Patients of Different Body Mass Index Classification and its Effect on Tube Current Time Product, Scanner Radiation Output and Image Quality as Applied in Multidetector Computed Tomography of the Whole Abdomen – A Retrospective Study

Ginalynn Fincale, M.D.[a], and Jackson Dy, M.D.[b]

Abstract

OBJECTIVE: This study aimed to retrospectively determine if there is significant difference in the tube current-time product (mAs) used and radiation output in patients of different BMI classification undergoing CT study, and how this would affect image quality.

METHODS: This study included 144 adult patients who underwent CT of abdomen. Patients were classified according to their BMI. The mAs is set by the CT machine, adjusted according to patient cross section. Radiation output parameters were collected after each study. Qualitative evaluation of images was done based on image noise and effect on diagnostic accuracy.

RESULTS: Correlation Analysis showed significant increase in mAs and radiation output in groups of patient with higher BMI. There is however no significant difference in image quality between BMI groups, such that there is no significant improvement in image quality when mAs is increased.

CONCLUSION: This study reiterates the need for body size-adapted CT protocol in imaging patients since the radiation dose required in patients of higher BMI is increased to maintain diagnostic quality of images.

[a]*CT-MRI Fellow-in-Training, Department of Radiology, Makati Medical Center*
[b]*Chairman, Research Adviser, Department of Radiology, Makati Medical Center*

INTRODUCTION and REVIEW OF RELATED LITERATURE

According to the International Atomic Energy Agency (IAEA), there has been a steady increase in the number of computed tomography (CT) studies performed that on an average, it now contributes 60 to 70% of patient dose for any given center. This is despite the fact that CT only makes up about 15% of all x-ray based imaging studies (16). CT imaging has revolutionized the way clinicians are able to manage their patient that it is not surprising that the number of CT studies is continuously increasing since the inception of the first CT machines in the early 1970s. However, the benefits of CT studies come with risks as expected for an imaging modality using radiation. The American College of Radiology has released a White Paper stating that "medical exposure might be responsible for approximately 1% of the cancer in the United States" (1). The upside with these events is that it has forced the medical community to re-evaluate the risk-benefit of ordering a CT study.

The steady and expected continuous increase in the utilization of CT poses a challenge to the radiologic community to uphold the principle of ALARA (as low as reasonably achievable). A topic associated in CT dose reduction and management is quantifying CT radiation dose. The scanner radiation output is most commonly represented by volume averaged CT dose index (CTDl), a measure of the amount of radiation delivered from a series of contiguous irradiations to standardized acrylic phantoms (10). Thus CTDI is not a reflection of dose for an individual patient, rather represents the dose within the scan volume from a particular scan protocol. The SI unit is milligray (mGy). Dose-Length Product (DLP) on the other hand, is an indicator of the integrated radiation dose of an entire CT examination (8). It is the product of CTDI and scan length (z-extent), and is given in units of milligray-centimeters. DLP better represents the overall energy delivered by a given scan protocol (10). The effective dose (E), is not actually a measurement of dose, but rather reflects the stochastic risk from an exposure to ionizing radiation (14). What it does is it allows an approximate comparison of radiation induced risk among different types of examinations (18). It takes into account the tissue that has absorbed the radiation, and attempts to approximate whole-body radiation, and thus is a weighted average of organ doses (13). Be wary that effective dose should not be used to predict absolute risk for an actual individual patient. Effective dose is measured in millisieverts (mSv). DLP values can be converted from mGy-cm to mSv using a weighting factor (k) coefficient (in mSv/[mGy-cm]) (9, 10, 13).

The benefit of an appropriately indicated CT scan exceeds the associated risk, and it falls on the radiologist to make an accurate diagnosis vis-à-vis using the minimal amount of radiation required to obtain images adequate for evaluating the patient's condition. Reasonably, what radiologists do not want sacrificed in the goal of reducing patient dose is image diagnostic quality. The determination of optimal image quality is a complicated task and is assessed by both objective and subjective measures, the latter affected by inter-observer variation regarding the acceptable image noise. Two of the most commonly used image quality parameters are spatial resolution and low contrast resolution. The former is determined by the number of rays and spacing of the detectors in the CT machine for a projection. Contrast resolution on the other hand is determined solely by noise (6). Noise describes the variation in CT numbers in a physically uniform region. (18). The scan time, tube current and peak kilovoltage, pitch, and slice thickness all affect noise. More importantly, patient size is the lone parameter that cannot be controlled (9).

The tube current-time product with SI unit of milliamperage per second (mAs) is a measure of the photon flux and is the product of the tube current and exposure time. Radiation dose is directly proportional to mAs if all other factors are held constant. One can reduce tube current-time product by either lowering the tube current or increasing the x-ray tube rotation speed (decreasing the rotation time). X-rays are attenuated by soft tissue in an exponential fashion. To maintain a consistent noise level from thin to obese patient, the mAs setting would have to increase exponentially (9).

The relationship between kilovolt peak (kVp) and noise is less direct. Tube potential is defined as the x ray beam energy (5). Radiation dose is

is proportional to kVp raised to an exponential *n*th power, with *n* ranging from 2.49 to 3.12 depending on patient size (9, 17). For example, in a typical abdominal CT phantom, decreasing the peak voltage from 120 to 100 kVp reduces the dose by 28%-40%, and as much as 65% if kVp is further reduced to 80 kVp. The downside of decreasing kVp is an increase in image noise due to reduced photon flux and photon energy (9). The use of iodinated contrast media may further improve image quality, since the attenuation coefficient of iodine increase as photon energy decrease toward the k-edge energy of 33 keV. Thus pathologies that take up contrast are more conspicuous at lower kVp (12). The benefit of lower-kV for non-contrast CT exams is still in question since soft tissue contrast is not highly dependent on tube potential.

Automatic Exposure Control (AEC) systems are now installed in almost all major scanners manufactured in recent years, with the aim of adjusting radiation dose according to the patient's attenuation. It assesses the size of the patient cross-section being scanned and adjusts tube current relative to the reference effective mAs. In turn, the reference mAs is based on an "average size" patient, which is 70-80 kg for adults and 20 kg for pediatric patients. Pre-set peak kVp settings of 80, 100, 120 and 140 are found in the system. With this, image quality is maintained using the minimum required radiation exposure and can reduce dose by as much as 20-44% (8). Even with an existing AEC, the CT user must still be familiar with the parameters employed to ensure correct use. Any type of AEC system is not perfect, since it may not be technically feasible to maintain constant image noise over all patient sizes since it cannot achieve such extremely low and high tube current-time product values (10).

STUDY OBJECTIVES

1. To determine if there is significant difference in the value of the tube current-time product (mAs) among patients of different body mass index (BMI) classification.
2. To determine if the radiation output, measured as CT dose index (CTDI), Dose-Length Product (DLP) and effective dose (E), in patients of higher BMI classification is significantly increased due to increased tube current-time product (mAs).
3. To determine if the difference in tube current-time product (mAs) among patients of different BMI classification would significantly affect image quality.

Research hypothesis:

Null Hypothesis: Significant increase in tube current-time product (mAs) and thus radiation output is needed in patients of higher BMI classification to maintain image quality.

Alternate Hypothesis: Significant increase in tube current-time product (mAs) and thus radiation output is not needed in patients of higher BMI classification to maintain image quality.

METHODOLOGY

A. Justification of Study Design

A retrospective, cross sectional study was conducted. This was a cross sectional study because of the following factors: body mass index (BMI), tube current-time product (mAs), CT dose index (CTDI), Dose-Length Product (DLP) and effective does (E) were ascertained simultaneously within a defined time period.

B. Study Duration and Location.

The study was conducted in the Department of Radiology, Makati Medical Center. Included data were of patients who underwent CT of the abdomen following the inclusion criteria from April 2014 to July 2014.

C. Inclusion and Exclusion Criteria

Inclusion criteria:

1. Male and female adult patients ages 18 years old and above.
2. Studies requested for out-patients only.
3. CT whole abdomen with intravenous (IV) contrast which will include:

a. CT whole abdomen with intravenous (IV) contrast.
b. CT chest and whole abdomen with IV contrast.
c. CT whole abdomen with intravenous (IV) contrast, oral and/or rectal contrast.
d. CT chest and whole abdomen with intravenous (IV) contrast, oral and/or rectal contrast.

Exclusion criteria:

1. Pediatric patients/patients below 18 years old.
2. Patients without available height measurement needed for BMI measurement (e.g. wheelchair bound patients).
3. CT whole abdomen without IV contrast to eliminate discrepancy in image quality assessment between plain and contrast enhanced studies.

D. CT system and scanning protocol

The scanner used in this study was the Siemens Somatom Definition 128 MDCT machine. Patients were scanned using the available online tube current modulation software. The CT scanner Siemens Somatom has a reference milliamperage-based AEC system called CARE Dose. In this system, the peak kilovoltage setting in the CT console is set automatically to 120 kVp. Tube current-time product (mAs) is then set by Care Dose based on the patient cross-section measured from the initial tomogram scanning. The parameters set by the AEC system for each scanned patient including kVP and mAs, are seen in the CT scanner console and sent in the PACS file of each patient for reference. (Appendix 1).

The other components of the scanning protocol were the same as per usual in the department: single breath hold, 0.5 second rotation time, 0.6 pitch, individually adapted field of view, and a B20f smooth software reconstruction kernel. Images were reconstructed as 2 mm. thick sections with an increment of 2 mm. The contrast enhanced CT whole abdominal protocol in the department has three phases; arterial, portal venous and delayed. The amount of intravenous iodinated contrast (370 mg iodine/ml) given is 115 to 120 mL., administered at a rate of 2.5 to 3.0 mL/sec, depending on patient weight and catheter size.

E. Data Collection

Patient:

All out patients undergoing a diagnostic exam in the department have their gender, age, height (cm2) and weight (kg) obtained and recorded as part of completion of patient chart. Access to patient records was facilitated by the CT unit manager Joel Molina, RRT (Registered Radiologic Technologists) who is in charge of safe keeping of said records. Permission to access these records were given by the department chair, Jackson Dy MD. The patients were categorized according to their BMI based on the World Health Organization BMI classification: underweight (< 18.5 kg/m2), normal (18.5 – 24. 99), overweight (25 – 29.99), obese class I (30 – 34.99), obese class II (35 – 39.99) and obese class III (>/= 40).

Dose measurement:

Dose values based on the CT dose index (CTDl), dose length product (DLP) computed by the CT system were collected as seen in the CT scanner console and sent in the PACS file of each patient. The DLP values were then converted to effective dose (E) using the region specific coefficient for the abdomen (k = 0.015 mSc/mGy x cm.) as set by the International Commission on Radiation Protection (ICRP 60).

The acquired patient information and dose measurements were tabulated on a standard data collection template.

F. Image Quality Evaluation

Qualitative evaluation of images was done by two CT consultants from the Department of Radiology. Both were blinded as to the BMI of each patient. The images only from the portal venous phase of the

scan were included. Classification scheme used was based on another study (3). Images with distinct anatomic detail, sharp vessel edges was classified as 1 (excellent). Examinations with clear anatomic detail and mild to moderate increase in noise without impairment of diagnostic accuracy was rated as 2 (good). If with further increase of noise without impairment of diagnostic accuracy was rated as 3 (fair). A distinct increase in noise and extensive blurring, not sufficient for diagnosis were classified as 4 (nondiagnostic). Patients were assigned in an alternating basis to each consultant. Evaluations were conducted using digital picture archiving and communication system diagnostic workstation (NovaPACS). Quality scores were then tabulated on a standard data collection template.

ETHICAL CONSIDERATION

The investigators of this research study complied with the statement of agreement with the ethical principles set out in relevant guidelines (Declaration of Helsinki 2008, WHO Operational Guidelines, ICH-GCP, National Ethics Guidelines for Health Research, and FDA Policies on Drug Registration).

All identifiable data gathered during data collection were kept confidential, and known only to the principal author and radiologists assigned to participate in the image quality evaluation. Specific names of the patient were included in the data collection form for ease of retrieval of the images during qualitative evaluation of the images. Included patients were then assigned a number that was used during encoding for data analysis so that no patient name was used during statistical analysis part of the study. Specific names did not appear on the documents or spreadsheets for data analysis, and in the final paper. Used data collection forms were shredded after all data have been encoded in Excel spread sheet.

RESULT AND STATISTICAL ANALYSIS

Descriptive Statistics

A total of 144 patients were included in the study. As shown in the table below, age of patients ranged from 20 to 88 years old, with average age at 52.71 (SD of 7.16). BMI average is 24.19 (SD of 4.02), which is categorically "normal". In terms of radiation; average mAs is at 174.58 (SD of 68.27), average CTDI is at 11.81 (SD of 4.60), average DLP is at 620.31 (SD of 282.18), and average ED is at 9.26 (SD of 4.15).

TABLE 1. Descriptive Statistics

	N	Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Minimum	Maximum
Age	144	52.71	1.430	53.50	34.00	17.161	20.00	88.00
Weight	144	64.58	1.129	61.00	60.00	13.550	40.00	95.00
Height	144	163.12	0.901	164.79	152.00	10.811	122.00	183.00
BMI	144	24.19	0.335	23.88	20.56	4.016	16.02	36.79
mAs	144	174.58	5.689	156.00	148.00	68.266	103.00	491.00
CTDI	144	11.81	0.341	10.57	10.01	4.604	6.95	33.17
DLP	144	620.31	23.515	543.00	452.60	282.180	295.00	1,692.20
ED	144	9.26	0.346	8.15	6.19	4.150	4.42	25.38

Majority of patients are females (55.6%), while only 44.4% are males.

TABLE 2. Gender

	Frequency	Percent
Female	80	55.6
Male	64	44.4
Total	**144**	**100.0**

In terms of BMI group, more than half of patients are "normal" (60.4%), while more than one-third (34.7%) are overweight/obese, and only 5% are underweight.

TABLE 3. BMI Group

	Frequency	Percent
Underweight	7	4.9
Normal	87	60.4
Overweight	36	25.0
Obese 1	13	9.0
Obese 2	1	0.7
Total	**144**	**100.0**

Almost half (47.9%) of the samples got "2" image quality score, while 40.3% got the score of "3", and only 11.8% got the score of "1".

TABLE 4. Image Quality Score

	Frequency	Percent
1	17	11.8
2	69	47.9
3	58	40.3
Total	**144**	**100.0**

B. Hypothesis Testing – mAs and radiation output versus BMI

Ho: Tube current-time product (mAs) and radiation output are equal among BMI classification.

HA: Tube current-time product (mAs) and radiation output differs among BMI classification.

Using Pearson Correlation Analysis at 5% level of significance, results reveal that mAs and radiation output variables (CTDI, DLP, and ED) are **significantly** and positively related with BMI score. Hence, as BMI increases, mAs and radiation output variables also increases.

TABLE 5. Correlation Analysis

		BMI	mAs	CTDI	DLP	ED
BMI	Pearson Correlation	1	0.355**	0.357**	0.368**	0.351**
	P-Value (2-tailed)		0.000	0.000	0.000	0.000
	N	144	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

One Way Analysis of Variance (ANOVA) was used to determine if means of mAs and radiation output variables significantly differ among BMI group, at 5% level of significance. As shown below, means of mAs and radiation output variables increases as BMI group goes from underweight to obese (except for Obese 2 which is negligible because it only has 1 patient).

TABLE 6. Descriptive Statistics - per BMI Group

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval		Minimum	Maximum
						Lower	Upper		
mAs	Underweight	7	135.57	24.227	9.157	113.17	157.98	103.00	162.00
	Normal	87	165.23	75.736	8.120	149.09	181.37	105.00	491.00
	Overweight	36	176.50	28.629	4.772	166.81	186.19	119.00	234.00
	Obese 1	13	250.62	62.254	17.266	213.00	288.24	186.00	395.00
	Obese 2	1	204.00	.	.	.	.	204.00	204.00
	Total	**144**	**174.58**	**68.266**	**5.689**	**163.34**	**185.83**	**103.00**	**491.00**
CTDI	Underweight	7	9.17	1.626	0.615	7.67	10.68	6.95	10.95
	Normal	87	11.17	5.112	0.548	10.08	12.26	7.08	33.17
	Overweight	36	11.98	1.883	0.314	11.34	12.61	8.04	15.80
	Obese 1	13	16.94	4.203	1.166	14.41	19.48	12.59	26.71
	Obese 2	1	13.78	.	.	.	.	13.78	13.78
	Total	**144**	**11.81**	**4.604**	**0.384**	**11.05**	**12.57**	**6.95**	**33.17**
DLP	Underweight	7	491.29	137.030	51.793	364.55	618.02	355.70	681.00
	Normal	87	577.61	309.527	33.185	511.64	643.58	312.30	1,692.20
	Overweight	36	632.18	149.947	24.991	581.45	682.92	295.00	970.60
	Obese 1	13	929.32	240.775	66.779	783.82	1074.81	584.20	1,403.90
	Obese 2	1	794.30	.	.	.	.	794.30	794.30
	Total	**144**	**620.31**	**282.180**	**23.515**	**573.83**	**666.79**	**295.00**	**1,692.20**
ED	Underweight	7	7.37	2.055	0.777	5.46	9.27	5.33	10.21
	Normal	87	8.66	4.643	0.498	7.67	9.65	4.68	25.38
	Overweight	36	9.48	2.249	0.375	8.72	10.24	4.42	14.56
	Obese 1	13	13.52	2.978	0.826	11.72	15.32	8.76	16.72
	Obese 2	1	11.91	.	.	.	.	11.91	11.91
	Total	**144**	**9.26**	**4.150**	**0.346**	**8.58**	**9.95**	**4.42**	**25.38**

It can be seen in the table below that mAs and radiation output variables (CTDI, DLP, and ED) were all found to be **significant** at 5% level of significance. This means that mean values in at least one (1) BMI group significantly differs from other BMI groups.

TABLE 7. ANOVA table for mAs and Radiation output variables

		Sum of Squares	df	Mean Square	F	P-Value
mAs	Between Groups	94,413.806	4	23,603.452	5.736	**0.000****
	Within Groups	572,007.194	139	4,115.160		
	Total	666,421.000	143			
CTDI	Between Groups	432.179	4	108.045	5.777	**0.000****
	Within Groups	2,599.593	139	18.702		
	Total	3,031.772	143			
DLP	Between Groups	1,551,787.535	4	387,946.884	5.483	**0.000****
	Within Groups	9,834,694.250	139	70,753.196		
	Total	11,386,481.785	143			
ED	Between Groups	300.874	4	75.218	4.835	**0.001****
	Within Groups	2,162.473	139	15.557		
	Total	2,463.347	143			

**. Relationship is significant at the 0.01.

C. Hypothesis Testing – Image Quality Score vs. BMI Group

Ho: Image Quality Score is the same among BMI classification / mAs.

HA: Image Quality Score differs among BMI classification. / mAs.

Correlation Analysis results show that Image Quality Score is **not significantly correlated** with mAs and BMI scores.

TABLE 8. Correlation Analysis

		Quality	mAs	BMI
Quality Score	Pearson Correlation	1	-0.030^{ns}	0.117^{ns}
	P-Value (2-tailed)		0.724	0.163
	N	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

One Way Analysis of Variance (ANOVA) was used at 5% level of significance. As shown below, mean BMI score and mAs score appear to be equal among 3 image quality scores. This was confirmed to be **not significant** as shown in the ANOVA Table wherein p-value is 0.124 and 0.122, respectively.

TABLE 9. Descriptive statistics – per Image Quality Score

	Score	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval		Minimum	Maximum
						Lower	Upper		
BMI	1	17	24.24	4.875	1.182	21.74	26.75	18.64	32.56
	2	69	23.51	3.837	0.462	22.59	24.43	16.02	32.81
	3	58	24.97	3.879	0.509	23.95	25.99	16.02	36.79
	Total	**144**	**24.19**	**4.016**	**0.335**	**23.53**	**24.85**	**16.02**	**36.79**
mAs	1	17	200.65	81.936	19.872	158.52	242.77	112.00	329.00
	2	69	164.54	38.613	4.648	155.26	173.81	114.00	294.00
	3	58	178.90	87.662	11.511	155.85	201.95	103.00	491.00
	Total	**144**	**174.58**	**68.266**	**5.689**	**163.34**	**185.83**	**103.00**	**491.00**

TABLE 10. ANOVA Table – per Image Quality Score

		Sum of Squares	df	Mean Square	F	P-Value
BMI	Between Groups	67.398	2	33.699	2.122	**0 .124^{ns}**
	Within Groups	2,239.192	141	15.881		
	Total	2,306.590	143			
mAs	Between Groups	19,592.579	2	9,796.289	2.135	**0.122^{ns}**
	Within Groups	646,828.421	141	4,587.436		
	Total	666,421.000	143			

In terms of BMI group, below is the cross-tabulation of BMI Group with Image Quality Score. It can be noticed that there is no "pattern" established as to its relationship with each other. At 5% level of significance, both Pearson Chi-Square Analysis and Spearman Rank Correlation Analysis yield a **not significant** result, which means that there is no significant difference in image quality as BMI increases. Also, since as BMI is increased, mAs also is increased; it can be said that there is **no significant improvement** in image quality when mAs is increased.

TABLE 11. Crosstabulation – Image Quality Score per BMI Group

BMI vs. Quality	1	2	3	Total
Underweight	0	6	1	**7**
Normal	12	40	35	**87**
Overweight	2	18	16	**36**
Obese 1	3	5	5	**13**
Obese 2	0	0	1	**1**
Total	**17**	**69**	**58**	**144**
Pearson Chi-Square	**8.961, 0.346^{ns}**			
Correlation Coefficient	**0.065, 0.437^{ns}**			

ns. - not significant.

DISCUSSION and RECOMMENDATION

This research aimed to determine whether there is significant difference in tube current-time product (mAs) and radiation output in patients of different BMI classification. Pearson Correlation Analysis and ANOVA showed there is indeed significant increase in mAs as BMI increased (Table 5 and 6). As expected, there is corresponding increase in all radiation dose parameters, namely CTDI, DLP and effective dose (E), as BMI increased (Table 6 and 7). An increase in radiation dose with increasing BMI was observed even if the same peak kilovoltage (kVp = 120) was used in all BMI groups. This is due to the use of the Automatic Exposure Control (AEC) system in place in the CT scanner which adjusts the mAs to the size of the patient based on the initial topogram.

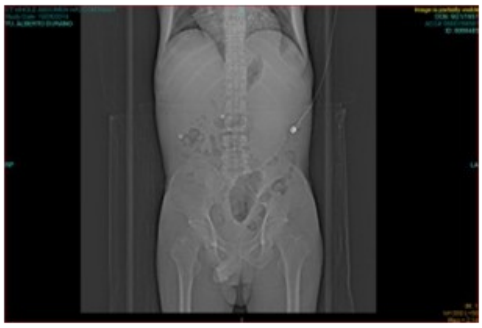
Another question asked by this study was whether there is a difference in the image quality of CT images of patients of different BMI classification due to differences in mAs. The most frequent score given across all BMI groups was 2 or "good", were in the images obtained had "clear anatomic detail with mild to moderate increase in noise but without impairment of diagnostic accuracy" (3). No score of 4 or a non-diagnostic image was obtained during the study. Correlation analysis showed that there is no significant correlation of image quality score with mAs and BMI (Table 8). Using ANOVA at 5% level of significance, the mean of the BMI and mAs among the three quality scores given – namely excellent (1), good (2) and fair (3), did not differ significantly (Table 9 and 10). This indicates that there is no significant difference in image quality with increasing mAs and BMI. In underweight, normal and overweight BMI groups, the most frequent quality score were all 2, while in the Obese 1 group, there is equal number of patients with scores of 2 and 3 (Table 10).

This study reiterates the need for body size-adapted CT protocol in imaging patients since the minimal radiation dose required would be varied even at the same diagnostic task. Several strategies have been proposed to modulate radiation dose. One modulation technique is to lower kilovoltage (kV) that allows reduction of radiation dose (8). However, an ideal balance between lowering the kV with corresponding increase in tube current time product (mAs) should be achieved since lowering the mAs simultaneously would increase contrast to noise ratio, and thus reduce image quality. Scan range should also be carefully planned considering the patient's body habitus to avoid exposure of any regions of the body that are not necessary for diagnosis (18). In this study, there is maintenance of diagnostic image quality even with increasing BMI due to increase in mAs. As reiterated by another study, this is the correct strategy since higher tube current is used at lower tube potential to compensate for the expected increase in noise (5). In particular in larger-sized patients, the use of lower tube potentials tends to increase noise due to higher absorption of lower-energy photons by the patient (17). However, even with an AEC system in place to limit radiation dose, the AEC system would still have to increase exponentially the mAs to achieve ideal contrast to noise ratio. The limitation of an AEC system is highlighted in this study since there is significant increase in radiation dose with higher BMI groups.

The author recommends future studies that will evaluate several protocols that may reduce radiation dose used in CT studies not just of the abdomen, but in evaluation of other body parts. This may be done by manipulating several scanning parameters such as kilovoltage, tube current, scan time and range. A more statistically sound method of evaluating quality is to compare quality between a control group and a group undergoing a reduced dose protocol. Patient safety without compromising image diagnostic quality should always be the primary aim of these studies.

APPENDIX I

CT SCAN ABDOMEN PROTOCOL



Activation of automatic exposure control (AEC)

Tube current-time product (mAs) is set by the AEC. AEC adjusts the mAS based on patient cross-section, which is based on initial topogram

Peak kilovoltage (kVp) set at 120 for all patients

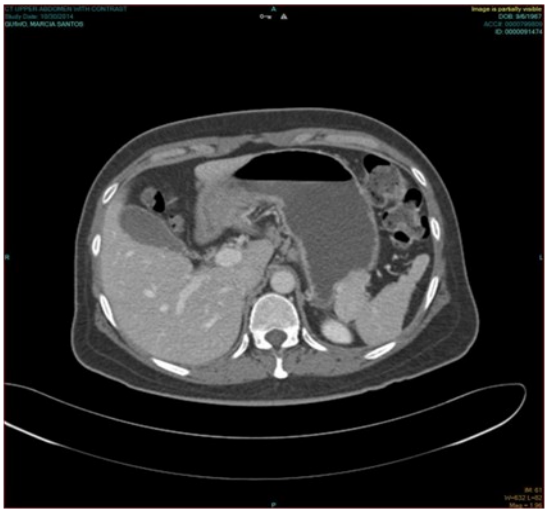
CT scan of abdomen conducted

CT scanning done, patient escorted out of CT machine suite

CT software system computes dose length product (DLP).

DLP, mAs, kVp and other CT parameters used for a patient's scan is displayed in CT monitor and sent to PACS for reference

Images sent to PACS for interpretation



INDEX OF ABBREVIATIONS and DEFINITIONS

Absorbed radiation dose:
Describes the amount of energy absorbed per unit mass at a specific point (13).

AEC: Automatic Exposure Control
Software installed in CT machines that are designed to reduce the radiation dose by altering the tube current as the x-ray tube rotates around the patient during multidetector CT scanning (17).

CTDI: Computed Tomography Dose Index
A measure of the amount of radiation delivered from a series of contiguous irradiations to standardized acrylic phantoms (10). It is a measure of the intensity of radiation directed at a given patient by the CT scanner (17). SI unit is milligray (mGy).

DLP: Dose-Length Product
CTDI multiplied by the length of the scan (in centimeters). SI unit is is milligray-centimeters (mGy-cm).

E: Effective dose
Sum of equivalent doses to organs and tissues exposed. It attempts to reflect the equivalent whole-body dose that results in a stochastic risk that is equivalent to the stochastic risk from the actual absorbed dose. It is a weighted average of organ doses (13). SI unit is millisieverts (mSv).

kVp: peak kilovoltage
SI unit for electric potential. It is the peak voltage applied to the X-ray tube and determines the highest energy of X-ray photon.

mAs: milliamperage per second
SI unit for electrical current or flow of electric charge in a defined boundary per second.

mGy: milligray
SI unit for absorbed dose. 1 Gray is equivalent to 1 Joule per kilogram (1 Gy = 1 J/kg).

mSv: millisieverts
SI unit for effective dose. 1 mSv is the dose produced by exposure to 1 milligray (mG) of radiation.

MDCT: Multi-Detector Computed Tomography
A form of CT technology that uses multiple arrays of detector which enables to acquire multiple slices simultaneously and greatly increases speed of image acquisition.

REFERENCES

1. American College of Radiology White Paper on Radiation Dose in Medicine. Journal of the American College of Radiology. Vol. 4. No. 5 May 2007.
2. Antypass E.J., et al. A Comprehensive Approach to CT Radiation Dose Reduction: One Institution's Experience. American Journal of Roentgenology. 2011; 197:935-940.
3. Das M., et al. Individually Adapted Examination Protocols for Reduction of Radiation Exposure for 16-MDCT Chest Examinations. American Journal of Roentgenology. 2005; 184:1437-1443.
4. Goldman A.R. and Maldjian P.D. Reducing Radiation Dose in Body CT: A Practical Approach to Optimizing CT Protocols. American Journal of Roentgenology. 2013; 200:748-754.
5. Goo H.W. CT Radiation Dose Optimization and Estimation: an Update for Radiologists. Korean Journal of Roentgenology. 2012; 13(1):1-11.
6. International Atomic Energy Agency. Dose Reduction in CT while Maintaining Diagnostic Confidence: A Feasibility/Demonstration Study. IAEA, Vienna, 2009.
7. Kalra M.K., et al. Clinical Comparison of Standard Dose and 50% Reduced-Dose Abdominal CT: Effect on Image Quality. American Journal of Roentgenology. 2002; 179:1101-1106.
8. Lee C.H., Goo J.M., Lee H.J., et al. Radiation Dose Modulation Techniques in the Multidetector CT Era: From Basics to Practice. RadioGraphics. 2008; 28:1451-1459.
9. Maldjian P.D. and Goldman A.R. Reducing Radiation Dose in Body CT: A Primer on Dose Metrics and Key CT Technical Parameters. American Journal of Roentgenology. 2013; 200:741-747.
10. McCollough C., Bruesewitz M., and Kofler J. CT dose reduction and dose management tools: Overview of available options. RadioGraphics. 2006; 26: 503-512.
11. McCollough C.H., Christner J.A. and Kofler J.M. How Effective is Effective Dose as a Predictor of Radiation Risk? American Journal of Roentgenology. 2010; 194:890-896.
12. McCollough C., et al. Strategies for Reducing Radiation Dose in CT. Radiologic Clinic North America. 2009 January; 47 (1): 27-40.
13. McNitt-Gray M. AAPM/RSNA Physics Tutorial for Residents: Topics in CT. RadioGraphics. 2002; 22: 1541-1553.
14. Nakayama Y., et al. Abdominal CT with Low Tube Voltage: Preliminary Observations about Radiation Dose, Contrast Enhancement, Image Quality and Noise.
15. Prasad SR., et al. Standard Dose and 50% Reduced-Dose Chest CT: Comparing the Effect on Image Quality. American Journal of Roentgenology. 2002; 179:461-465.
16. Tack D. et al. Dose Reduction in Multidetector CT Using Attenuation-Based Online Tube Current Modulation. American Journal of Roentgenology. 2003; 181: 331-334.
17. Tamm E., et al. CT Radiation Dose Reduction: How to Implement Change without Sacrificing Diagnostic Quality. RadioGraphics. 2011; 31:1823-1832.
18. Yu L., et al. Radiation dose reduction in computed tomography: techniques and future perspective. Imaging med. 2009 October; 1(1): 65-84.