Analysis of image quality and effective dose in adult chest phantom radiography with high BMI.

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Abstract

Aim: To investigate the impact of different kVp and mAs values on effective dose and image quality using a chest phantom that simulates a normal sized and an obese patient.

Methods and materials: A chest phantom with simulated pathological nodules was imaged at various kVp and mAs values. To determine the image quality, CNR and SNR were calculated. An observer study was carried out using relative visual grading with a 3-point Likert scale to assess image quality and nodule visibility. The VGA-study reference image was of the phantom at standard size without the chest plates using 125kVp, 2.4mAs by AEC and 24μSv. Visual grading scores were compared against SNR and CNR values in order to determine the optimal acquisition parameters. Effective dose was calculated using Monte Carlo simulation software, and a Figure of Merit was calculated.

Results: The image obtained with 125 kVp and 4.0 mAs had the highest SNR, and the one with 125 kVp and 2.0 mAs had the highest CNR. The observers found that 125 kVp/4.0 mAs was the most optimal image and 125 kVp/6.88 mAs had the least image quality, when compared to the reference image. On calculating the Figure of Merit, 125 kVp/2.0 mAs has the highest score. The effective dose varied from 5.34 μSv to 73.5 μSv for the range of parameters used.

Conclusion: It is possible to get higher SNR, CNR and VGA-scores in large sized patient chest radiography at lower mAs than that given by using standard AEC, due to post-processing. Manual mAs better control the image quality than using AEC. Anatomical features are better detected using a higher mAs and a standard kVp. Better image contrast is achieved when a lower kVp and standard mAs is utilised. A protocol for larger patients needs to be tailored accordingly.

Introduction

The prevalence of obesity in European Union (EU) member states is increasing rapidly. In 2014, it was estimated that 51.6% of the EU's population was overweight.[1] The World Health Organization (WHO) regards obesity as a global epidemic.[2] Obesity also increases the risk of developing diseases and results in an increased need for medical procedures, including x-ray examinations, compared with normal weight individuals.[3]

Overweight people have a greater body volume than those with normal weight. Consequently, for a good quality diagnostic image, the x-ray beam requires more energy and intensity to pass through obese patients as the image receptor has to receive adequate radiation.[4] Therefore, using a standard postero-anterior (PA) chest protocol for a high body mass index (BMI) patient will give an inadequate exposure resulting in suboptimal image quality, thus impacting on pathology identification and its characterisation. A suboptimal image will likely require an additional image, thereby exposing the patient to an unnecessary second radiation dose.

The European Guidelines only state the diagnostic requirements and criteria for a standard sized adult patient at 70 kg and 170 cm height.[(1)] A *one size fits all* approach will not work in terms of producing acceptable image quality together with the directive 'As Low As Reasonably Practicable' (ALARP).[6] Therefore, it is important that imaging departments are prepared to manage larger patients.

Using an anthropomorphic phantom, our study aims to investigate the impact of different kVp and mAs values on dose and image quality for PA chest radiography with a view to evaluate a new protocol.

Materials and methods

Equipment

A multipurpose anthropomorphic adult male chest phantom (Lungman)[7] was imaged. This phantom is commonly used in medical imaging research[8] and Lungman has a chest girth of 94 cm, with dimensions of 43 cm (w) x 40 cm (d) x 48 cm (h). The approximate weight of the phantom is 18 kg; which is representative of a standard patient of 65.4 kg. The approximate BMI of Lungman is 23.1 kg/m^2, which is considered normal weight. Chest plates, representing human adipose tissue,[7] measuring 30 mm in thickness were added to the anterior and posterior aspects of the Lungman to simulate a larger body type (See Fig. 1). The weight of the larger Lungman is 36 kg; which is representative of a larger, non-standard patient weight of approximately 82 kg (figure 1).[7] The approximate BMI of the larger Lungman is 29 kg/m^2, which is considered overweight.

Figure 1: The Lungman multipurpose anthropo¬morphic adult male chest phantom and 30 mm chest plates.

Three spherical nodules in sizes 8 mm, 10 mm, 12 mm with a soft tissue density of +100 Hounsfields Units were inserted within the pulmonary vasculature of the Lungman at three different left lung locations to mimic real pathology.[7]

A Siemens Multix Top X-ray Tube and a Siemens Vertix Top Bucky wall stand were used.
A 35 cm x 43 cm Canon CXDI-701C wireless CsI digital detector was used with an anti scatter grid (grid ratio of 1:17 and 70 grid lines/cm). A broad focal spot of 1.0 mm was selected, which also complies with the European Guidelines and the manufacturer's recommendations. The Tungsten anode had an angle of 12°. Total filtration of the beam was 3.0 mm Aluminium.[5]

The Lungman was placed in a fixed PA position, to eliminate re-positioning errors, against the vertical bucky (see Fig. 2)[9] with a constant 180 cm source to image distance (SID).[5] The primary x-ray beam was collimated to the lateral margins of the phantom.[10]

The acquisition parameters for the initial exposure were based on the European Guidelines for PA chest radiography of a standard sized patient.[5] The kVp was set to 125 with the automatic exposure control (AEC). Both lateral AEC chambers were selected[11] and a resultant 2.4 mAs was measured.

To test other parameters used in the clinical setting images were acquired by altering kVp to 133, 117 and 90 whilst keeping the mAs constant at 2.5 mAs.[12] This constant value of 2.5 mAs was based on the AEC result in the first exposure.

As the Signal-to-Noise Ratio (SNR) changes with the number of photons detected, different mAs values from 0.5 to 4.5 mAs were used with a fixed voltage.

Eleven images of Lungman without the plates were acquired using the parameters in Tab. 1.

The chest plates were placed on Lungman (referred to as 'non-standard Lungman') and the experimental procedure was repeated as indicated above.

Dose Calculation

The mAs values were used to calculate the effective dose (ICRP 103)[13] using Monte Carlo simulation software (PCXMC 2.0).[14] The focus to skin distance for the standard Lungman was 160 cm and for the non-standard, 154.0 cm.

The collimation size for the images was 33.7 cm width and 34.6 cm height. The maximum energy of the tube was 150 keV and the number of photons produced 900 000.

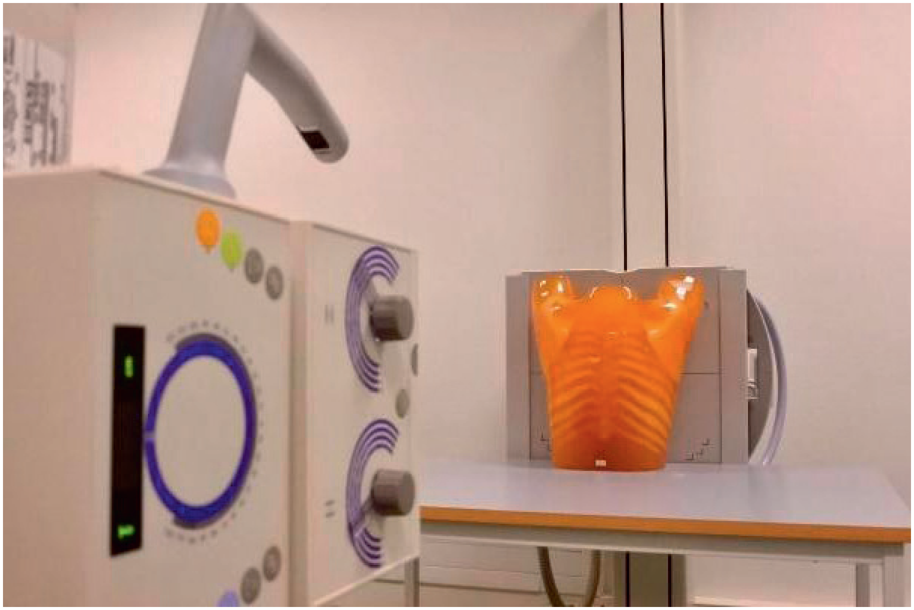

Figure 2: Lungman in PA position against the vertical bucky.

Table 1: Acquisition parameters for standard Lungman exposure and effective dose.

kVp	mAs	Effective dose (µSv)
90	2.5	9.857
117	2.5	20.817
125	0.5	4.961
	1.0	9.922
	1.6	15.876
	2.0	19.844
	2.4 (AEC)	22.522
	3.2	31.751
	4.0	39.689
	4.5	44.65
133	2.5	29.121

SNR/CNR

SNR and Contrast-to-Noise Ratio (CNR) were calculated using Eq. 1 and 2.[15] $\bar{x}$ stands for average pixel value (signal) and σ for the standard deviation (noise). $\bar{x}_1$ and σ_1 represent the background values, $\bar{x}_2$ and σ_2 represent the object values.

$$SNR = \frac{\bar{x}}{\sigma} \qquad \text{Equation 1}$$

$$CNR = \frac{|\bar{x}_1-\bar{x}_2|}{\frac{\sqrt{\sigma_1^2+\sigma_2^2}}{2}} \qquad \text{Equation 2}$$

ImageJ software[16] were used to define Regions of Interest (ROIs) for calculating CNR and SNR. Eight ROIs (1-8) were placed on various anatomical regions.[17] A further three ROIs (9-11) were placed on the nodules (see Fig. 3). The ROI's were placed in the same position and had the same diameter. SNR of an image is the average of the eight SNR values that were calculated.[3] CNR from the ROI of the nodules against the lung parenchyma were calculated and averaged to obtain the image CNR.

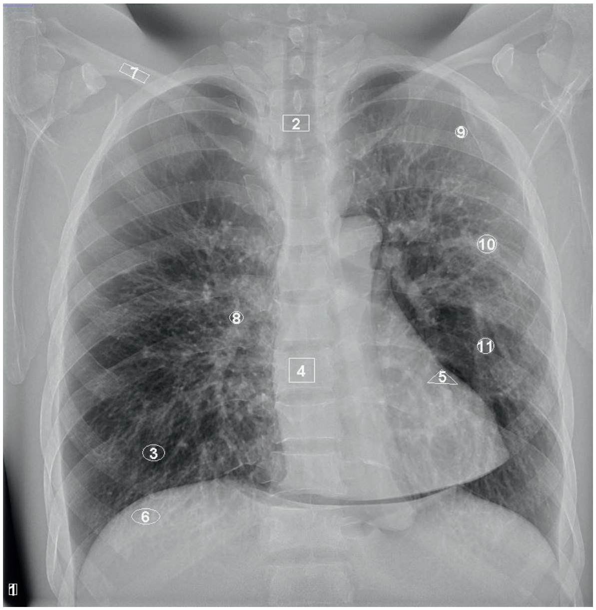

Figure 3: Image of Lungman to demonstrate ROI positions used in the SNR and CNR calculations.

A reference image for relative visual garding was selected based the SNR/CNR measurements, group consensus and the effective dose.

Observer Study

An observer study was performed using relative visual grading.[18] The reference image was compared with 6 images; 'itself' and 5 images of the non-standard Lungman. The images were viewed on dual screen EIZO 5 Megapixels monitors, which were calibrated to DICOM Grey Scale Standard. Twenty observers aged 20 - 64 years old with upto 40 years experience in assessing radiographs reviewed the images. The observer room had no windows and the lights were switched off. A 3-point Likert scale (worse/equal/better) was used to grade the images. The 8 image quality questions used to compare the images (Tab. 2) were adapted from the EU guidelines[5]. The observer could select only one answer for each of the questions.

IBM SPSS Statistics 22[20] was used to calculate the inter class correlation of the observers answers.

Table 2: Questions for the relative visual grading study [5, 19]

#	Questions
Q1	Compare the sharpness of the heart between the image and the reference image
Q2	Compare the sharpness of the aorta between the image and the reference image
Q3	Compare the sharpness of the left diaphragm between the image and the reference image
Q4	Compare the sharpness of the right diaphragm between the image and the reference image
Q5	Compare the sharpness of the edges of these 3 nodules between the image and the reference image
Q6	Compare the contrast with the background for all of the nodules between the image and the reference image
Q7	Less noise means a better image quality. Knowing this, what do you think of the image quality of this image
Q8	Compare the differentiation between soft tissue, air and bone on this image and the reference image

Figure of Merit

A figure of Merit was calculated to correlate the findings of the observer study with the effective dose. The images that scored better than the reference had a value of 2, the images that scored equal had a value of 1 and the images that scored worse than the reference image had a score of 0. The sum of the image quality of the visual grading study was divided by the effective dose to give a figure of Merit.

Results

SNR and CNR

To determine the standard protocol, SNR and CNR were calculated for all of the images of the standard Lungman (see Fig. 4). The image with the acquisition parameters 125 kVp and 2.4 mAs had the highest SNR (24.88). The image with the acquisition parameters 125 kVp and 1.6 mAs had the highest CNR (7.95). Based on SNR, CNR, the effective dose and their appearance, five images of the non-standard Lungman were selected to compare against the reference image of the Lungman.

Fig. 5 shows the SNR and CNR of the images of the non-standard Lungman that were selected for the observer study. 125 kVp and 4.0 mAs resulted in the highest SNR (20.41). 125 kVp and 2.0 mAs resulted in the highest CNR (8.77). Furthermore, 125 kVp and 6.88 mAs both SNR/CNR are reduced.

Observer Study

The consistency of the observers, in terms of image analysis was tested, using the IBM SPSS software. The test scored 0.778 ($p<0.0005$), highlighting although ages and experience of the observers varied, their results were consistent.

Tab. 3 illustrates the relative visual grading results. It lists the observers answers highlighting which images were equal/better to the reference image for each question. The total value is the sum of all observer scores fo each image. The values highlighted represent the highest score for each question and total.

The visual grading study indicates that 125 kVp/4.0 mAs for the non-standard Lungman is the best in terms of image quality. 51% of the answers from the visual grading study deemed this image to be of equal/better image quality compared with the reference image. According to the observers this image better differentiates between the soft tissue, air and bone than the other images.

The image acquired with 125 kVp and 4.0 mAs received the highest proportion of equal/better responses, totalling 82, (green box Tab. 3) highlighting that it had either an equal or better image quality than the reference image. The blue boxes illustrate which of the images scored the highest response for

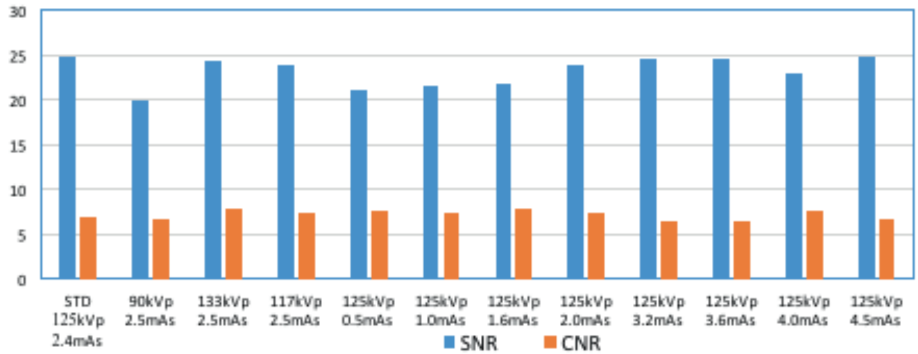

Figure 4: SNR and CNR in Lungman x-ray images with different parameters

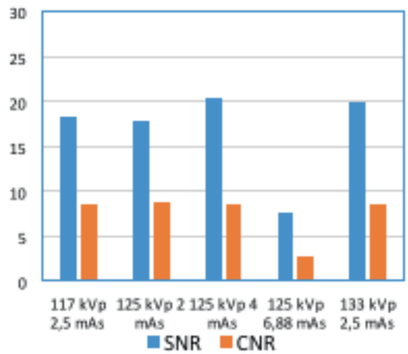

Figure 5: SNR and CNR in non-standard Lungman x-ray images with different parameters

Tabel 3: Results of relative visual grading performed by 20 observers with eught quiations as listed in Tab. 2.

Image	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Total
STD 125 kVp 2.4mAs	19	20	18	19	17	19	19	17	148
117 kVp 2.5mAs	6	10	14	14	2	9	4	7	66
125 kVp 2.0mAs	7	9	13	13	2	3	3	5	55
125 kVp 4.0mAs	10	14	13	13	7	8	8	9	82
125 kVp 6.88mAs	8	6	8	8	2	1	3	1	37
133 kVp 2.5mAs	5	8	13	11	2	5	4	7	55

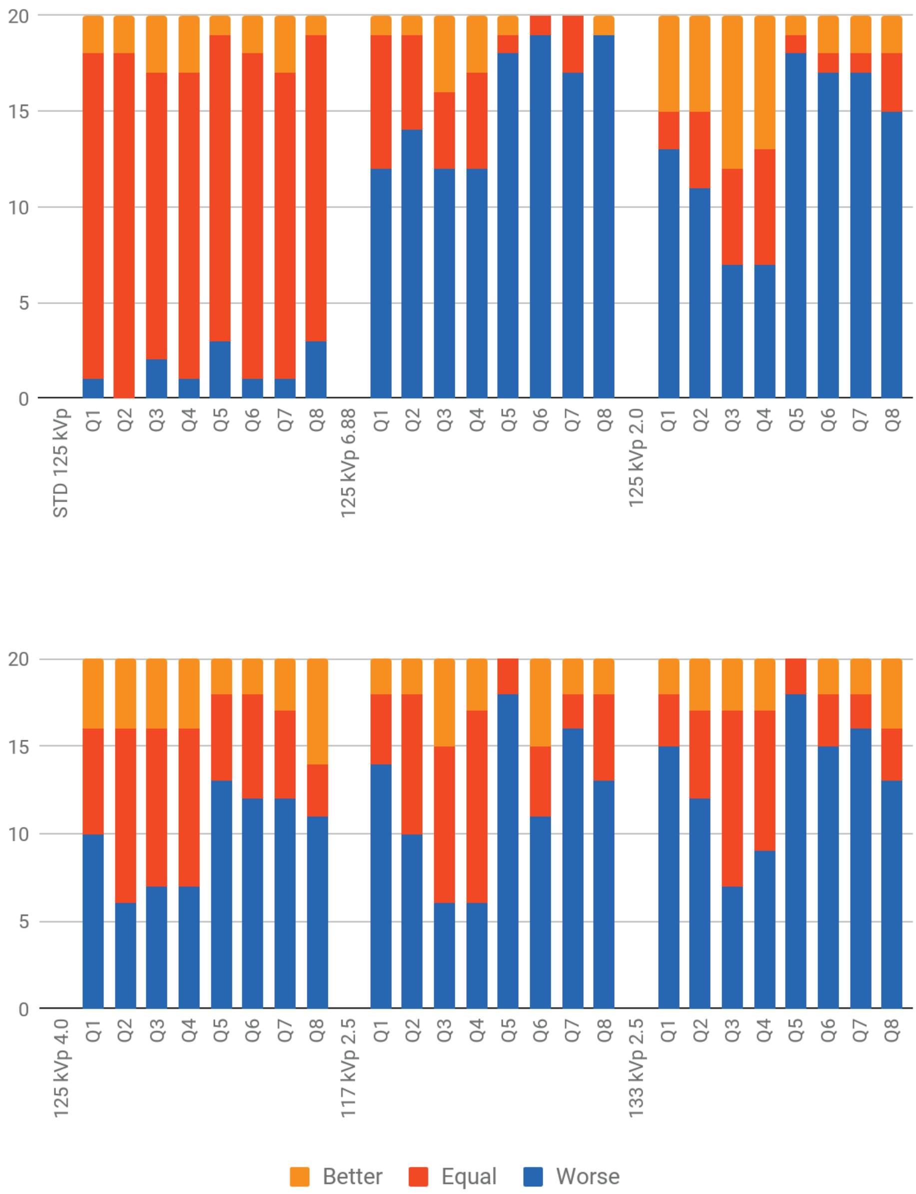

Figure 6: Representation of visual grading study results

particular questions. The observers found that image 4 was of equal/better image quality in terms of the sharpness of the aorta and heart, sharpness of the nodules and the noise and contrast of the overall image. Hence, this table highlights that 125 kVp and 4.0 mAs produced the best results in terms of image quality for the non-standard Lungman. 117 kVp/2.5 mAs scored the highest response rate for the other three questions. The lower kVp and mAs resulted in an equal/better sharpness of the diaphragms and contrast of the nodules relative to both the reference image and image with 125 kVp/4.0 mAs, according to the observers.

Fig. 6 represents the results from the visual grading study. The answers to each of the questions are displayed for each image.

The estimated effective dose varied from 21.4 μSv to 73.6 μSv for the non-standard Lungman (see Fig.7) with a calculation error of ≤0.1%.

The result of the Figure of Merit (Tab. 4) calculation doesn't necessarily mean that the image is better than the others, but that the image has the most optimal image quality at the lowest dose. On calculating the figure of Merit it was found that 125 kVp/2.0 mAs has the highest score.

Discussion

The aim of this study was to investigate the effect of different kVp and mAs values in PA chest radiography for Lungman, with and without chest plates. To date, the European Guidelines (1996) only have a standard protocol for standard sized patients.[5] These guidelines are outdated and not reflective of recent patient trends in terms of size.[2] Technical parameters should be

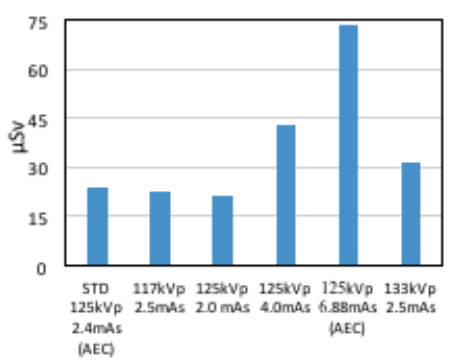

Figure 7. Effective dose for the STD image and the five non-standard Lungman images estimated with PCSMC 2.0.

Image	Visual Grading Score	Effective Dose (µSv)	Figure of Merit
STD 125kVp 2.4mAs (AEC)	165	23.8	6.93
117kVp 2.5mAs	87	22.4	3.88
12 kVp 2.0mAs	87	21.4	4.07
125kVp 4.0mAs	111	42.8	2.60
125kVp 6.88mAs	48	73.6	0.65
133kVp 2.5mAs	74	31.4	2.36

Table 4: Figure of Merit

adjusted to different patient types, not only in terms of collimation, but also in terms of kVp and mAs values.

Our study found that based on both SNR/CNR calculations and the observer study that 125 kVp and 4.0 mAs produce the image of highest quality for non-standard Lungman. However, the Figure of Merit found that 125 kVp and 2.0 mAs were the optimal acquisition parameters for diagnostic image quality and low effective dose.

SNR/CNR

Carcuri[26] states that utilisation of the AEC helps overcome reduced image receptor signal. However, utilisation of the AEC (6.88 mAs) for the non-standard Lungman resulted in an image of very poor image quality as is reflected in the SNR/CNR values. In contrast, the 125 kVp/4.0 mAs image of the non-standard Lungman has an SNR of 20.20, this was the highest value.

The image obtained with 125 kVp/6.88 mAs has the lowest CNR; 2.72. The CNR value of the 125 kVp/4.0 mAs image is 8.76. Thus, imaging the non-standard Lungman with a higher kVp and a lower mAs results in a lower dose and an higher SNR and CNR values.

Observer study

An optimal exposure technique gives good anatomical detail. It was found that the observers matched the SNR/CNR findings and graded the image obtained using 125 kVp/4.0 mAs to be of equal/better image quality to the reference image. The observers found that the overall sharpness of this image was of equal/better quality compared to reference image. This is to be expected as a higher mAs value was selected which improves the sharpness of anatomical features.

Interestingly the image that was acquired with 125 kVp/ 6.88 mAs was found to be of worse image quality across all criteria when compared to the reference image. Thus, the observers subjectives analysis is therefore reflective of the low SNR value that was observed in the physical measurements.

The observer study found that the image produced using 117 kVp/2.5 mAs was the second most optimal, according to observer, in terms of image quality. It has the best contrast differentiation for the nodules.

Figure of Merit

The parameters 125 kVp/4.0 mAs produce the best quality image according to the physical and subjective datasets. However, this image is not optimal in terms of dose. Whilst the dose increases due to non-standard Lungman size it is still important that the dose remains ALARP. The figure of Merit found that 125 kVp/2.0 mAs produced the most optimal image in terms of image quality and effective dose. However, the findings of the visual grading study state that 125 kVp/ 2.0 mAs lacked clarity for nodule identification, mainly as a result of the lack of contrast that could be visually detected.

The lower value of 2.0 mAs is reflective of the post processing that occurs within the imaging system. It seems that post processing of images on the system can result in a diagnostic image at a lower effective dose.[21] This further reinforces the fact that the current guidelines are outdated and not representative of current imaging practices and imaging systems.

Conclusion

The physical measures and the observer study concluded that 125 kVp/4.0 mAs were the optimal acquisition parameters for high image quality. However, the figure of Merit determines the image quality in terms of the effective dose and concluded that 125 kVp/2.0 mAs were the optimal parameters. This highlights that diagnostic images can be obtained using lower doses when both the image quality and the effective dose are taken into consideration.

Furthermore, our study found that AEC does not always result in optimal image quality or a lower effective dose. Hence, a protocol for larger patients' needs to be tailored accordingly. Manual exposure parameters better control the image quality. Anatomical features are better detected using a higher mAs and a standard kVp. Better image contrast is achieved when a lower kVp and standard mAs is utilised.

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