International Journal of Healthcare Sciences ISSN 2348-5728 (Online)
Vol. 4, Issue 1, pp: (232-238), Month: April 2016 - September 2016, Available at: www.researchpublish.com

OPTIMISATION OF IMAGE QUALITY AND RADIATION DOSE USING AIR-GAP TECHNIQUE IN PELVIC RADIOGRAPHY

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Abstract: **The aim of the study was to investigate the effectiveness of the air-gap technique as a substitute for the grid in the pelvic examination for patient radiation dose reduction while maintaining the image quality. An anthropomorphic phantom (PBU-50) was used in this study to simulate an actual human pelvic structure. The phantom was exposed for pelvic examination using the grid and the air-gap technique to compare the exposure factors, the patient dose and the image quality produced from both methods. The patient dose was measured using a Dose Area Product (DAP) meter which was then used to estimate the gonadal dose. The images were scored by three experienced radiographers based on the Commission of European Communities (CEC) image quality criteria to determine the image quality. The result of the study indicated that the air-gap of 25 cm was the optimum air-gap distance. The gonadal dose and the effective dose were reduced from 0.130 mGy to 0.062 mGy and from 0.357 mGy to 0.172 mGy respectively when using the air-gap technique and when using the grid. The study indicated that the image quality produced by the air-gap technique was more superior to the grid. In conclusion, besides the magnification issue, the air-gap technique is suitable to be used in the pelvic radiographic examination as it reduces the patient radiation dose while improving the image quality.**

Keywords: **Air gap technique, pelvic radiography, anti-scatter grid, gonadal dose, effective dose.**

1. INTRODUCTION

The pelvic radiography is one of the examinations commonly carried out in the medical imaging department. In 2008, the annual statistics on x-ray examinations revealed that a total of 174,518 pelvis examinations were carried out in the United Kingdom [1]. This implies that one out of six radiographic examinations done in the United Kingdom is the pelvis examination. In Malaysia, the annual statistics of the pelvic radiographic examination in 2009 was 4% of the total number of the general x-ray examinations [2]. Therefore, its impact on the patient in terms of risk and long term effects and to the population at large has to be known. Scatter radiation is the main contributing factor to the patient radiation dose. The amount of scatter radiation can increase due to factors such as increasing kilovoltage (kVp) and increasing the volume of the tissue irradiated. The radiation dose received by the gonad is of utmost concern as it is a radio-sensitive organ and the effects of ionising radiation to the gonads are highly associated to infertility and cancer. Previous studies indicated that the average gonadal dose received for male and female patients in the radiographic examination of the pelvis is 3 mGy and 1.5 mGy respectively [3]. High scatter radiation produced during radiographic examination of the pelvis will not only give effects to the patient radiation dose but also degrades the image quality by adding overall density to the image receptor thereby lowering the image contrast. Previous studies have proven that the air-gap technique is capable of reducing the scattered radiation from reaching the image receptor and reducing as much as half the radiation dose to the patient when using the grid [4]. The purpose of the study was to ascertain the exposure factors and the air-gap distance in optimising image quality and radiation dose and to relate the absorbed dose in the gonad and its associated risk when using the air gap technique to that of the grid.

2. MATERIALS AND METHODS

2.1 Materials:

The experimental study involved the use of an x-ray unit which consisted of a ceiling mounted x-ray tube, floor mounted table top and a high frequency generator and the pelvic section of the whole body anthropomorphic PBU-50 phantom. A DAP meter, Kermax plus IDP was used to measure the entrance surface air kerma (ESAK). The device was inserted at the lower accessory rails of the collimator. The air gap device consisted of a wooden box constructed with slots for putting the imaging plates (Figure 1). The air-gap used was from 5 cm to 25 cm with five cm interval.

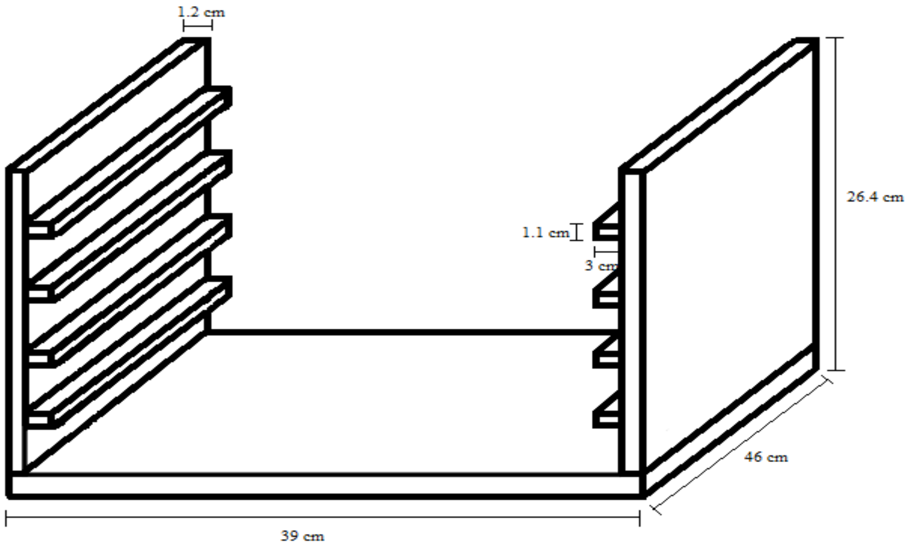

Figure.1: The air-gap device

2.2 Methods:

Image acquisitions were divided into two phases, the examination using the grid and the air-gap. The examination with grid used the normal gridded pelvic examination exposure factors. This was done to obtain the reference image to compare the image of the pelvis in the air-gap technique. The dose received during the x-ray examination was recorded using the DAP meter.

Phase one was carried out by positioning the PBU-50 phantom for AP pelvis examination. The region of interest was then properly collimated. The size of the collimation was recorded to ensure that the collimation was kept constant throughout the examination. The space between the table and the image receptor was taken into consideration whereby there was 5 cm gap that could cause magnification. The pelvis examination was carried out using the imaging parameters shown in Table 1.

Table.1: Details of the imaging parameters used with the gridded technique for AP pelvis

Imaging parameters	Details
Imaging plate size	14 x 17 inches, crosswise
Source to image distance	100 cm
Grid	Moving grid (grid ratio – 12:1)
Kilo-Voltage peak (kVp)	60, 64.5, 70, 75, 81, 85, 90
Focal spot	Large (1.0 mm)
AEC	On

Seven images were produced using the imaging parameters as shown in Table 1 were evaluated by three certified radiographers with more than three years clinical experience in the medical imaging field using the image criteria scoring sheet based on the European Guidelines on Quality Criteria for Diagnostic Radiographic Images [5]. Inter rater agreement of the scores obtained from the radiographers were then assessed using the Kappa coefficient. Two imaging parameters were chosen based on accepted image quality and lowest dose recorded and was used as references for the air-gap technique.

For phase two, the examination was carried out on the floor as the distance between the x-ray tube and the table was not sufficient for the distance required for the air-gap study. The phantom was placed on top of the wooden box and was positioned for AP pelvis examination. The set-up of the study is as shown in Figure 2.

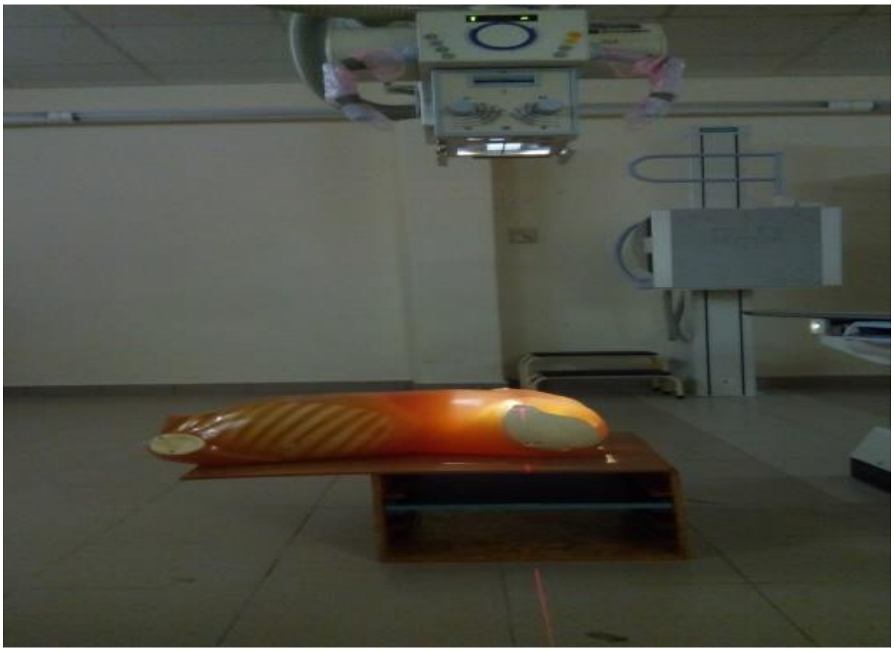

Figure.2: Set-up for the air-gap study of pelvis examination

Table.2: Details of imaging parameter for air-gap AP pelvis

Imaging parameters	Details
Imaging plate size	14 x 17 inches, crosswise
Source to image distance	130 cm
Kilo-Voltage peak (kVp)	81, 85
Air Gap	5 cm, 10 cm, 15 cm, 20 cm, 25 cm
Focal spot	Large (1.0 mm)
AEC	Off

The imaging parameters used for the air-gap study is as shown in Table 2. The kilovoltage used was based on the exposure factors selected from the grid-based examination. The tube current-time used was determined using the formula as shown in equation (1) and (2).

$$\text{Grid Conversion Factor (GCF)} = \frac{mAs\ with\ grid}{mAs\ without\ grid} \qquad \text{Equation (1)}$$

$$\text{Change of mAs with change in SID} = \frac{mAs_1}{mAs_2} = \frac{D_1 2}{D_2 2} \qquad \text{Equation (2)}$$

Ten images produced with the imaging parameters are as shown in Table 2 were evaluated by the same certified radiographers that evaluated the image quality of the radiographs in phase one with using the same image criteria scoring sheet.

Low and high contrast sensitivity and spatial resolution limit were evaluated using the TOR (CDR) test tool. The low contrast sensitivity was evaluated by counting the large circular details on the image and the high contrast sensitivity was evaluated via counting small (0.5 mm) details that were visible while the resolution was assessed by viewing the line pair test pattern on the image that is visible.

2.3 Data Analysis:

The data obtained from the study was analyzed using the Statistical Package for the Social Sciences (SPSS) version 12.0.1. Non parametric statistical data analysis; Wilcoxon Signed Rank Test was used to analyze two related samples obtained in the study.

3. RESULTS

The summary of the technical parameters used for the study using the grid together with the image quality and radiation dose obtained are as shown in Table 3.

Table.3: The technical factors, radiation dose and image quality obtained from the examination using the grid

kVp	mAs	ESAK (mGy)	Image quality score* Evaluator A/B
60	42.1	1.028	3/3
64.5	30.9	0.883	3/3
70	22.5	0.758	1/1
75	17.4	0.667	1/1
81	13.3	0.594	1/1
85	11.3	0.543	1/1
90	9.45	0.499	1/3

*1= fully acceptable; 2= probably acceptable; 3= only acceptable under limited clinical conditions; 4= unacceptable

Based on the results obtained using the grid, 81 kVp and 85 kVp were selected for the kVp to be used for the air-gap technique as these two kVps resulted in the low radiation dose and good image quality. The degree of image quality was determined by the overall image acceptability rated by the evaluators. The Kappa coefficient for score reliability between the two evaluators was 0.731 ($p < 0.05$). A kappa coefficient above 0.7 represents good agreement which indicated the result was reliable between the two evaluators. The first numeral under image quality score presented in Table 3 refers to evaluator A while the second numeral refers to evaluator B. In overall acceptability, high scores were given for image quality that resulted from using tube potential of 70, 75, 81 and 85 kVp. Based on the above findings, 81 kVp and 85 kVp were used in the air-gap technique. Table 4 summarizes the technical parameters used, the radiation dose and the image quality obtained.

Table.4: The technical factors, radiation dose and image quality obtained from the examination using air-gap technique

kVp	mAs	Air gap distance (cm)	ESAK (mGy)	Image quality score* Evaluator A/B
81	5	5	0.216	4/4
	5.6	10	0.228	4/4
	5.6	15	0.228	3/4
	6.3	20	0.257	2/3
	6.3	25	0.258	2/2
85	3.6	5	0.163	4/4
	4.0	10	0.180	4/4
	4.5	15	0.202	3/3
	5.0	20	0.224	2/3
	5.6	25	0.251	1/2

*1= fully acceptable; 2= probably acceptable; 3= only acceptable under limited clinical conditions; 4= unacceptable

Based on the findings as shown in Table 4 when using the air-gap technique, 85 kVp using 25 cm gap resulted in low radiation dose and the best image quality. The degree of image quality was determined by the overall image acceptability rated by the evaluators. The first numeral under image quality score presented in Table 4 refers to evaluator A while the second numeral refers to evaluator B. In overall acceptability, the highest score was attained when using 85 kVp, 5.6 mAs and 25 centimeters air gap.

Table.5: Gonadal and effective dose between using the grid and the air-gap technique

Variable	Mean gonadal dose (mGy)	*p*-value	Effective Dose (mGy)	*p*-value
Grid	0.130	0.025	0.357	0.025
Air-gap	0.062		0.172	

The Wilcoxon signed ranks test indicated that there was a significant difference in the gonadal and the effective dose received when using the grid and when using the air gap technique for examination of pelvis, $Z = -2.236$, $p < 0.05$.

Determination of image quality obtained when using the grid and when using the air-gap technique was carried out using the Leeds TOR test tool. The results obtained are as shown in Table 6.

Table.6: Results of Leeds TOR test tool to determine image quality

Variable	KVp	mAs	Low-contrast disc number resolved*	High-contrast disc number resolved**	Spatial Resolution bar group***
Use of Grid	85	11	13	13	15
Use of Air-gap	85	5.6	14	15	16

* 13: 0.009; 14: 0.007

** 13: 0.088; 15: 0.061

***15: 2.50 lp/mm; 16: 2.80 lp/mm

Referring to the specifications of the test details, the results in Table 6 indicated that the low contrast sensitivity for grid and air-gap was 0.009 and 0.007 respectively while the high contrast sensitivity for grid and air-gap was 0.088 and 0.061 respectively. The limiting resolution for grid and air-gap was 2.5 lp/mm and 2.8 lp/mm respectively. The result of low and high-contrast sensitivity of the air-gap technique indicated lower values for the air-gap technique compared to when using the grid. The manual indicated that the lower values obtained, the higher is the sensitivity to the contrast. Lower values obtained in the air-gap technique indicated its ability to detect low and high contrast compared to when the grid was used. The findings also indicated that the radiograph obtained using the air-gap has better resolution than that obtained when using the grid. Based on the results shown, it can be concluded that this study has refute the existing knowledge with respect to the use of the grid.

4. DISCUSSION

The tube current recorded in the study was the highest when using the lowest tube potential which indicated that higher tube potential will allow the tube current-time to be reduced as evidenced by [6] without compromising on the image quality. Since the tube current-time was the main contributing factor to the patient dose, higher tube current-time could lead to higher patient dose that can induce radiation risk. Thus high tube potential is beneficial in reducing patient radiation dose by providing higher penetrability of x-ray photons and lower absorbed dose to the patient. Furthermore, from the image quality scores obtained with the use of a grid which indicated that a high tube potential resulted in higher acceptability than that of lower tube potential. The explanation of such result may be due to the lower tube potential produced images of higher contrast as opposed to the higher tube potential, the image produced manifests a lower contrast as a result of longer gray scale [7]. An image of long gray scale was preferable in pelvis radiography since the pelvic structure was made of thick and thin structures.

In the air-gap study, the tube potential of 81 kVp and 85 kVp were used as it indicated in the study to have resulted in the usage of low mAs, low patient dose and acceptable image quality. The grid ratio used in the study was 12:1. Therefore, theoretically the mAs should be reduced by five times when non grid was used [8]. This resulted in a lower tube current-time being used in the air-gap technique. A reduction in tube current-time was indicated when using the air-gap technique due to the path for the radiation beam to pass through was unobstructed compared when using the grid. Thus, less exposure was needed in the air-gap technique. As the air-gap distance gradually increase, it was necessary to compensate for the tube current-time following the inverse square law [9]. This is consistent with the method used in this study whereby the exposures were increased as the air-gap was increased in the air-gap study.

The image quality score showed that the image produced using the air-gap distance less than 20 cm were scored as unacceptable or low acceptability. This indicated that the gap less than 20 cm was inadequate in blocking the scatter radiation from reaching the image receptor. This was in contrary to the study by Chan and Fung [10] for the same examination which they found that 10 cm air-gap was adequate to absorb the scatter radiation before reaching the image receptor. The differences in findings can be due to different phantom being used in their study. This study indicated that the 25 cm was the best air gap to remove scatter radiation.

The image produced when the grid was used showed a high contrast image with sharp structure visualization and less magnification. On the other hand, the image produced when 25 cm air-gap was utilized showed a lower contrast and magnified image. Although the image produced when the grid was used provided sharper structure visualization, the thin structure (inferior ramus) was not well visualized as compared to the image produced with the 25 cm air-gap the inferior ramus was better visualized and thus, may contribute to better diagnosis.

Theoretically, since the patient radiation dose was reduced when using the air-gap technique as opposed to when using the grid, hence the gonadal dose will also be reduced as the gonadal dose is based on the absorbed dose. Since a higher exposure factor was employed when using the grid as opposed to that when using the air-gap technique hence it is concurrent to the finding of this study that the gonadal dose was statistically significant when using the grid and when using the air-gap technique. As the absorbed dose is a major contributing factor of the effective dose, therefore, a lower patient radiation dose will ultimately bring about a lower absorbed dose and hence a lower effective dose to the patient. The effective dose is one of the measures used to relate the risk of cancer incidence of a population arising from the procedure.

5. CONCLUSION

The findings of the study indicated that the air-gap technique for pelvis radiographic examination is the recommended technique as it offers more benefit such as better image quality with lower radiation dose as compared to when using the grid. In theory, the air-gap technique reduced the patient radiation dose because of the lower tube current-time utilized. However, because of the large object-to-image distance, magnification existed that will degrade the image quality. However, contrary to this fact this study indicated that the air-gap technique scored higher both in contrast and spatial resolution when compared to that when using a grid. In pelvis radiography, the long gray scale is preferable since the pelvic structures are made of thick and thin structures. Therefore, it was evident from this study that the optimum tube potential used for pelvis radiographic examination was 85 kVp because high tube potential will result in a long gray scale to be produced in the image. With the use of high tube potential, the tube current-time was reduced. The optimum exposure factors found in this study when using the grid was 85 kVp and 11.3 mAs whereas for the air-gap technique was 85 kVp and 5.6 mAs which was found to be statistically significant. Undoubtedly, this finding was theoretically relevant as when using the grid, exposure factors had to be increased due to the partial absorption of the primary beam by the lead slats in the grid. Despite the increase SID adopted when using the air-gap technique, the exposure factor used was still lower compared to that when using the grid. Theoretically, the image quality obtained when using the air-gap technique should be more inferior compared to when using the grid due to magnification which affects the resolution. However, the findings of this study indicated that the image quality obtained when using the air-gap technique was more superior probably due to less penumbra effect with the increased SID used when using the air-gap technique. Another contributing factor was that with the 25 cm air-gap used, the scatter was prevented from reaching the image receptor and hence scored higher both in high and low contrast sensitivity. Thus, the air-gap technique is the technique of choice for pelvis radiographic examination using 85 kVp, 5.6 mAs and 25 cm air-gap.

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