Research Article

Assessment of radiation dose reduction potential and clinical utilization of automatic tube current systems

This study investigated the patient dose reduction potential and clinical utilization of Automatic Tube Current Modulation (ATCM) systems in CT examinations. Assessment of the effectiveness of ATCM was conducted using standard CT phantoms of diameters 16 cm and 32 cm, and water phantoms of diameters 20 cm and 22 cm, which were scanned with and without activating ATCM. Assessment of clinical utilization of the ATCM systems was conducted by investigating in real time practice on utilization of ATCM during patient scanning, and from information of scan parameters were extracted from CT database for 125 patients that underwent different routine examinations at six multislice CT scanners acquired by six hospitals. From the database, information about the operation and utilization of automatic tube current modulation systems during different examinations was obtained. This information included the activation/ deactivation status of the systems, reference image quality mAs, effective mAs, mAs per slice and CTDIvol. In the phantom study, systems were found to reduce radiation dose with marginal increase in image noise, and that they are more effective in reduction of radiation dose for smaller patients than the large ones. Direct observations and analysis of the informations extracted from CT database revealed that most technologists had limited knowledge about the operation and utilization of the ATCM systems of respective scanners. These limitations were attributed to lack of standardization of different types and versions of the ATCM systems that are, in addition, not user-friendly. Some technologists claimed that the diagnostic image qualities were low when the ATCM systems were activated for some examinations. The radiographers and radiologists should attend the in-service training programmes to learn on how to operate and effectively utilize the ATCM systems. The CT scanner manufacturers should produce the standard and more user-friendly ATCM systems during future designs.

KEYWORDS: ATCM ▪ Phantom ▪ Clinical ▪ Multislice ▪ Diagnostic

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Introduction

High concern about radiation dose and cancer risks associated with CT examinations had been expressed in literature. Like elsewhere, CT examinations had been found to be the leading sources of collective dose in radiology in Tanzania [1,2]. To overcome the problem of radiation dose inherent in CT examinations, automatic tube current modulation systems have been introduced in most multislice CT scanners [3,4]. Tube current modulation adjust patient radiation dose depending on size, shape, and material composition of tissues or organs that constitute the scan region. There are three features of ATCM systems: Angular modulation, longitudinal modulation, and combined modulation as described in Table 1.

Different manufacturers have different ATCM systems with different operation principle. Care Dose 4D is an ATCM system incorporated in Siemens CT scanners. Care Dose 4D system can be activated provided the topogram, which is alocalizer image for Siemens CT, of patient has been acquired and the image quality reference mAs set. Based on the topogram and the image quality reference mAs setting, the Care Dose 4D system learns patient attenuation profiles of different body sections in order to choose mAs values for different body sections. The mAs values used for different sections are automatically averaged and displayed on the scanner consoles as effective mAs. The effective mAs value can be lower, equal, or larger than the image quality reference mAs value. In the case, the patient size is smaller than the reference patient (32 cm in diameter); the effective mAs value used is lower than the image quality reference mAs value. Similarly, if the patient size is larger than the reference patient, then the effective mAs value displayed on the console will be larger than the image quality reference mAs [5,6]. If the user's selection is slim, tube load modulation strength can further be selected as weak decrease, average decrease or strong decrease of tube load as described in Table 2. If the selection is obese, then weak, average, or strong selections will result into the weak increase, average increase, or a strong increase of tube current, respectively.

Dose Right is the dose reduction systems built-in Philips CT scanners. This feature modulates radiation dose based on reference image quality.

Table 1. Features of ATCM systems [21].	
Feature	**Principle of modulation**
Angular modulation	Tube load is adjusted during each gantry rotation according to size shape and attenuation of scanned region.
Longitudinal modulation	Tube load is adjusted along the z-axis according to size, attenuation of anatomic region and pre-determined image quality.
Combined modulation	Tube load is adjusted both during each gantry rotation and for each slice position.

Table 2. Modulation strengths of Care Dose 4D systems [20].			
Patient	**Modulation strengths**		
Size	Weak	Average	Strong
Slim	Weak decrease in tube load	Moderate decrease in tube load	Strong decrease in tube load
Obese	Weak increase in tube load	Moderate increase in tube load	Strong increase in tube load

Table 3. Multislice CT scanner types and models acquired between 2009 and 2012.					
Hospital	**Type and model**	**No. of detectors**	**Manufacturer**	**Manufacturer date**	**Installation date**
MM	Siemens Somatom Emotion 6	6	China Siemens	Nov 2008	Jun 2009
RM	Philips Brilliance 64	64	USA Philips	Apr 2009	Aug 2010
TM	Siemens Somatom Sensation 16	16	Siemens HealthCare German	Mar 2012	Aug 2012
MN	Philips Brilliance 6	6	Ohio USA Philips	Feb 2009	Jun 2009
HS	Siemens Somatom Perspective 128	128	Siemens Shanghai Medical China	Jul 2012	Sep 2012
AK	Siemens Somatom Emotion 6	6	Siemens HealthCare German	Nov 2011	Jul 2012

The reference image quality setting is made after acquiring the surview of patient. The user then selects the suitable image of the previous examination from CT database. The system stores the selected image data, including the raw projection data and the surview. The stored information is taken as the data of a standard patient size (33 cm in diameter) to be used as a baseline for the Dose Right system when it proposes mAs values for different patient sizes to achieve constant image noise level [7,8]. The Dose Right system operates using three features: Automatic Current Selection (ACS), Dynamic Dose Modulation (D-DOM) and longitudinal dose modulation (Z-DOM). Currently, however, it is not possible to utilize all three modulation features simultaneously but one can use a combination of ACS with D-DOM or ACS with Z-DOM [9,10]. The ACS feature works with patient's attenuation properties acquired from the surview and matched to the attenuation properties of the reference survey. If the patient size is larger than the reference patient, an increase of mAs values follows and vice versa. However, it is possible to use the mAs value that is different from that suggested by the ACS feature. In which case, the ACS feature will learn the user's preference mAs settings interactively after few examinations [11,12]. The D-DOM feature is the tube current modulation based on patient's symmetrical variations in the x-y-plane. This modulation is achieved online during each rotation, by utilizing data of previous rotation to determine the next modulation. The D-DOM feature makes use of the detector dose to assess the part of rotation that would benefit from the reduced dose without loss of diagnostic image quality [13,14]. The Z-DOM feature adjusts tube load according to changes in body attenuation profile along the longitudinal direction. The Z-DOM feature obtains the mAs values from the surview to achieve the same level of image quality along the z-direction.

During scanning, the Z-DOM feature varies mAs values continuously according to the attenuation variations of the body sections in the z-direction [15,16].

The ATCM system used by General Electric scanners is called AutomA 3D system. This system consists of AutomA and SmartmA features that provide longitudinal and rotational (angular) modulation, respectively. To activate the AutomA 3D feature, the scout of patient is acquired first, for the system to learn the attenuation profile of different body sections of patient [17,18]. After the scout has been acquired, the user then specifies noise index, minimum and maximum mA values. The noise index allows the user to set the required image quality and it is referenced to the image noise index, which influences quantum noise, in the central region of homogeneous water phantom [19,20]. The minimum and maximum tube currents define the range of tube current modulation desired for constant image noise for each slice position along the z-axis and during each rotation. The AutomA feature, which controls tube current modulation along the z-direction, can be activated without activating the SmartmA feature. On the other hand, the SmartmA feature, which adjusts tube current for different projection angles during each gantry rotation can only be activated provided the Automa feature is active [21,22]. Sure Exposure 3D is the ATCM system for Toshiba CT scanners. This feature offers two alternatives for image quality settings: the standard deviation of CT numbers or an image quality level. Both alternatives are, however, based on measurements of the standard deviation of CT numbers in a patient-equivalent water phantom [23,24]. To activate the Sure Exposure 3D system, the user first specifies the standard deviation for the image noise, minimum and maximum tube current values required for diagnostic image quality. The process follows with the acquisition of one frontal and one lateral scanogram. Information from the scanogram is used to map the selected image quality level to the corresponding tube currents. The Sure Exposure 3D system then makes use of the frontal and lateral diameters, and the intensity of the X-ray beam reaching the detector to account for the tube current modulation during each gantry rotation [25,26].

It can be evidently predicted from these complicated and unstandardized principles of operation of ATCM systems that the question of proper operation and utilization of the systems for patient dose and image quality optimization needs to be studied. Despite the potential of ATCM systems, questions of clinical utilization of these techniques have gained little or no attention in the literature.

This study therefore assessed radiation dose reduction potential based on patient size and clinical utilization of automatic tube current systems for patient dose and image noise optimization.

Materials and Methods

▪ Phantom study

A study of the influence of patient size on Care Dose 4D system optimization of patients dose and image noise was conducted at three different Siemens CT scanners which were acquired by three hospitals coded AK, TM and HS for privacy purposes and described in Table 3. The remaining three CT scanners in this table have been used in the next study [27,28].

To study the influence of patient size on the effectiveness of ATCM systems, four homogeneous tissue equivalent phantoms were used. These were two PMMA phantoms of diameters 16 and 32 cm, and two water phantoms of diameters 20 and 22 cm. The water phantoms used in this study were the water sections of the CT performance phantoms made respectively by the CT scanner manufacturers, and the American Association of Physicists in Medicine for evaluation of CT number and image noise [29,30]. For the sake of phantom homogeneity, the PMMA phantoms had their holes fitted with their insert rods.

The 16 cm PMMA phantom was placed in the scan plane, and the topogram image of the phantom was acquired. Based on the topogram, the scan range and the scan parameters settings for routine abdomen protocol were selected. This was followed by activating CareDose 4D system, and then the phantom scanned to acquire CT images of the phantom. The images were reconstructed using filtered back projection algorithm and smoothed using standard kernel for routine abdomen [31,32]. The CT ROI software tool was then used to draw a region of interest of about 0.5 cm^2 at the centre of the reconstructed images and obtain the mean and standard deviation of CT numbers were then obtained from the selected region of interest. The same procedures were repeated when the Care Dose 4D system was off. Then, similar measurements were made for the 20 cm water section of manufacturers' CT performance phantom, 22 cm water portion of ACR phantom, and 32 cm PMMA phantom using the same procedures [33,34]. The scan parameters used, the console CTDIvol values displayed, and the mean and standard deviation of the CT numbers obtained are presented in Appendix 1.

▪ Patient study

Assessment of clinical utilization of the ATCM systems was conducted by investigating in real time about operators practice on utilization of ATCM systems during patient scanning and information about scan parameters extracted from CT database for 125 patients that underwent different routine examinations at six multislice CT scanners acquired by six hospitals:

MN, RM, TM, HS, MM, and AK. From the database, information about the operation and utilization of ATCM systems during different examinations was obtained. This information included the activation/deactivation status of the ATCM systems, reference image quality mAs, effective mAs, mAs per slice and CTDI vol.

Results and Discussion

■ Phantom study

In the phantom study, large variations were observed in radiation dose and the image noise optimization as indicated in Figures 1 and 2. The observed variations could be attributed to differences in tube potentials, image quality reference mAs settings and phantom sizes as presented in Appendix 1.

In general, the Care Dose 4D systems performed dose reduction at the expense of increased image noise [35,36]. Despite the noise increase observed when the Care Dose 4D systems were on, as indicated in Figure 1, the appearance of the images obtained were not significantly different as compared to those obtained when the Care Dose 4D systems were off. On average, the scanner used at HS did well in dose reduction as compared. This can be explained by the use of lower reference image quality mAs setting of 130 mAs as presented in [37].

The Care Dose 4D systems have different dose and noise optimization features for different phantom sizes. It is evident that, radiation dose reduction was significant for small phantoms of diameters 16, 20 and 22 cm, and marginal for large phantom i.e. 32 cm diameter. This was expected because the systems were specifically designed to reduce dose for pediatric and small sized adult examinations. It is evident also from Table 4 that the radiation dose increased for the 32 cm diameter phantom scanned at AK and TM. This was expected because the system learned that this patient was obese. Thus, in order to maintain the preference image quality, the radiation dose had to increase. It was surprising to observe the marginal increase of both radiation dose and image noise for the 32 cm diameter phantom scanned at TM with the Care Dose 4D system activated, as indicated in Figures 1 and 2. This could be attributed to the use of low tube potential of 120 kV that has low penetrating capability at the reference mAs setting of 200 mAs, for large patients [38].

The plots of image noise against radiation dose for different phantoms sizes are presented in Figures 3-5. For small phantom (16 cm diameter), it was observed that noise varied inversely proportional to the square root of dose and shown elsewhere [39]. For medium phantoms (20 cm-22 cm diameters) and large phantom (32 cm diameter), the variations of image noises with radiation doses are less predictable, respectively as observed elsewhere [40]. This phantom study could not be performed at RM and MN because of failure to activate and deactivate the Dose Right systems (features). The same could not be performed at MM because the CT scanner was not working during these measurements.

■ Patient study

In the patient study, generally, it was observed that most ATCM systems investigated in this study were automatically activated for most routine examinations. Conversely, the Dose Right system used in the Brilliance 64 scanner

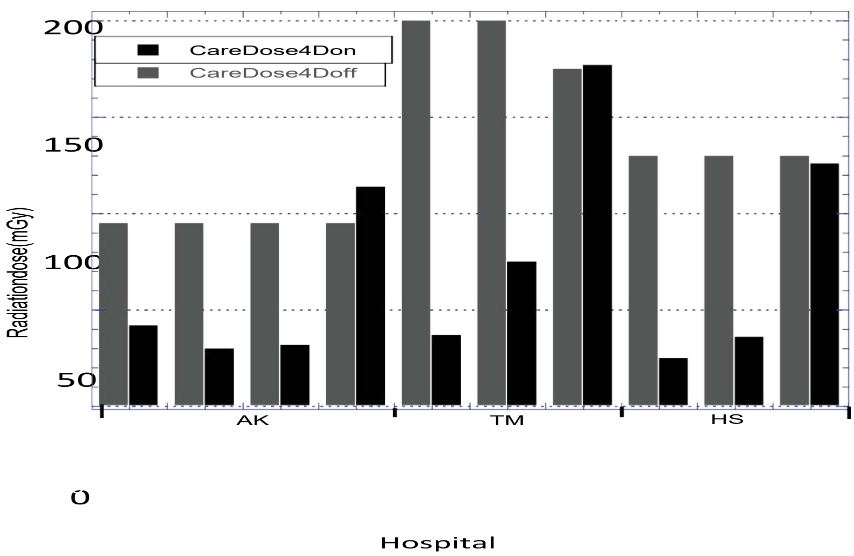

Figure 1. Radiation dose to different phantoms obtained with and without ATCM systems.

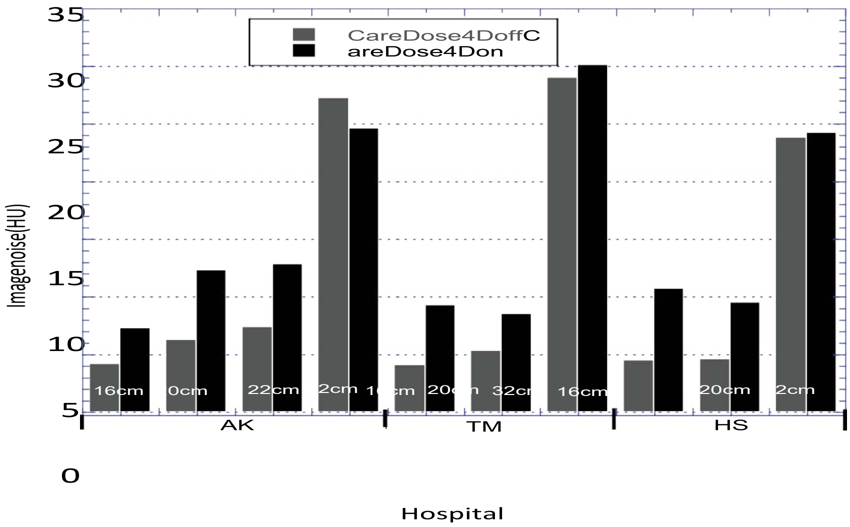

Figure 2. Image noise of different phantoms obtained with and without ATCM systems.

of RM was observed to be inactive for all examinations. In addition, Brilliance 6 scanner used at MN had only the ACS feature active with the D-DOM feature inactive in all examinations. The Z-DOM feature of Dose Right system could not be seen in scanner used by MN. Failure to activate Dose Right features of Philips scanners was attributed to technical limitations including the complicated procedures to be followed when selecting the preference reference image. It was further observed that, sometimes, the ACS feature of the Dose Right system of Brilliance 6 scanner used at MN was deactivated. This deactivation, however, occurred automatically provided the scan range limit was exceeded [41,42]. Likewise, it was observed that, modulation strength features (weak, moderate and strong) of the Care Dose 4D systems were not utilized. This was attributed to technical limitations including failure to access the software in the Siemens scanner consoles that could allow the selection for the modulation strength such as weak, moderate or strong, and the selection of the patient size as slim or obese.

Direct observations revealed that most technologists had limited knowledge about the operation and utilization of the ATCM systems of respective scanners. These limitations were attributed to lack of standardization of different types and versions of the ATCM systems that are, in addition, not user-friendly. Some technologists claimed that the diagnostic image qualities were low when the ATCM systems were activated for some examinations as observed elsewhere [43,44]. This could explain why HS deactivated the Care Dose 4D systems for all examinations except lumbar spine. Similar was observed at AK during abdomen examination to the female patient whose form is shown in Figure 6.

In this case, the Care Dose 4D system was deactivated during the second and third series. The use of fixed mAs in the second and third series delivered radiation dose of 6.75 and 10.83 mGy, respectively as compared to 24 mGy when the Care Dose 4D system was on. Higher dose delivered in the third series was attributed to the use of larger tube potential of 130 kV compared to 110 kV used in the first and second series.

Also, this study assessed dose reduction effectiveness of different ATCM systems to patients undergoing routine examinations in different hospitals by comparing eff.mAs or mAs/slice used for different examinations as presented, large variations of tube loads (radiation dose) used in similar examinations were observed in different hospitals. This could be attributed to variations of patient sizes, tube potentials and reference image quality mAs settings as presented in Appendix 1. It is evident from that, all the ATCM systems assigned low radiation doses to the chest (thorax). This was expected because the thorax constitutes a large volume occupied with air. High radiation doses assigned for the chest examinations at MN could be attributed to the variations of patient sizes and reference image mAs settings of the Dose Right systems.

In addition, high doses for the chest (and other) examinations conducted at MN were expected because the Brilliance 6 scanner used at this hospital had only the ACS feature active with the rest (D-DOM or Z-DOM) being inactive or unavailable, respectively. However, it was interesting to observe that the scanner used by this hospital could reduce radiation dose significantly for children compared to adult patients as shown in Figure 7 and presented in Table 4.

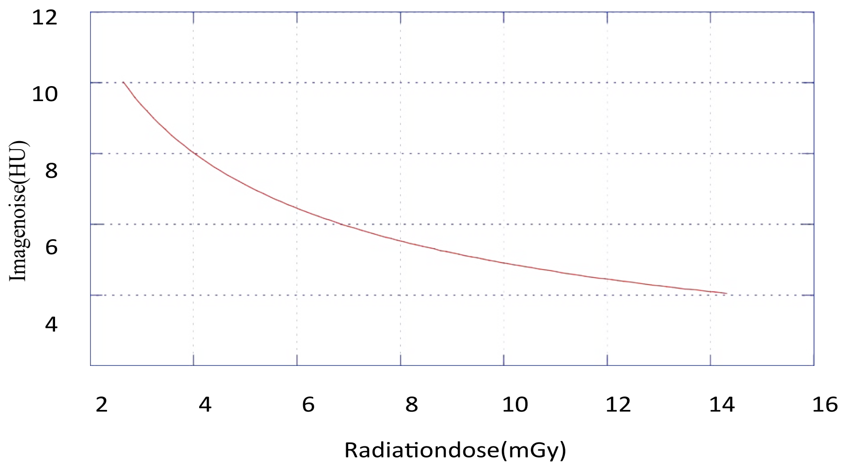

Figure 3. Variation of image noise with radiation dose for phantom of diameter 16 cm.

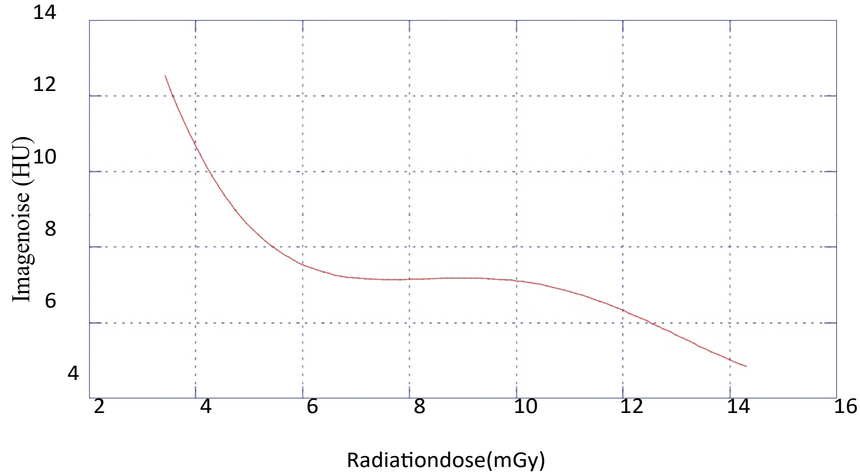

Figure 4. Variation of image noise with radiation dose for phantoms of diameters 20 and 22 cm.

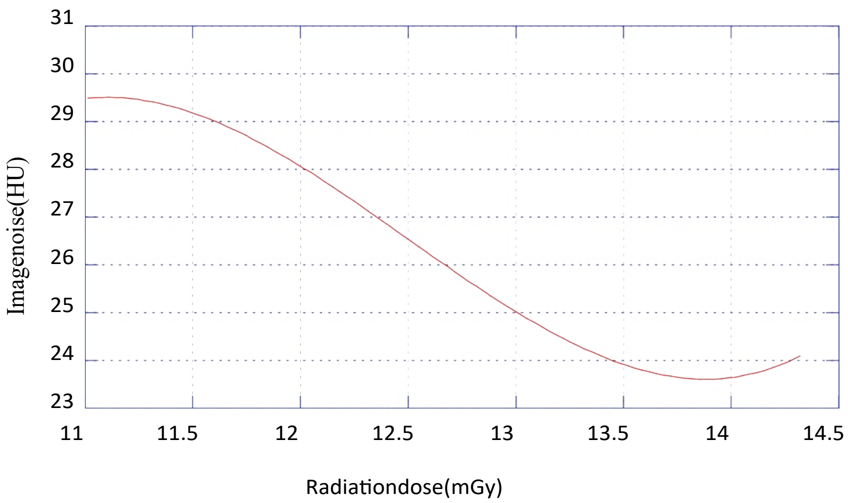

Figure 5. Variation of image noise with radiation dose for phantom of diameter 32 cm.

Moreover, the Care Dose 4D system for the Emotion-6 scanner used by AK was observed to assign low abdomen dose compared to other scanners as presented. The use of low radiation dose for the abdomen CT at this hospital was attributed to the use of low reference mAs

SIEMENS CT SCANNER PATIENT EXAMINATION FORM

Centre: AG CT Model: Emotion 6 Exam: Abdomenv Date: 18/08/2012

Patient Reg.No: 254 Age (years): 18 Sex: F

Scan parameters	Series 1	Series 2	Series 3
	Plain	IV Contrast	Delayed
Care Dose 4D	ON	OFF	OFF
Weak	-----------	-----------	-----------
Average	-----------	----------	-----------
Strong	-----------	-----------	----------
kV	110	110	130
Ref. *mAs*	60	-	-
Eff. *mAs*	24	95	95
CTDI vol (mGy)	1.92	6.75	10.83
Slice width (mm)	5	5	5
Slice collimation (mm)	6 x 2	6 x 2	6 x 2
Pitch	1.5	0.8	0.8
Table Feed(mm)	-	-	-
Rotation time(s)	0.8	0.8	0.8
Scan length (cm)	42	42	42

Figure 6. Patient examination forms for 18 years old adult female who underwent abdomen CT at AG.

PHILIPS CT SCANNER PATIENT EXAMINATION FORM

Centre: MN CT Model: Briliance 6 . Exam: Thorax Date: 31/08/12

Patient Reg.No: 439 Age (years): 32 Sex: M

Scan parameters		Series 1	Series 2	Series 3
		Plain	IV-Contrast	
Dose Right	ACS	ON	ON	
	D-DOM	OFF	OFF	
	Z-DOM			
kV		120	120	
mAs/slice		156	156	
CTDI vol (mGy)		12.5	12.5	
Slice thickness (mm)		3.0	3.0	
Collimation (mm)		6 x 1.5	6x 1.5	
Pitch		0.8	0.8	
Table feed (mm)		1.5	1.5	
Rotation time (s)		0.75	0.75	
Scan length (mm)		29	29	

(a)

PHILIPS CT SCANNER PATIENT EXAMINATION FORM

Centre: MN CT Model: Briliance 6 . Exam: Thorax Date: 31/08/12

Patient Reg.No: 434 Age (years): 2 Sex: F

Scan parameters		Series 1	Series 2	Series 3
		Plain	IV-Contrast	
Dose Right	ACS	ON	ON	
	D-DOM	OFF	OFF	
	Z-DOM			
kV		120	120	
mAs/slice		78	79	
CTDI vol (mGy)		6.2	6.3	
Slice thickness (mm)		3.0	3.0	
Collimation (mm)		6 x 1.5	6x 1.5	
Pitch		0.692	0.692	
Table feed (mm)		1.5	1.5	
Rotation time (s)		0.75	0.75	
Scan length (mm)		22	22	

(b)

Figure 7. Patient examination forms for (a) a 32 years old adult and (b) a 2 years old child who underwent abdomen CT at MN.

settings such as 56, 60 and 95 for three different abdomen examinations. Despite significantly dose reduction, the variations of the reference mAs settings are not recommended for individual patients but rather to the level of diagnostic image quality required by the hospital [45,46]. It was further observed in this study that, despite using the same settings of the reference

Table 4. Radiation dose reduction using different ATCM systems in various routine examinations.						
Routine examination	**Hospital**	**Patient Reg.No.**	**Patient age (y)/sex**	**kV**	**Ref.imagemAs**	**Eff.mAs or mAs/ slice per exam**
Chest	MM	125	37/F	130	70	52
	MM	64	54/F	130	70	35
	AK	332	75/F	130	70	54
	TM	119-12	28/F	120	100	63
	MN	439	32/M	120	-	156
	MN	434	2/F	120	-	79
	MN	432	36/M	120	-	141
Abdomen	MM	128	65/M	130	120	77
	MM	108	25/F	130	120	93
	MM	56	64/M	130	120	78
	MM	45	45/F	130	120	63
	MM	101	29/M	130	120	64
	AK	254	18/F	110	60	24
	AK	304	4/M	130	56	59
	AK	331	9/M	130	95	27
	TM	116-12	38/M	120	200	75
	TM	117-12	34/F	120	200	135
	TM	123-12	38/M	120	200	82
	TM	126-12	37/F	120	200	104
	TM	127-12	56/F	120	200	270
	TM	TM-1	67/F	120	200	171
	TM	186-12	51/F	120	200	173
	TM	188-12	55/F	120	200	87
	TM	188b-12	50/F	120	200	111
	TM	190-12	59/F	120	200	242
	MN	236	75/F	120	-	205
	MN	420	59/F	120	-	169
	MN	429	35/F	120	-	213
C/spine	AK	AK-1	32/F	130	190	188
	HS	36/12	43/M	130	190	72
L/spine	MM	122	33/M	130	190	124
	AK	291	37/F	130	190	172
	AK	294	22/F	130	320	294
	AK	308	47/M	130	190	132
	HS	23-Dec	54/F	130	190	180
	HS	HS-1	62/F	130	190	167
	HS	HS-2	54/F	130	190	135
Pelvis	MM	97	20/M	130	120	94

image quality mAs (190 mAs) for lumbar spine examinations, the scanners used at MM, AK and HS assigned different radiation dose reduction. This was caused by variations in patient sizes and differences in the scanner designs.

Conclusion

This study assessed the patient dose reduction potential and clinical utilization of automatic tube current systems in CT examinations. In all cases, ATCM systems effectively reduced radiation doses with marginal reduction of subjective image quality. These systems reduced patient radiation doses by as much as 60%-88% for small patients. The dose reduction for larger patients was marginal and in some circumstances, the radiation doses slightly increased in order to maintain constant image noise. The observed dose reduction features were expected because the ATCM systems were specifically designed to be more effective in reducing dose for small patients especially children and young adults. Direct observations and analysis of the information extracted from CT database revealed that most technologists had limited knowledge about the operation and utilization of the ATCM systems of respective scanners. These limitations were attributed to lack of standardization of different types and versions of the ATCM systems that are, in addition, not user-friendly. Some technologists claimed that the diagnostic image qualities were low when the ATCM systems were activated for some examinations.

Recommendations

The technologists and radiologists should attend the in-service training programmes to learn on how to operate and effectively utilize the ATCM systems. The CT scanner manufacturers should produce the standard and more user-friendly ATCM systems during future designs. The use of cylindrical CT phantoms in the assessment the ATCM systems made it difficult to investigate all features of the ATCM systems. Thus, further study should use the anatomically shaped phantoms to assess the effectiveness, in terms of dose reduction, of all features of the ATCM systems.

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