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Assessment of Adult Patient Radiation Dose and Image Quality in CT Examinations Performed Using Automatic Exposure Control and Fixed Tube Current Techniques: A Phantom Case Study

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ABSTRACT

The aim of the study was to compare radiation dose and image quality for adult routine medical CT examinations performed with automatic exposure control (AEC) and fixed tube current (FTC) techniques. Head and body dosimetry CT phantoms were used to mimic an adult head and torso region for routine adult CT examinations (head, chest, abdomen and pelvis). The same acquisition parameters were used, except with varying tube current time product (mAs) for the FTC technique. Dose measurements were performed using a CT dose Profiler probe connected to an electrometer. Image quality was assessed in terms of spatial resolution, low contrast resolution and contrast to noise ratio (CNR) using the Catphan 700 phantom. For AEC activated scans, the estimated CTDIvol were; 32.8, 6.7, 14.3, and 11.7 mGy for head CT, chest CT, abdomen CT and pelvis CT examinations respectively. Scans performed with FTC ranged from 32.9 - 53.0 mGy (head CT), 9.5 - 26.2 mGy (chest CT), 9.5 - 24.2 mGy (abdomen CT) and 9.5 - 26.0 mGy (pelvis CT). For the DLP, scans with AEC activated were; 593, 108, 240, and 190 mGy.cm for head, chest, abdomen and pelvis CT examinations respectively. That of FTC technique ranged from 571 - 946 mGy.cm (head CT), 284 - 780 mGy.cm (chest CT), 165 - 543 mGy.cm (abdomen CT), and 250 - 690 mGy.cm (pelvis CT). The use of AEC resulted in up to 19.4% and 18.2% mean dose reduction in CTDIvol and DLP for head CT and a mean reduction of 12% - 59.4% in CTDIvol and 7.1% - 78.3% in DLP for chest CT, abdomen CT and pelvis CT. The overall image quality test for spatial resolution was 4.20 and 4.40, and low contrast detectability score of 11.20 and 14.60 for the supra slice contrast level and 9.40 and 6.0 for the sub-slice contrast level for the two scan techniques respectively, with no significant differences ($P > 0.05$). However a difference of significance was noted in the contrast to noise ratio score ($P=0.014$). Thus, CT scans performed using the AEC system reduces the radiation doses with no compromise in image quality compared with FTC technique.

Keywords: Radiation dose; Computed tomography; Image quality; Automatic exposure control; Fixed tube current; Catphan phantom; CT dose Profiler.

I. INTRODUCTION

Computed Tomography (CT) is a medical diagnostic tool that has made remarkable technological development in recent times especially after the introduction of helical CT technology in the late 1980s [1] . Information obtained from CT examination makes it one of the most powerful and widely used medical tool for diagnosis of a wide range of diseases.

The radiation dose to patients from CT examinations is the highest contributor of diagnostic medical exposure and has made radiation exposure from CT a matter of great public concern. Reports indicate that CT contribution to the total global collective dose is about 43% of the total collective dose due to diagnostic medical radiology [2]. It is also reported that CT usage in the United States of America (USA) has been on the increase by 10% -15% every year [3, 4] with similar trends been perceived in other parts of the world. This trend nearly doubles the number of CT scans performed in the USA in the last few decades due to the use of CT in hospital settings [5, 6] .

In the United Kingdom (UK) and Germany, CT examination accounted for about 60% and 82% of the total radiology collective effective dose [7, 8]. Even though there is inadequate information on national reliable data regarding radiation exposure from radiological examinations in Ghana, CT dose contribution due to medical exposure is likely not different from other reported trends. In order to compensate for this trend in a broader perspective, numerous measures have been suggested to reduce the radiation doses from CT scans whiles achieving adequate image quality in line with the As-Low-As-Reasonable Achievable (ALARA) principle consistent with clinical requirements [9].

In clinical practice, quality images are desirous for accurate diagnosis of patients' ailments. Thus, keeping a fine balancing of the radiation dose imparted to patients' and the quality of images obtained becomes imperative. This has been a challenge to the medical community in establishing adequate image quality whiles delivery the lowest possible radiation to the patient, in agreement with the ALARA principle. Image quality in CT has many components affected by some technical parameters. These components include image noise; which describes the variation of CT numbers in a physically uniform region. The high-contrast spatial resolution, which quantifies the minimum size of a high-contrast object that can be resolved. The low-contrast spatial resolution which quantifies the minimum size of a low-contrast object that can be differentiated from the background, which is related both to the contrast of the material and the noise resolution properties of the system. The contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) are also some common metrics that often quantify the overall image quality [10]. To optimize image quality, the dose to the patient and relevant CT dosimetry should not be ignored as obtaining high-quality images is always associated with high patient doses.

Minimizing dose whiles obtaining optimum quality images is imperative in CT examinations and various dose reduction and optimization techniques have been formulated aimed at increasing the benefit to risk ratio. One parameter that affects radiation dose is the electrical current, and manual modulation of the current according to patient size is the traditional approach to reducing the radiation dose[4, 11]. An effective approach is the application of an automatic exposure control (AEC) system which modulate the X-ray tube current (mAs) during scanning. This technique adjusts the mAs in either the x - y plane (angular modulation technique) or z - plane (z-axis modulation technique) to provide a constant level of image noise on the basis of patient size, attenuation profile, and the scanned parameters [12].

The AEC decreases the mAs automatically for regions with lower attenuation and increases the radiation dose literally (higher attenuation parts) whilst maintaining an acceptable level of image noise in the acquired images [13]. The aim of the study was to comparatively assess the radiation dose and image quality for most common adult medical routine CT examinations performed using automatic exposure control (AEC) system activated and fixed tube current (FTC) techniques.

II. MATERIALS AND METHODS

A multi-detector row Siemens Somatom Emotion CT scanner (Siemens Healthcare, Forchheim, Germany) with 16 channel detector configuration was used in this study. The CT scanner uses the CareDose4D as its automatic exposure control feature which enables automatic adjustment of the tube current in various planes (x-y and z) axis based on the size and attenuation of the body area being scanned to achieve an image quality adequate for diagnosis. A standard CT dosimetry Polymethylmethacrylate (PMMA) cylindrical acrylic head (16-cm diameter) and body (32-cm diameter) phantoms were used to mimic an adult head and torso region (representing thorax, abdomen, and pelvis) respectively. A CT dose Profiler probe (RTI electronics, Sweden) connected via an extension cable to a barracuda and a computer system with an ocean software was used for the dose measurements. The image quality assessment was conducted using a Catphan 700 phantom. The acquired images were evaluated for spatial resolution, low contrast detectability and contrast to noise ratio.

2.1 Dose Measurement Procedure

Dose measurements were performed by setting up the CT head and body phantoms in succession. The head phantom was first set up on the CT couch and centred at the isocenter of the scanner with the long axis of the phantom aligned with the z-axis of the scanner. A scanogram of 1 mm slice image of the phantom was acquired for purposes of alignment.

The CT Dose profiler was connected via an extension cable to a barracuda and a computer with the ocean software. The dose profiler was placed at the central hole of the phantom and a scanogram image used to select the exact volume to be scanned. The AEC was activated for the first scan with the standard protocol for routine head CT examination as shown in Table 1.

Table 1. Routine patient imaging protocols using the automatic exposure control technique.

	CT Examination				
Protocol	**Head**	**Chest**	**Abdomen**	**Pelvis**	**Spine**
kVp	130	130	130	130	130
mAs	220	100	120	120	190
Rotation Time (s)	1.5	0.6	0.6	1.0	1.0
Slice Thickness (mm)	4.0	5.0	5.0	5.0	3.0
Pitch	0.55	0.8	0.8	1.5	0.65
Collimation (mm)	16×1.2	16×1.2	16×1.2	16×1.2	16×0.6
Reconstruction Kernel	H31S	B41S	B41S	B41S	B31S
FOV (cm)	214	214	214	214	214

The head CT scan was repeated with manual selection of fixed tube current values of (140, 160, 180, 200, 220, 240, 260, 280, and 300 mAs) while maintaining other exposure parameters constant as presented in Table 2. The scan was performed in a spiral mode with the exposure factor of 130 kVp and a reference mAs of 220 mAs. The varying tube current values were chosen to provide a range of data points for both above and below the default setting in order to check the functionality of the AEC system as well as to ascertain the effects of the setting on both dose and image quality. Similarly, the scanned procedure was repeated with the body phantom for routine chest CT, abdomen CT and pelvis CT examinations. The AEC technique was scanned with the standard protocol for a routine chest, abdomen, and pelvis CT scan technique with exposure factor of 130 kVp as shown in Table 1. The body phantom scans were repeated with manual selection of fixed tube currents values of (80, 100, 120, 140, 160, 180, 200, 210 and 220 mAs) whiles other parameters were kept constant as indicated in Table 3. The dose index $CTDI_{vol}$ and the dose length product (DLP) values, were automatically calculated and displayed by the ocean software (that was installed on a computer) after each scan of the head and body CT examinations. To ensure accuracy, dose measurements were performed three times, and the averaged values calculated. Fig 1 shows the experimental setup for dose measurements with the phantoms in the CT scanner.

The dose reduction (DR) was calculated for the $CTDI_{vol}$ and dose length product (DLP) values using equations (1) and (2). For the $CTDI_{vol}$;

$$DR = \frac{CTDI_{vol\,FTC} - CTDI_{vol\,AEC}}{CTDI_{vol\,FTC}} \times 100\% \qquad (1)$$

In terms of the DLP, the dose reduction was calculated as; Dose reduction, (DR)

$$DR = \frac{DLP_{FTC} - DLP_{AEC}}{DLP_{FTC}} \times 100\% \qquad (2)$$

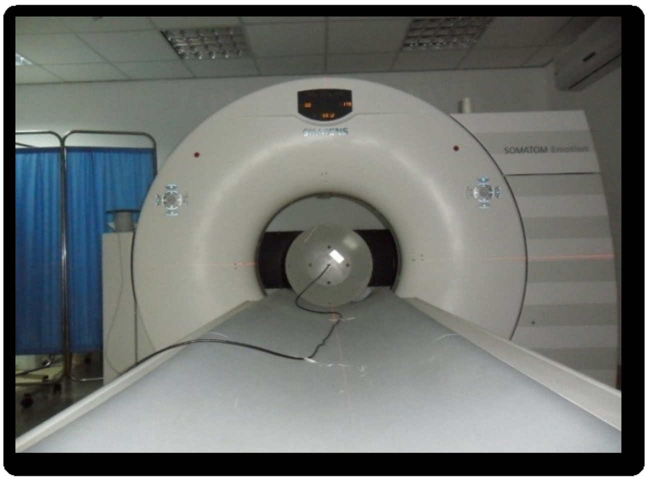


Figure 1. Experimental Setup of body CT phantom in the CT gantry for dose measurements.

Table 2. Head CT scan protocols with fixed tube current technique.

Examination	kVp	mAs	RT (s)	Pitch	ST (mm)	Beam width (mm)	RS (mm)	Reconstruction kernel
Head	130	140	1.5	0.55	4	16x1.2	3	H31S
Head	130	160	1.5	0.55	4	16x1.2	3	H31S
Head	130	180	1.5	0.55	4	16x1.2	3	H31S
Head	130	200	1.5	0.55	4	16x1.2	3	H31S
Head	130	220	1.5	0.55	4	16x1.2	3	H31S
Head	130	240	1.5	0.55	4	16.1.2	3	H31S
Head	130	260	1.5	0.55	4	16.1.2	3	H31S
Head	130	280	1.5	0.55	4	16x1.2	3	H31S
Head	130	300	1.5	0.55	4	16x1.2	3	H31S

Note: kVp: Kilo voltage; RT: Rotation time; mm: Milli meter; mAs: Milli ampere seconds; ST: Slice thickness; RS: Reconstruction slice; S: seconds.

Table 3. Body (chest, abdomen and chest) CT scan protocol with fixed tube current technique.

Examination	kVp	mAs	RT	Pitch	ST	Beam width	RS	Reconstruction
	-	-	(s)	-	(mm)	(mm)	(mm)	kernel
Body	130	80	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	100	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	120	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	140	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	160	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	180	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	200	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	210	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S
Body	130	220	0.6, 1.0, 0.6	0.8, 1.5, 0.8	5	16×1.2	3	B41S

Note: kVp: Kilo voltage; RT: Rotation time; mm: Milli meter; mAs: Milli Ampere seconds; ST: Slice thickness; RS: Reconstruction slice; S: seconds.

Table 4: Scan protocol for image quality test with fixed tube current technique (FTC).

	CT Examination				
Protocol	Head	Chest	Abdomen	Pelvis	Spine
kVp	130	130	130	130	130
mAs	220	100	120	120	190
Rotation Time (s)	1.5	0.6	0.6	1.0	1.0
Slice Thickness (mm)	4.0	5.0	5.0	5.0	3.0
Pitch	0.55	0.8	0.8	1.5	0.65
Collimation (mm)	16×1.2	16×1.2	16×1.2	16×1.2	16×0.6
Reconstruction Kernel	H31S	B41S	B41S	B41S	B31S
FOV (cm)	214	214	214	214	214

Note: kVp: Kilo voltage; FOV: Field of view; mm: Milli meter; mAs: Milli ampere seconds, cm: centimetre.

2.2 Image Quality Evaluation

The image quality of the CT images obtained for the two imaging techniques (i.e. AEC and FTC techniques) were qualitatively evaluated for measurements of spatial resolution, low contrast detectability and quantitatively for contrast to noise ratio using a Catphan 700 phantom (The Phantom Laboratory Inc., Greenwich. NY). Five different routine CT scan protocols were used in scanning the Catphan phantom for the two techniques respectively. These were the routine scan protocols for the various CT examinations conducted. Tables 1 and 4 shows the routine scan protocols used in performing the different CT examinations in this study.

2.2.1 Spatial Resolution

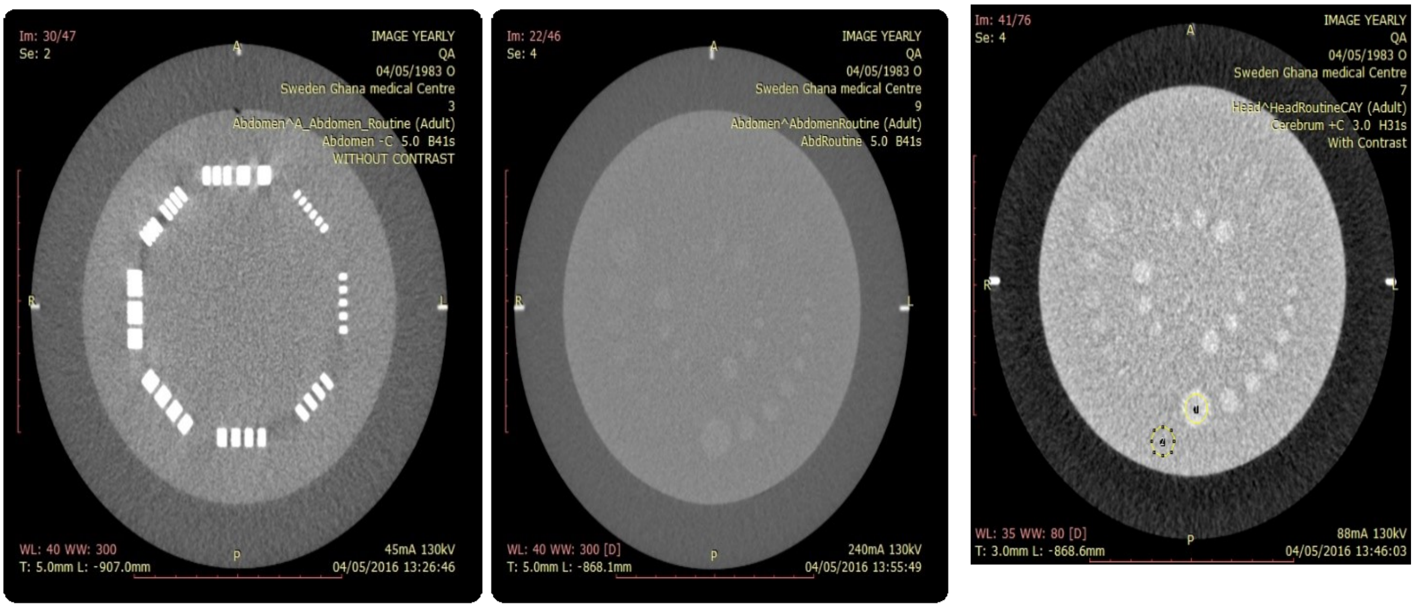
The spatial resolution described the ability of the CT scanner to display, as separate images, two objects that are very close to each other. The spatial resolution module CTP 714 of the phantom contains a 30 line pair per cm gauge cut from 2 mm thick aluminium sheets and cast into epoxy. This was assessed using acquired images of CTP 714 module of the Catphan phantom by determining the number of line pairs one could visualize with the eye without zooming the image, out of a total number of 30 line pair per centimetre gauge of the CTP 714 module as shown in Figure 2.

2.2.2 Low Contrast Detectability

The low contrast resolution and contrast to noise ratio were assessed with module CTP515 of the catphan phantom. The low contrast detectability is the ability of the imaging system to display as distinct images areas that differ in density by a very small amount. The low contrast module CTP 515 of the phantom contains the supra-slice and sub- slice targets contrast levels of 1.0 %, 0.5%, and 0.3 % with varying diameters Fig 2, used to evaluate the ability to differentiate objects with slightly different densities. The low contrast was measured by the counting number of visible targets of the supra-slice and sub-slice contrast targets after reading the image on a RadiAnt DICOM viewer. The Supra - slice contrast was measured by determining the total number of visible targets at 1.0 %, 0.5 % and 0.3 % contrast levels with each image scored on a scale of 0 - 27 depending on the number of targets visualized. The sup-slice contrast was determined by counting the total number of targets in the 3 mm, 5 mm, and 7 mm sections each at 1.0 % contrast level with a score of 0 - 12 for the sub-slice contrast.

The contrast to noise ratio (CNR) in the present study was measured quantitatively using acquired images of CTP515 low contrast module of the Catphan phantom. To quantitatively evaluate the CNR the acquired images were exported into an ImageJ software after reading the obtained image on a RadiAnt DICOM viewer. The CNR was determined by placing same size region of interest (ROI) of 5.4 cm^2 in the 1.0 % (15 mm diameter target) contrast level to measure the mean CT-number, background standard deviation and the mean adjacent background CT number in the low contrast module as shown in Figure 2. Thus, the CNR was then computed using the relation;

$$CNR = \frac{Target\ mean\ value\ -\ Background\ mean\ value}{Backgroug\ Standard\ deviation} \qquad (3)$$



(a) CT image of spatial resolution module. (b) CT image of low contrast detectability module. (c) CT image for contrast to noise to ratio.

Figure 2. CT images of (from left to right) scan spatial resolution module, low contrast detectability module and the contrast to noise ratio (Catphan manual).

2.3 Data Analysis

Data collected were analysed using Microsoft Excel (2010) and the Statistical Package for the Social Sciences (SPSS) version 20.0. The SPSS was used to conduct the relevant statistical analysis of the results obtained. Image J software was used for the CNR analysis study [14] .The paired t-test was used to compare the estimated $CTDI_{vol}$ and DLP of scans performed with AEC system and FTC technique and image quality test done. A P-value of less than 0.05($P < 0.05$) was considered to indicated significant difference.

III. RESULTS AND DISCUSSION

A. Results

In this study, a comparison of patient radiation dose and image quality have been assessed for CT examinations of the head, chest, abdomen and pelvis performed with AEC activated and with FTC technique using scan parameters routinely used for CT examination. Results of $CTDI_{vol}$ and DLP obtained from an average of three measurements made with the head and body phantoms, with scan settings of the selected examinations performed with AEC and FTC are presented in Tables 5 and 6, while the comparison made with published data for [15-19], are summarized in Tables 7 and 8 respectively.

Table 5. Estimated $CTDI_{vol}$ and DLP for head and body CT examinations with AEC

	CT Examination			
	Head	Chest	Abdomen	Pelvis
$CTDI_{vol}$ (mGy)	32.8	6.7	14.3	11.7
DLP(mGy.cm)	593.0	108.0	240.0	190.0

Table 6. Estimated $CTDI_{vol}$ and DLP for head and body CT examinations with FTC

Head CT Examination			Body CT Examination						
mAs	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	mAs	$CTDI_{vol}$ (mGy)			DLP (mGy.cm)		
				C	A	P	C	A	P
140	32.9	571	80	9.5	9.5	9.5	284	165	250
160	33.4	602	100	11.0	11.2	11.9	354	181	314
180	34.5	615	120	14.3	13.5	14.3	426	197	376
200	37.2	664	140	16.7	15.6	16.7	497	251	439
220	41.0	731	160	19.0	18.0	19.0	568	290	502
240	44.6	797	180	21.4	20.0	21.1	639	327	565
260	50.7	904	200	23.8	22.8	24.0	710	357	658
280	51.4	922	210	25.0	23.5	25.0	745	327	627
300	53.0	946	220	26.2	24.2	26.2	780	543	690

Note: C, A, and P denotes chest CT, abdomen CT and pelvis CT examinations respectively.

Table 7. Comparison of $CTDI_{vol}$ and DLP obtained with AEC and other studies

CT Examination	$CTDI_{vol}$ (mGy) and DLP (mGy.cm)					
	This Study		Tsapaki et al., 2006 [16]		Bongartz et al., 2004 [15]	
	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
Head	32.8	593	47.0	527	64.0	337
Chest	6.7	108	9.5	447	7.8	267
Abdomen	14.3	240	10.9	696	14.5	724
Pelvis	11.7	190	-	-	14.5	724

Note: Dash (-) indicate no available data.

Table 8: Comparison of estimated $CTDI_{vol}$ and DLP obtained with FTC and other studies

Fixed mAs	$CTDI_{vol}$ (mGy)				DLP (mGy.cm)			
	Head	Chest	Abdomen	Pelvis	Head	Chest	Abdomen	Pelvis
80	32.9	9.5	9.5	9.5	571	284	165	250
100	33.4	11.0	11.2	11.9	602	354	181	314
120	34.5	14.3	13.5	14.3	615	426	197	376
140	37.2	16.7	15.6	16.7	664	497	251	439
160	41.0	19.0	18.0	19.0	731	568	290	502
180	44.6	21.4	20.0	21.1	797	639	327	565
200	50.7	23.8	22.8	24.0	904	710	357	658
210	51.4	25.0	23.5	25.0	922	745	327	627
220	53.0	26.2	24.2	26.2	946	780	543	690

Other Studies								
Pontas et al., (2011)[17]	-	-	-	-	733	394	464	434
Turkey, (2015)[18]	66.4	11.6	13	19.4	810	389	204	421
Ireland, (2012) [19]	66.2	9.2	12	12.3	940	393	598	598
IAEA Study; Tsapaki et al.(2006)[16]	47	9.5	11	-	527	447	696	-

Note: Dash (-) indicate no available data, IAEA = International Atomic Energy Agency.

Tables 9 –11, shows the estimated percentage dose reduction for the CT examinations in respect of $CTDI_{vol}$ and DLP between the two scan techniques. The head CT scan with AEC activated showed a mean percentage dose reduction of 19.4% (0.3 - 38.1%) and 18.2% (-3.9 - 37.3%) in terms of $CTDI_{vol}$ and DLP compared with the FTC technique. A paired t-test on $CTDI_{vol}$ and DLP showed a statistically significant difference between the two scan techniques ($P < 0.05$). For the chest abdomen and pelvis CT, a mean percentage dose reductions of 12 - 59.4% and 7.1 - 78.3% in $CTDI_{vol}$ and DLP were noted for scans performed with AEC and FTC, with statistically significant difference noted for chest and pelvic examinations ($P < 0.05$), while for abdomen CT examination no statistically significant difference was noted ($P > 0.05$).

Table 9: Estimated dose reduction (DR) in $CTDI_{vol}$ and DLP for head phantom between AEC and FTC.

Scanning Type	$CTDI_{vol}$ (mGy)	DR for $CTDI_{vol}$ [%]	DLP (mGy.cm)	DR for DLP [%]
AEC	32.8	-	593.0	-
140	32.9	0.3	571.0	-3.9
160	33.4	1.7	602.0	1.5
180	34.5	4.9	614.9	3.6
200	37.2	11.8	663.5	10.6
220	41.0	20.0	731.3	18.9
240	44.6	26.5	796.8	25.6
260	50.7	35.3	904.2	34.4
280	51.4	36.2	921.6	35.7
300	53.0	38.1	945.5	37.3
	P - value 0.009	*19.4%*	*P – value 0.013*	*18.2%*

Table 10: Estimated dose reduction (DR) in $CTDI_{vol}$ for body phantom between AEC and FTC.

Scanning Type	$CTDI_{vol}$ (mGy)			DR [%]		
	C	A	P	C	A	P
AEC	6.7	14.0	12.0	-	-	-
80	9.5	9.5	9.5	29.5	-47.4	-26.3
100	11.0	11.2	12.0	39.1	-25.0	-1.0
120	14.3	13.5	14.0	53.1	-3.7	16.1
140	16.7	15.6	17.0	59.9	10.3	28.1
160	19.0	18.0	19.0	64.7	22.2	36.8
180	21.4	20.0	21.0	68.7	30.0	43.1
200	23.8	22.8	24.0	71.8	38.6	50.0
210	25.0	23.5	25.0	73.2	40.4	52.0
220	26.2	24.2	26.0	74.4	42.1	54.2
P-value	*$3.9x10^{-4}$*	*0.84*	*0.01*	*59.4%*	*12%*	*28.1%*

Note: C, A, and P denotes chest CT, abdomen CT and pelvis CT examinations respectively.

Table 11: Estimated dose reduction (DR) in DLP for body phantom between AEC and FTC.

Scanning Type	DLP (mGy.cm)			DR [%]		
	C	A	P	C	A	P
AEC	108	240	190	-	-	-
80	284	165	250	62.0	-45.5	24.0
100	354	181	314	69.5	-32.6	39.5
120	426	197	376	74.6	-21.8	49.5
140	497	251	439	78.3	4.4	56.7
160	568	290	502	81.0	17.2	62.2
180	639	327	565	83.1	26.6	66.4
200	710	357	658	84.8	32.8	71.1
210	745	327	627	85.5	26.6	69.7
220	780	543	690	86.2	55.8	72.5
P-value	*$6.5x10^{-5}$*	*0.209*	*$4.2x10^{-4}$*	78.3%	7.1%	56.8%

Note: C, A, and P denotes chest CT, abdomen CT and pelvis CT respectively.

Qualitatively, the image quality analyses for spatial resolution and low contrast resolution are presented in Figures 3 – 5. For the AEC scan images, a range of 2 - 6 lp/cm was differentiated for all the examinations and a range of 3 - 6 lp/cm in respect of the FTC technique. Generally, there were slight variations in the spatial resolution scores for all the examinations for the two techniques. A paired t-test on the overall spatial resolution scores shows no significant difference between the scan techniques ($P > 0.05$) as shown in Table 13.

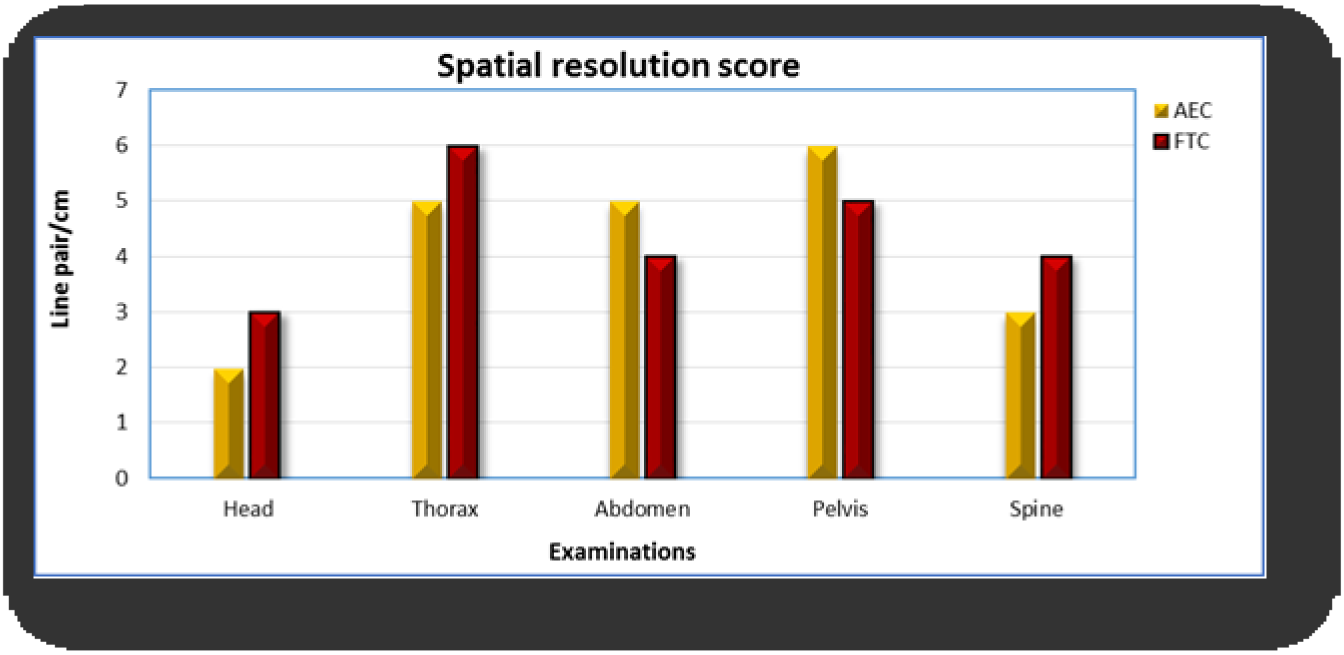


Figure 3. Comparison of spatial resolution test (lp/cm) between AEC and FTC techniques.

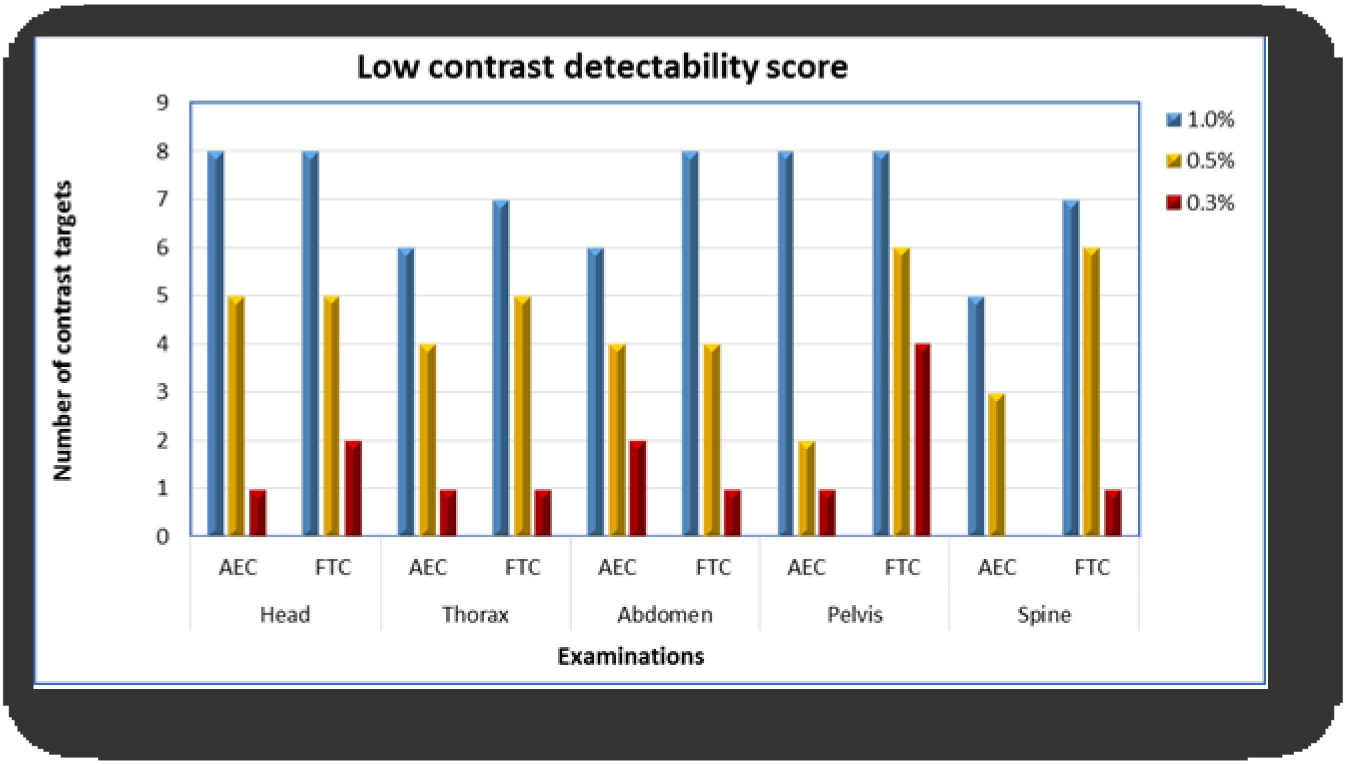


Figure 4. Comparison of low contrast detectability test between AEC and FTC techniques in the supra-slice contrast section.

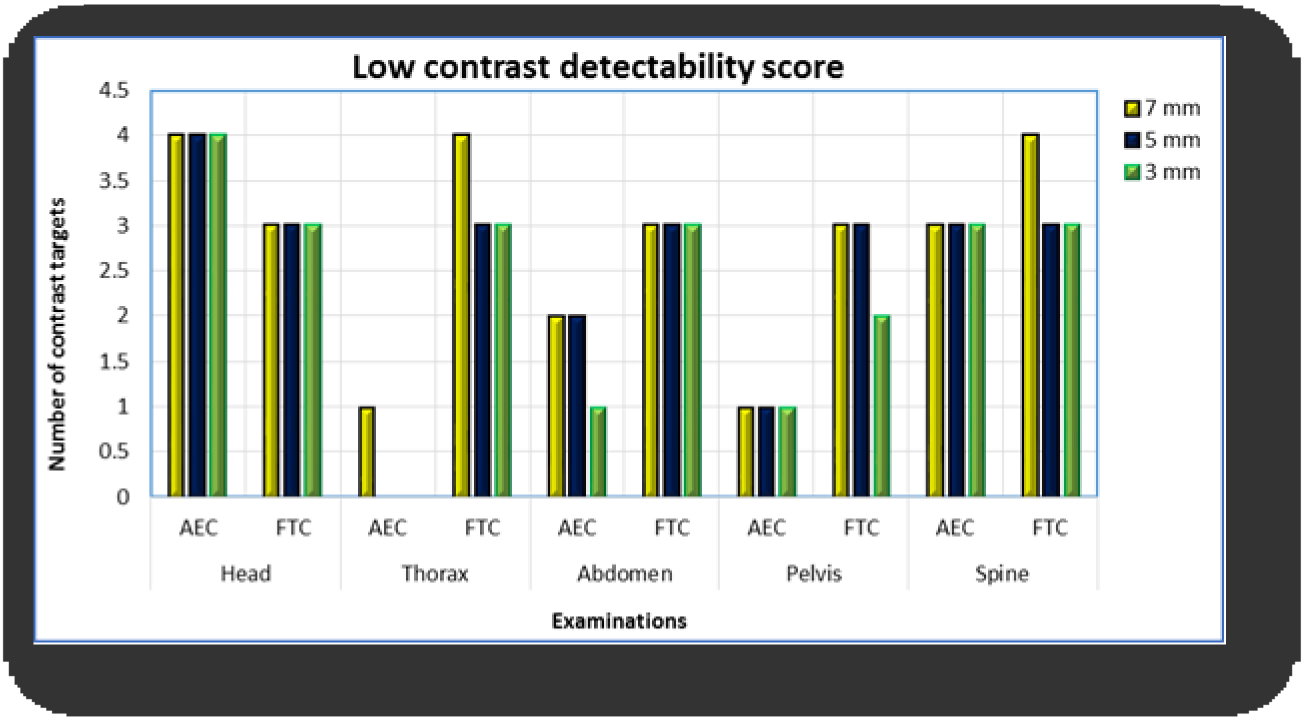


Figure 5. Comparison of low contrast detectability test between AEC and FTC techniques in the sub-slice contrast section.

The low contrast detectability for images obtained with AEC scans ranged from 8 – 5, 2 – 5 and 1 – 2 and a range of 8 - 7, 6 - 4, and 1 - 4 visualized targets for images obtained with FTC techniques for the 1.0%, 0.5% and 0.3% contrast resolution groups of the supra slice contrast resolutions for all the examinations. In the sub-slice low contrast resolution section, a score range of 1 - 4, and 0 - 4, and a range of 3 - 4, 3, and 2 - 3 visualized targets were recorded for AEC and FTC techniques in the 7 mm, 5 mm, and 3 mm contrast resolution groups for all the CT examinations. Overall low contrast detectability shows no significant difference between the scan techniques ($P > 0.05$) as shown in Table 13.

The quantitative analyses of contrast to noise ratio at 1% contrast target for the two scan techniques as shown in Table 12. The CNR values ranged from 0.8 - 2.3 for all scans performed with AEC activated and a range of 1.9 - 2.5 for the FTC technique. The CNR score shows clearly that, images for scans performed with FTC had a much better CNR score compared to those obtained using AEC for all cases. Overall, CNR paired t-test between the two scan techniques shows a difference of significant ($P < 0.05$).

Table 12. Contrast to noise ratio (CNR) score for the various CT examination

	Supra slice @ 15 mm target contrast level: 1.0%							
	Target mean		Background Mean		Background Std. Dev		CNR	
CT Examination	AEC	FTC	AEC	FTC	AEC	FTC	AEC	FTC
Head	186.8	209.7	153.4	175.6	14.5	13.6	2.3	2.5
Thorax	140.7	139.9	134.0	133.4	6.1	3.5	1.1	1.9
Abdomen	143.5	144.0	135.7	135.6	8.1	4.0	1.0	2.1
Pelvis	145.1	146.3	138.9	138.9	8.0	3.5	0.8	2.1
Spine	142.8	141.7	134.5	135.1	6.4	3.4	1.3	1.9
P – value							0.014	

Table 13. P-values of pair t-test (at 95% confidence interval) on overall image quality between the two different imaging techniques

Image quality test	AEC	FTC	p - value
Spatial resolution	4.20 (±1.64)	4.4 (±1.14)	0.704
Low contrast resolution			
Supra slice contrast level	11.20 (±2.17)	14.60 (±2.07)	0.060
Sub slice contrast level	9.40 (±0.89)	6.0 (± 4.47)	0.187

B. Discussion

The use of automatic tube current (AEC) modulation devices in recent CT scanners is to minimize subjective selection of tube current required to obtain the desired image quality at reasonable radiation exposure levels. The application of AEC systems in clinical examinations permit empirical automatic adjustment of exposure technique factors according to the size of the patients [20]. The system is designed to increase the radiation dose literally and decrease it in the anteroposterior direction by changing the mAs on the basis of patient size and different attenuation which is in contrast to the FTC where the same exposure parameters are used for all patients irrespective of the difference in patient sizes. In the review of literature, some studies have reported a substantial reduction in radiation dose for scans performed with AEC compared with FTC technique. A study conducted by Sabri et al [21] (using a thorax phantom) show a reduction in radiation exposure of 17 - 52% for thorax CT examination when performed using angular modulation technique compared with FTC technique. A similar study conducted by Greess et al [22] reported a dose reduction of 15 - 25% for the abdomen and pelvic single section CT examinations. In the present study, radiation dose and image quality for CT scans performed, recorded significant increases in $CTDI_{vol}$ and DLP for FTC compared to AEC system. The estimated $CTDI_{vol}$ and DLP for the head CT examinations had a mean dose reduction of 19.4% (0.3 – 38.1%) and 18.2% (-3.9 – 37.3%) for scans performed with AEC compared with FTC technique as summarise in Table 9.

The chest CT examination had a mean dose reduction of 59.4% in $CTDI_{vol}$ (Table 10). This was similar to that reported by Sabri et al [21] for thorax CT examination when performed using angular modulation technique compared with FTC technique. The abdomen and pelvis CT examinations mean dose reduction were 12% and 28.1% with respect to $CTDI_{vol}$ (Table 10). This was consistent with a study conducted by Greess et al [22] for the abdomen and pelvic single section CT examination. DLP monitoring in CT examination provides control taking into account the technique parameters, length of scanned volume and the number of series for an overall patient exposure. As expected, the estimated DLP for chest, abdomen and pelvis CT examinations for the two scan techniques had a mean dose reduction of 78.3%, 7.1% and 56.8 % respectively (Table 11).

Comparison of $CTDI_{vol}$ and DLP estimated between the two scan techniques for all the examinations considered showed there were significant differences ($P < 0.05$) for head CT, chest CT and pelvis CT examinations except for the abdomen examination that showed no statistical significant difference ($P > 0.05$) (Tables 9 - 11). It is worthy to note that, in this study disparities in the dose estimates were observed for all the examinations considered. This might be attributed to the imaging technique used, the tube current values and the other related variables. Measurements of $CTDI_{vol}$ represent the absorbed dose along the z-axis and CT radiation output which is very useful for comparing radiation dose between protocols, different scanner outputs as well as for quality assurance purpose. The $CTDI_{vol}$ had been used for comparison of DRLs in term of the dose delivered by American College of Radiology Dose Index Registry [23, 24].

The estimated $CTDI_{vol}$ and DLP for the two scan techniques were compared with published data from International Atomic Energy Agency (IAEA) study-Tsapaki et al., [16], Bongartz et al., [15], Pontas et al., [17], Turkey [18] and Ireland [19] (Tables 7 and 8). As expected, various variations across the dose descriptors were observed for some of the CT examinations considered compared with the results in this study with the dose reference levels (DRLs). In respect of $CTDI_{vol}$, the dose estimates for scans performed with AEC for all the CT examinations were 1 - 95% lesser than DRLs for Bongartz et al., [15] (14.5 - 64 mGy). The head and chest CT estimated doses were 43% and 42% lesser than Tsapaki et al., [16] (9.5 - 47 mGy), except for the abdomen CT examination which exceeded the DRLs for Tsapaki et al., [16] (10.9 mGy) by 24% but close to Bongartz et al., [15] value of (14.5 mGy). The DLP for all the CT examinations were 147-281% lesser than DRLs for Bongartz et al., [15] (267 - 724 mGy.cm) and also lower than DRLs for Tsapaki et al., [16] (447 and 698 mGy.cm) by 313% and 190% respectively. However, the head CT examinations exceeded by 11% and 43% compared to that of Tsapaki et al., [16] (527 mGy.cm) and Bongartz et al., [15] (337 mGy.cm) respectively. The variations in the dose descriptors between this study and the DRLs may be attributed to the exposure settings, scan length and the CT equipment model used for the CT examinations considered.

The mean $CTDI_{vol}$ and DLP values for FTC technique compared with DRLs reported for Pontas et al., [17], Turkey DRLs [18], Ireland DRLs [19] and IAEA study-Tsapaki et al., [16] as presented in (Table 8). The mean $CTDI_{vol}$ value for head CT examination was observed to be lesser by up to 25% and 24.9% in comparison with DRLs for Turkey [18] and Ireland [19] respectively, but exceeded by 11% for Tsapaki et al., [16]. The chest CT, abdomen CT, and pelvis CT examinations mean $CTDI_{vol}$ were observed to be higher than some of the DRLs by up to 56% and 64%, for Turkey [18] and Tsapaki et al., [16], 46%, 50%

and 54% for Turkey [18], Ireland DRLs [19], and Tsapaki et al., [16], and 26% and 53% for Ireland DRLs [19] and Tsapaki et al., [16] respectively.

It was noted in this study that, DLP for chest CT were inconsistently varied compared with DRLs reported by other studies. The head DLP values were lower in comparison with those reported for the international DRLs by 0.2%, and 2% for Pantos et al., [17], Turkey DRLs [18] and Ireland DRLs [19] but exceeds that of IAEA study-Tsapaki et al., [16] DRLs by 44%. The DLP for abdomen CT examination were lower in comparison with Pontas et al., [17], Ireland DRLs [19] and IAEA study-Tsapaki et al., [16] and higher than DRLs for Turkey DRLs [18] whiles that for pelvic CT examination, the DLP was slightly lower than DRLs for Ireland [19] and IAEA study-Tsapaki et al., [16] but exceeded DRLs of Pontas et al., [17], and Turkey [18].

The image quality assessment in the present study included; spatial resolution, low contrast resolution, and contrast to noise ratio. The spatial resolution was measured by viewing acquired images of the appropriate phantom section. In terms of resolution of the images, the scan images obtained with AEC and FTC was fairly consistent. Fig 3 shows the number of resolved line pair scored in the AEC and FTC images obtained. Except for abdomen CT and pelvis CT examinations protocol which had the lowest spatial resolution score, the head CT, thorax CT and spine CT examinations had the highest spatial resolution score when the FTC was used in comparison with the AEC technique. This observation could largely be attributed to the anatomical compositions of the body part examined, which reduces the mAs literally at low attenuation parts (soft tissue) and increases at high attenuation parts of the body. A Pair t-test conducted on the overall spatial resolution scores to test the statistically significant difference between the two imaging techniques shows, no significant difference between the two imaging techniques (*$P = 0.704$)* as shown in Table 13.

The low contrast resolution was measured by quantifying the smallest disc visible in each low contrast disc at 1.0%, 0.5%, and 0.3% contrasts. Fig 4 and 5 depicts the low contrast detectability scores at the supra slice and sub slice levels for the two imaging techniques. Contrast resolution was measured using different slice thickness. The results of low contrast resolution in the sup – slice and sub – slice sections vary at the different scan routine, with inconsistent contrast disc visibility observed across all the examination scan protocols. Despite the inconsistency, it was realized that the head CT, thorax CT, abdomen CT and pelvis CT protocols at 1.0%, 0.5%, and 0.3% contrasts targets in the supra – slice and the spine protocol in the sub - slice at 5 mm and 3 mm targets however recorded some consistent contrast disc visibility. The overall supra and sub slice low contrast detectability scores of the obtained images for two imaging techniques show no statistically significant difference *($P > 0.05$)* as shown in Table 13.

The contrast to noise ratio in an image described the overall image quality with respect to how much noise is seen in the image. Generally, the larger the CNR value the lesser the image noise and the more quality the image is and vice versa. The most significant difference between the AEC and FTC images were observed in the contrast to noise ratio test *($P = 0.014$)* as illustrated in Table 13. The results indicate that images obtained with FTC technique have the highest CNR (least noise) compared with the AEC system images for all the CT examinations as shown in Table 12.

The low CNR values in the AEC system images indicates the presence of excessive noise compared with the FTC images. This is largely influence by the use of low mAs which is associated with the anatomical composition of the scan region. It is worthy to note that, other parameters might have a direct influence on the CNR which was difficult for one to tell. The CNR results actually reflect the low contrast detectability scores where only a few targets were visible with images that have the low contrast to noise ratio. The study has some limitations. The doses estimates were determined using standard size PPMA phantoms. Similar to regular CT examinations, actual patient's doses might differ from the determined values because of differences in patient anatomy. Nevertheless, the determined dose values allowed a rough estimation of dose values for standard size patients. Also, the image quality evaluation was done using a CT dosimetry Catphan phantom and not on actual patients images. Nonetheless, the dose estimates and the image quality results can facilitate clinical dosimetry assessment and also serve as a baseline towards establishing optimized dosimetry protocols as these doses can be compared with reference levels to assess the performance of the CT scanner in this study. In spite of the fact that, radiation dose reduction is an important exercise, maintaining a high quality of a diagnostic imaging study is also essential to provide an accurate and effective diagnosis. It is, therefore, worthwhile to keep a fine balance between image quality and radiation dose. It is recommended that similar work be done with patients after the required ethical clearance had been obtained. The results from this study can then be applied clinically for the optimisation of patient protection.

IV. CONCLUSION

The AEC system performance was better than FTC in the assessment of $CTDI_{vol}$ and DLP values. There were significant increase in radiation dose for scans performed with FTC technique in terms of $CTDI_{vol}$ and DLP with better image resolution compared to when the AEC system was used. The estimated CTDIvol and DLP for the head CT examinations had a mean dose reduction of 19.4% (0.3 – 38.1%) and 18.2% (-3.9 – 37.3%) for scans performed with AEC compared with FTC technique However, the contrast to noise ratio score on images obtained with AEC technique was slightly lower, with significant difference *(P = 0.014)* compared with the fixed tube current technique

V. ACKNOWLEDGMENTS

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VI. CONFLICTS OF INTEREST

The authors declare that, there are no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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