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Radiation Dose and Image Quality with Exposure Factor Variation Using a Virtual Grid in Digital Radiography

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ABSTRACT

Digital radiography technology provides many advantages. However, there are still frequent repetitions of inspections due to failure to determine the exposure factor due to a decrease in image quality. Virtual Grid is a digital radiographic image processing technology that converts image quality that is deteriorating due to X-ray scattering to better image quality by reducing the effects of X-ray scattering. Application of a virtual grid can contribute to improving image quality and increasing the procedural efficiency of the workflow in a radiographic examination. This study uses a research-experimental design, with a One-Shot Case Study. The sample selection of 60 samples was carried out randomly by judgmental or purposive sampling. The sampling technique was carried out with specific considerations for the research objectives to determine the optimal exposure factor by using a virtual grid for the skull, lumbar, and pelvic radiographic examinations. Then, it was analyzed quantitatively and qualitatively visually by three radiologists—a bivariate analysis of data using one-way ANOVA. Qualitative analysis was carried out as well as a test. Feel free to assess the agreement of the informants. Results In the quantitative and qualitative analysis, the exposure factor and the ideal virtual grid ratio for optimization are skull AP: 106 kV, 2 mAs, ratio 14:1, skull lateral: 106 kV, 1.25 mAs, ratio 14:1, skull lumbar AP: 106 kV, 4 mAs, ratio 14:1, skull lumbar lateral: 113 kV, 6.3 mAs, 10:1 ratio, and pelvis AP: 92 kV, 8 mAs, 14:1 ratio.

Keywords: Exposure Factor, Virtual Grid, Radiation Dose, Image Quality.

I. INTRODUCTION

Although radiographic imaging has become a standard tool in modern medicine, its widespread use has also resulted in an increase in the cumulative radiation dose to patients. Optimization of radiographic examinations can be done with several efforts, such as equipping prospective radiographers or radiographers with an understanding of theoretical and clinical doses due to radiation exposure received by patients, emphasizing the need to always assess the exposure factor, whether the exposure is "too high" or "too low, and selecting technical parameters that provide good image quality without excessively increasing the radiation dose to the patient [1][2][3].

Optimization in diagnostic radiology is interpreted as an attempt to make the dose received by the patient as low as possible while maintaining the quality of the images obtained as optimally as possible. One way to optimize protection is with a guide level of medical exposure, or diagnostic reference level (DRL) [4][5]. In the medical display, the patient is part of the object of investigation or the treatment of medical actions that use a source of ionizing radiation. That is, the patient obtains a more significant direct benefit from the medical action, so the patient does not need dose limitation, as is the case with the dose limit value for workers and the community. Even so, the dose received by the patient must be justified and optimized to prevent unnecessary radiation exposure or unnecessary radiation exposure [6].

One of the efforts to optimize patient doses is to vary exposure factors. In the International Atomic Energy Agency (IAEA) Technical Report Series No. 457 referring to International Comission Radiation Unit (ICRU) 74 of 2005, it is stated that entrance surface dose (ESD) is one of the quantity units used in diagnostics to express the radiation dose received by a radiation object phantom or patient. Exposure factors, especially tube voltage, will affect the ESD value [7]. Common radiographic techniques with low kVp and high mAs will increase the doses. The optimal ESD value will be obtained by applying the right procedure [8]. The process of radiographic contrast formation is influenced by scatter radiation, so it can affect the quality of radiographic images. Therefore, to overcome this, the decrease in contrast caused by scatter radiation can be anticipated by using the grid [9].

A grid is a device consisting of strips of metal with a high atomic number, which are arranged parallel to each other and separated by an insulating material or interspace material that X-rays can penetrate. The use of the grid is mainly for radiological examinations of parts of human organs that have high atomic numbers. The grid function absorbs scattered radiation that is not in the same direction as it comes from the exposed object. In its development, the grid, which was originally in the form of a metal plate, is now possible to be replaced with a grid that is only one piece of software that is planted on the program image processing on digital radiography, which in some digital radiography equipment is called a virtual grid [10].

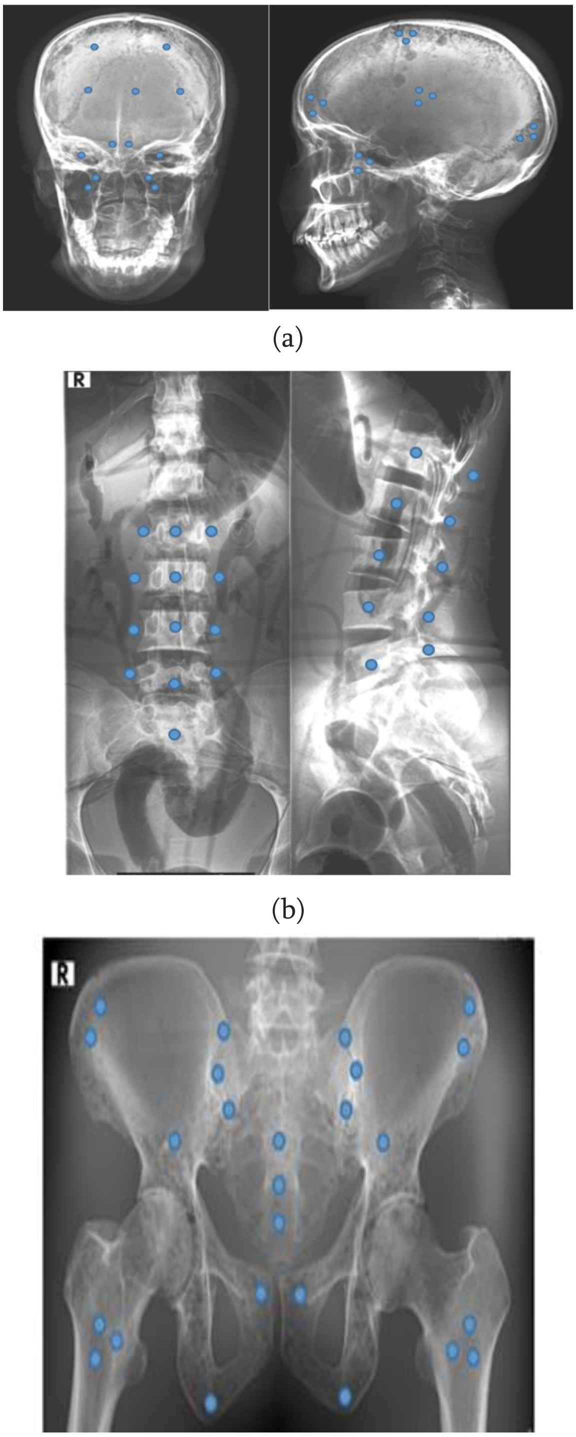
Virtual Grid is a digital radiographic image processing technology that converts image quality that is deteriorating due to X-ray scattering to better image quality by reducing the effects of X-ray scattering. Virtual grids designed to improve image quality degrade from scattering radiation when conventional anti-scattering grids are not used. Research has been carried out, and it has been verified that the use of this technology can improve contrast degradation and granularity caused by X-ray scattering, thereby improving image quality. A wide application of technology such as the virtual grid can contribute to improving image quality and increasing the procedural efficiency of the workflow in a radiographic examination [11].

A preliminary study conducted by the author on 35 radiographer respondents in three hospitals region : Jakarta, Lampung, and Padang, regarding the understanding of the virtual grid and the use of exposure factors in examining the AP skull, lateral skull, AP lumbar vertebrae, lateral lumbar vertebrae, and AP pelvis obtained the following data: Average for Skull AP 71.7 kV, 15.9 mAs; Skull Lateral AP 71.7 kV, 15.7 mAs; V. Lumbar AP 77.1 kV, 18.5 mAs; V. Lumbar Lateral 83.1 kV, 23.6 mAs; and Pelvis AP 74.5 kV, 19.1 mAs. To optimize the dose according to the ALARA principles and regulations of the Republic of Indonesia's Nuclear Energy Regulatory Agency (BAPETEN) Number 4 of 2020, Concerning Radiation Safety in the Use of X-Ray Equipment in Diagnostic and Interventional Radiology, this research was carried out using a virtual grid on digital radiographic images. The image results are evaluated to obtain the ideal exposure factor value with the lowest patient radiation dose and optimal image quality, so that this will support radiation protection efforts for patients while still producing optimal image quality.

II. METHODS AND MATERIAL

A. Research design

The type of research used is quantitative, which is experimental to answer problems. This study emphasizes the analysis of numerical data, which is processed using statistical methods for data interpretation. Based on objectives, relationships between variables, and other types of data, this research uses descriptive methods, namely to describe or analyze a research result but not to draw broader conclusions. Research is conducted with the main objective of making a picture or description of an objective situation to solve or answer the problems being faced in the current situation through the steps of data collection, classification, data processing or analysis, and making conclusions and reports. This study uses a research-experimental design with One-Shot Case Study There is a group that is given treatment, and then the results are observed. Treatment is an independent variable, and results are the dependent variable [12][13]. In this study, variations in exposure factors and variations in grid ratios are a form of treatment carried out in a group to obtain a result in the form of a low patient dose and optimal image quality.



(a)

(b)

(c)

Figure 1. ROI on radiographic examination of the skull, lumbar, and pelvis

Table 1. Variation of treatment on objects with a virtual grid

Projection	Exposure factor	Grids	Ratio Grid
Skull AP	1. 68 kV, 16 mAs	VG	6:1, 10:1, 14:1
	2. 80 kV, 8 mAs	VG	6:1, 10:1, 14:1
	3. 92 kV, 4 mAs	VG	6:1, 10:1, 14:1
	4. 106 kV, 2 mAs	VG	6:1, 10:1, 14:1
Skull Lateral	1. 68 kV, 10 mAs	VG	6:1, 10:1, 14:1
	2. 80 kV, 5 mAs	VG	6:1, 10:1, 14:1
	3. 92 kV, 2.5 mAs	VG	6:1, 10:1, 14:1
	4. 106 kV, 1.25 mAs	VG	6:1, 10:1, 14:1
Lumbar AP	1. 68 kV, 32 mAS	VG	6:1, 10:1, 14:1
	2. 80 kV, 16 mAs	VG	6:1, 10:1, 14:1
	3. 92 kV, 8 mAs	VG	6:1, 10:1, 14:1
	4. 106 kV, 4 mAs	VG	6:1, 10:1, 14:1
Lumbar Lateral	1. 72 kV, 50 mAS	VG	6:1, 10:1, 14:1
	2. 85 kV, 25 mAs	VG	6:1, 10:1, 14:1
	3. 98 kV, 12.5 mAs	VG	6:1, 10:1, 14:1
	4. 113 kV, 6.3 mAs	VG	6:1, 10:1, 14:1
Pelvis AP	1. 68 kV, 32 mAS	VG	6:1, 10:1, 14:1
	2. 80 kV, 16 mAs	VG	6:1, 10:1, 14:1
	3. 92 kV, 8 mAs	VG	6:1, 10:1, 14:1
	4. 106 kV, 4 mAs	VG	6:1, 10:1, 14:1

B. Data collection

Quantitative data sampling is done by nonprobability sampling, regularly judgmental sampling, or purposive sampling. The sampling technique is carried out with certain considerations based on the desired research objectives. Image data of a digital radiographic examination of the AP skull and lateral, AP and lateral lumbar vertebrae, and AP pelvis with variations in exposure factors and variations in grid ratios using a virtual grid. The research was conducted by examining and processing data from digital radiographic images with a variety of exposure factors and grid ratios using a virtual grid. Preparation of the research object, namely the phantom, according to the type of object to be researched. Then calibrate the X-ray machine that will be used for research, which includes output tests (kV, mA, and s). After that, do the calibration. Flat panel detector (FPD) on the digital radiographic device to be used. Next, perform a value calibration of the exposure index and region of interest (ROI) on the digital radiography device to be used. Preparations are made to find out and ensure the standard conditions of the tools to be used in research. If the tool is not standard, then it must be repaired first so it can be used for research. After that, perform a radiographic examination of the head, lumbar vertebrae, and pelvis using a virtual grid with four variations of exposure factors and three variations of grid ratios, with each treatment replicated 3 times as shown in the Table 1. Measure the dose of ESD patients by exposing the same object to the image and with the same exposure factor variation by placing the radiation detector at the center point or center of the exposure area.

Evaluation of image results with image processing applications Image-J in the form of pixel values, CNR, and SNR. The pixel values are obtained from the analysis of the histogram graph, which is the distribution of the pixel intensity values. The SNR value is calculated from the average standard deviation of the pixel values. The greater the SNR value, the better the image quality. The greater the CNR value, the more the image is considered capable of showing differences in sharpness between the two adjacent anatomies [14].The first stage of image data processing is to determine the ROI for measuring pixel values. ROI placement is carried out in several parts of the image [15]. Figure 1 shows the process of placing ROI in an image. SNR value measurement to determine the level of noise image by using equation 1. Measuring the CNR value to know the difference between the two adjacent anatomies can be measured using equation 2 [16][17]:

$$SNR = \frac{Mean_{ROI\ objek}}{STDV_{ROI\ objek}} \quad (1)$$

$$CNR = \frac{Mean_{ROI\ objek} - Mean_{ROI\ BG}}{STDV_{ROI\ BG}} \quad (2)$$

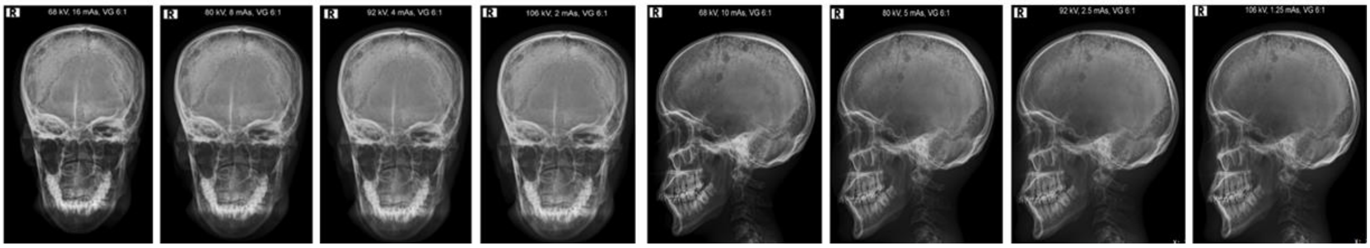
A visual image quality analysis was performed by three radiologists as informants. Image data was analyzed without going through the process of editing W/L. The questionnaire was conducted through questions with five levels of answers Likert scale [15]. If the test results have a value, A value of 1 is given if the observed image is of poor quality (very unclear). A value of 2 is given if the observed image has sufficient quality (unclear). A value of 3 is given if the observed image has moderate quality (seems clear enough). A value of 4 is given if the observed image has good quality (seems clear). A value of 5 is given if the observed image has very good quality (looks very clear).

C. Statistical analysis

The measurement of the dose in entrance surface dose (ESD) patients at each examination shows the dose quantity in units of Gray (Gy). The radiation dose is used to determine optimization efforts so that the exposure factor used during the examination can be reduced as much as possible so that the dose received by the patient is more optimal. Statistical tests with SPSS were carried out to assess the dose associated with the use of exposure factors. Linear regression test analysis and optimization of image quality and dosage with a figure of merit (FoM) to determine the level of radiation dose relationship to the quality of radiographic images as an optimization goal The optimization approach by FoM analysis is given as a contrast ratio against noise (CNR) squared per unit dose. The optimization strategy is carried out by maximizing the CNR, minimizing the dose, and maximizing the figure of merit (FoM). The bivariate analysis of qualitative data from questionnaires given to three informants was then tested for validity by testing product moment and Pearson, and we proceeded with the one-way ANOVA to see the highest average score of the three informants on each examination. Then, to find out the agreement between the three informants, the Fleiss Kappa test was carried out [18]. According to Fleiss's kappa value categories, they are as follows [19]: The value of $k < 0.40$ is a weak agreement. A value of $0.40 < k < 0.75$ is a good agreement. Values of $k > 0.75$ are in very good agreement. The Mark kappa that can be relied upon to be used is between 0.61 and 1.00 [20].

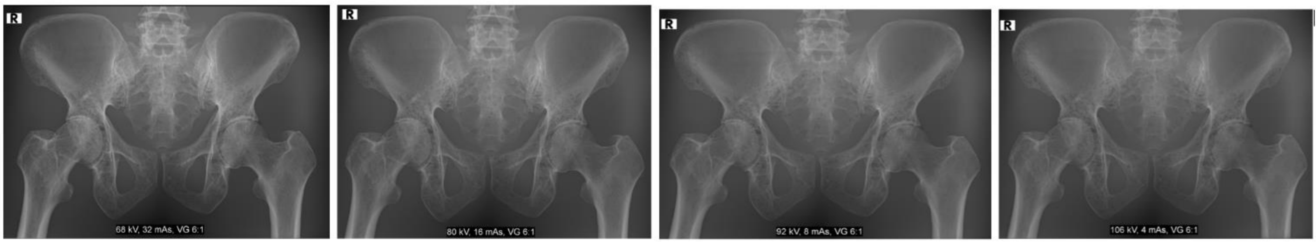
III.RESULTS AND DISCUSSION

Image results of skull, lumbar, and pelvic radiographic examinations are shown in Figure 2. Meanwhile, the analysis of image quality and radiation dose is shown in Table 2. The results of image quality on AP skull radiographic examinations showed the highest SNR value of 66.88 at an exposure factor of 92 kV 4 mAs with a grid ratio of 14:1, the highest CNR of 261.14 at an exposure factor of 68 kV 16 mAs with a grid ratio of 14:1, and the highest FoM of 5.06 at an exposure factor of 92 kV 4 mAs with a grid ratio of 10:1. Then the radiographic examination of the lateral skull value of the highest SNR was 24.82 at an exposure factor of 106 kV 1.25 mAs with a grid ratio of 6:1, for the highest CNR of 53.23 at an exposure factor of 92 kV 2.5 mAs with a grid ratio of 14:1, and for the highest FoM of 4.28 at an exposure factor of 106 kV 1.25 mAs at a 14:1 grid ratio.



(a)

(b)



(c)

Figure 2. Image : (a) skull: AP and Lateral (b) lumbar: AP and Lateral (c) pelvic

Table 2. Analysis of image quality and radiation dose radiographic examination of the skull, lumbar and pelvis

Procedure		Exposure Factors	SNR			CNR			ESD (mGy)			FoM		
			Ratio Virtual Grid			Ratio Virtual Grid			Ratio Virtual Grid			Ratio Virtual Grid		
			6:1	10:1	14:1	6:1	10:1	14:1	6:1	10:1	14:1	6:1	10:1	14:1
Skull	AP	68 kV, 16 mAs	52.56	52.96	52.13	160.45	247.50	261.14	0.61	0.61	0.61	4.62	5	5.06
		80 kV, 8 mAs	62.24	57.03	56.79	173.70	171.92	165.31	0.47	0.47	0.47	4.80	4.79	4.7
		92 kV, 4 mAs	66.48	60.08	66.88	177.31	195.52	194.17	0.33	0.33	0.33	4.97	5.06*	5.05*
		106 kV, 2 mAs	61.68	60.02	62.80	126.20	149.96	160.45	0.23	0.23	0.23	4.84	4.99	5.04*
	LATERAL	68 kV, 10 mAs	20.96	17.58	15.86	26.46	16.95	18.59	0.36	0.36	0.36	3.28	2.90	2.98
		80 kV, 5 mAs	24.07	21.17	18.87	43.91	39.14	32.87	0.27	0.27	0.27	3.85*	3.75	3.60
		92 kV, 2.5 mAs	24.33	21.93	20.56	30.62	32.19	53.23	0.19	0.19	0.19	3.69	3.73	4.17*
		106 kV, 1.25 mAs	24.82	21.16	19.25	28.86	30.03	49.76	0.13	0.13	0.13	3.80	3.84	4.28*
Lumbar	AP	68 kV, 32 mAS	20.17	54.21	15.83	35.29	44.07	38.25	1.16	1.16	1.16	3.03	3.22*	3.10
		80 kV, 16 mAs	29.25	21.26	19.21	27.68	34.60	38.40	0.88	0.88	0.88	2.94	3.13	3.22*
		92 kV, 8 mAs	27.82	25.18	21.18	28.40	29.23	31.65	0.62	0.62	0.62	3.11	3.13	3.20
		106 kV, 4 mAs	29.71	24.51	21.95	24.22	25.40	29.54	0.43	0.43	0.43	3.13	3.17	3.30*
	LATERAL	72 kV, 50 mAS	25.73	21.67	20.02	10.24	8.90	8.29	2.65	2.65	2.65	2.67	2.86*	2.74
		85 kV, 25 mAs	31.32	24.08	23.29	8.66	9.84	8.97	2.04	2.04	2.04	2.57	2.76	2.85*
		98 kV, 12.5 mAs	28.32	24.28	23.93	8.67	9.52	9.06	1.42	1.42	1.42	2.75	2.77	2.84
		113 kV, 6.3 mAs	27.77	27.62	23.07	6.17	8.45	9.62	0.99	0.99	0.99	2.77	2.81	2.94*
Pelvis	AP	68 kV, 32 mAS	53.61	48.72	46.14	100.77	128.67	105.67	1.12	1.12	1.12	3.95	4.17*	3.99
		80 kV, 16 mAs	67.65	61.81	59.68	78.61	100.23	92.35	0.85	0.85	0.85	3.86	4.07*	4.00
		92 kV, 8 mAs	75.04	67.48	64.66	68.16	77.28	83.14	0.60	0.60	0.60	3.88	3.99	4.06*
		106 kV, 4 mAs	78.02	69.86	66.09	49.43	58.87	64.13	0.42	0.42	0.42	3.76	3.91	3.99

*Exposure factor for recommendation optimization methods

Furthermore, for image quality results on AP lumbar radiographic examination, the highest SNR value was 29.71 at an exposure factor of 106 kV 4 mAs with a grid ratio of 6:1, the highest CNR was 44.07 at an exposure factor of 68 kV 32 mAs with a grid ratio of 10:1, and the highest FoM was 3.30 at an exposure factor of 106 kV 4 mAs with a grid ratio of 14:1. Then the lateral lumbar radiographic examination had the highest SNR value of 31.32 at an exposure factor of 85 kV 25 mAs with a grid ratio of 6:1, the highest CNR of 10.24 at an exposure factor of 72 kV 50 mAs with a grid ratio of 6:1, and the highest FoM of 2.94 at an exposure factor of 113 kV 6.3 mAs with a grid ratio of 14:1.

Image quality results on the AP pelvic radiography examination The highest SNR value was 78.02 at an exposure factor of 106 kV 4 mAs with a grid ratio of 6:1, the highest CNR was 128.67 at an exposure factor of 68 kV 32 mAs with a grid ratio of 10:1, and the highest FoM was 4.17 at an exposure factor of 68 kV 32 mAs with a grid ratio of 10:1.

Based on test values obtained with the agreement of the three respondents, skull AP obtained a value of 0.789, skull lateral 0.989, AP Lumbar Vertebrae 0.828, lateral Lumbar Vertebrae 0.993, and pelvis AP 0.960. All show a very good agreement, as shown in Table 3.

Table 3. Value of informant agreement

Procedure	Fleiss's kappa
Skull AP	0.789
Skull Lateral	0.989
Lumbar AP	0.828
Lumbar Lateral	0.993
Pelvis AP	0.960

Quantitative image assessment is done by measuring the values of SNR and CNR with the results of the image taken and used for assessment without going through processing. Higher SNR and CNR values indicate a better-quality image [16]. SNR and CNR analysis and visual anatomical information should yield comparable values. The characteristics of the sample were selected based on the criteria that radiographic examination requires a high exposure factor due to the high level of object tissue density (high atomic number). High kV will produce low image contrast, and high mAs will increase the density and patient dose [21].

Based on the Indonesian Diagnostic Guide Level which is the Decree of the Head of the Nuclear Energy Regulatory Agency No.1211/k/v/2021, concerning the Determination of the Indonesian Diagnostic Guideline Level Value for CT Scan X-Ray Modalities and General Radiography [22], the ESD results in this study for all variations in exposure factors are still below the DRL value set by BAPETEN in 2021.

Quantitative analysis of image results was assessed visually by three radiologist specialists through a questionnaire. The results of the visual evaluation were then analyzed for the average value of image quality based on examination, exposure factor variations, and ratio variations on a virtual grid. The range of values 4–5 (obvious–very clear) is a value that can be used for image quality optimization. To find out the level of agreement regarding the image quality of the three informants, a test was carried out. Optimization is carried out to obtain exposure factor values that produce the lowest dose that can be achieved and optimal image quality. The FoM method is to compare the CNR value to the ESD value.

Optimization results for each skull AP examination were the FoM 5.06 at 92 kV, 4 mAs, ratio virtual grid 10:1 to the two nearest values of FoM 5.05 at 92 kV, 4 mAs, ratio virtual grid 14:1 and FoM 5.049 at 106 kV, 2 mAs, ratio virtual grid 14:1. Skull Lateral was the FoM 4.28 at 106 kV, 1.25 mAs, ratio virtual grid 14:1 to the two nearest values of FoM 4.17 at 92 kV, 2.5 mAs, ratio virtual grid 14:1 and FoM 3.85 at 80 kV, 5 mAs, ratio virtual *grid* 6:1. Lumbar AP was the FoM 3.30 at 106 kV, 4 mAs, ratio virtual grid 14:1 to the two nearest values of FoM 3.22 at 80 kV, 16 mAs, ratio virtual grid 14:1 and FoM 3.22 at 68 kV, 32 mAs, ratio virtual grid 10:1. Lumbar Lateral was the FoM 2.94 at 113 kV, 6.3 mAs Ratio *virtual grid* 14:1 to the two nearest values of FoM 2.86 at 72 kV, 50 mAs, ratio virtual grid 10:1 and FoM 2.85 at 85 kV, 25 mAs, ratio virtual grid 14:1. Pelvis AP was the FoM 4.17 at 68 kV, 32 mAs, ratio virtual grid 10:1 to the two nearest values of FoM 4.07

at 80 kV, 16 mAs, ratio virtual grid 10:1) and FoM 4.06 at 92 kV, 8 mAs, ratio virtual grid 14:1. The closest value to the highest value in the optimization results is intended to provide choices in the use of exposure factors and the ratio virtual grid. The closest value can be an option by looking at the amount of dose the patient gets. Image quality at the three FoM values for each of the above examinations is the image quality at an acceptable or optimal level of diagnostic evaluation.

IV. CONCLUSION

Optimization results with the FoM method and qualitative analysis visually produce recommendations for choosing exposure factors and a ratio virtual grid for radiographic examination skull AP: 106 kV, 2 mAs, ratio 14:1, skull lateral: 106 kV, 1.25 mAs, ratio 14:1, skull lumbar AP: 106 kV, 4 mAs, ratio 14:1, skull lumbar lateral: 113 kV, 6.3 mAs, 10:1 ratio, and pelvis AP: 92 kV, 8 mAs, 14:1 ratio. This exposure factor recommendation is for the lowest dose to the patient, with the resulting image quality at an acceptable or optimal level of diagnostic evaluation.

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