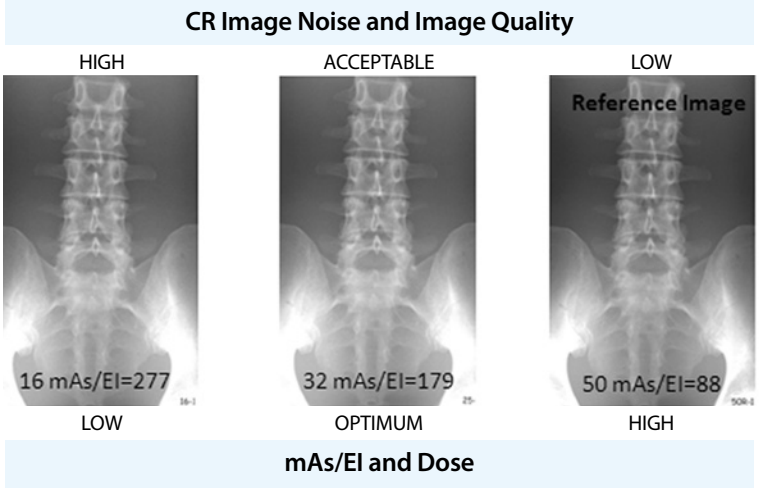

Figure 9. *The main findings of the VGA study demonstrating that the optimum mAs/EI for the AP lumbar spine is 25 mAs/179 compared with the manufacturer's reference image obtained at 50 mAs and an EI value of 88. Reprinted with permission from Seeram E. The new exposure indicator for digital radiography.* J Med Imaging Radiat Sci. *2014;45(2):144-158.*

manufacturers of digital radiography imaging systems causes confusion among technologists.[3] Therefore, a standardized EI is needed. Today, all digital radiography vendors offer the standardized EI; however, Seibert and Morin noted that "the nuances of this new exposure index standard are now at the beginning of clinical implementation and testing."[27] Keeping this in mind, the logical next step would be to extend this study to explore how radiologic technologists should implement the standardized EI.

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