ORIGINAL ARTICLE

Determining the Feasibility of Dose Reduction Strategies on Radiation Dose: An Experimental Phantom Study

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ABSTRACT

Introduction: Radiation exposure during the CT examination has always been a concern due to its associated cancer risk. The guidelines suggest the optimization of radiation dose reduction. Therefore, this study aims to determine the feasibility of dose reduction strategies on radiation dose reduction using a phantom. **Methods:** Head and body phantoms of 16 cm and 32 cm, respectively, were used to calculate the radiation dose and measure the quantitative image quality. The phantoms were positioned and scanned with the standard protocol and low dose protocol. For dose reduction strategies, scan length was reduced in head phantom, and tube voltage and tube current were manipulated individually and by combining both and tested in both head and body phantoms. Also, the influence of rotation time was investigated in body phantom. Quantitative image quality was determined by drawing a region of interest on the obtained image. **Results:** Reducing scan length showed 41% reduction of radiation dose and reducing tube current, and tube voltage showed up to 75% reduction of radiation dose in head phantom and 70% reduction of radiation dose in body phantom compared to the standard protocol. The reduction of the rotation time, however, reduced the scan time and the radiation dose but the maximum mAs or tube current allowed was limited. Quantitative image quality was reduced when using a lower dose protocol. **Conclusion:** The dose reduction strategies showed a reduced dose, but the quantitative image quality score was reduced when scanned with low dose protocol. Further manipulation can be performed to maintain image quality.

Keywords: Dose reduction Strategies, Radiation dose, Quantitative image quality, Tube Voltage, Tube Current

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INTRODUCTION

Computed Tomography (CT) amongst other diagnostic modalities has become the preferred modality of choice for the diagnosis of many diseases. The demand for CT examination has increased since the advancement in technology (1, 2). The advancements led to a reduction in contrast material volume used during contrast-enhanced CT examination, which increased the demand for CT angiography for differential diagnosis of diseases (3). Expansion in CT examination use has resulted in a significant source of medical radiation exposure of diagnostic X-rays. For example, according to National Radiological Protection Board (NRPB) (report 1997), in the UK, CT was responsible for approximately 40% of medical exposure to X-rays and globally, medical exposure from CT was responsible for an annual collective dose of 34%, from 1991 to 1996 data (4).

The concern of radiation exposure during CT scan has more attention towards its potential risk of cancer, especially with the increasing use of CT angiography (5, 6). For example, in the United States, it was estimated that 1.5 – 2.0 % of cancer is attributable to CT scanning (7). The cancer risk due to radiation is even present with low dose exposure to ionizing radiation and also predicted to result from sporadic rather than subsequent scanning, however, the risk increases with a frequent scan or multiphase scanning (8). With these concerns of increasing risk of radiation during the CT examination, various professional bodies have endorsed diagnostic reference levels (DRLs) and suggested to implement optimization where ever the dose exceeds the normal limit (9). There are several strategies one can choose to optimize radiation dose, where manipulating tube potential, tube current, scan length, rotation time and pitch are the basic strategies (10). The use of automatic tube current modulation (ATCM), adaptive dose shielding, and advancement in image reconstruction algorithms are the current strategies for dose optimization (3). Present literature on DRLs and dose reduction strategies are mostly on routine CT examination such as head, chest, and abdomen/pelvis examination (11-13) and CT coronary angiography examination (14, 15). There are very limited resources available on DRLs and most importantly on dose optimization for CT angiographic examinations such as CT cerebral angiography, CT pulmonary angiography and CT lower limb angiography. Since this CT angiographic examination demands the use of the multiphase protocol, there is always an increased risk of cancer. Therefore, this experimental phantom study is performed to determine the feasibility of dose reduction strategies on radiation dose.

MATERIALS AND METHODS

The study was carried out in head phantom measuring 16 cm and body phantom measuring 32 cm in 128 slice Philips Incisive CT scanner. The phantom was centered on the couch by adjusting it with the sagittal laser light of the system and the height was adjusted with the coronal laser light.

The phantom scan was performed in two phases. Firstly, the scan was performed with the standard protocol set by the manufacturer and then the dose reduction strategies protocol set in the institute. The dose report was obtained from the system generated dose info.

Experiment using Head Phantom

After positioning the head phantom, the scan was performed using the standard protocol. The standard protocol parameters used to initiate the phantom scan is described in table I. The dose descriptor obtained using standard protocol was used as baseline values.

In the second phase of the experiment, influence of dose reduction strategies were investigated. Firstly, the influence of scan length on dose reduction was investigated. Scan length was reduced to 150 mm from 300 mm while all the other parameters were kept constant (Table I). The influence of tube voltage and tube current on radiation dose was investigated by creating three different protocols A, B, and C by changing only the kVp, and mAs (mA) settings, while keeping all the other parameters similar to standard protocol (Table I).

The influence of tube voltage and tube current individually was investigated. Firstly, the scan was performed by changing only the kVp values while keeping all the other standard protocol parameters in table I constant. The kVp values used was 120, 100 and 80. Secondly, the scan was performed by changing only the mAs value while keeping all the other standard protocol parameters in table I constant. The mAs value used was 200, 300 and 350.

Experiment using Body Phantom

A similar experiment was performed using body phantom and parameters listed in table II were kept constant, and variable kVp of 80,100 and 120 were used. The kVp setting of 120 was considered as standard protocol, and the obtained volumetric computed tomography dose index ($CTDI_{Vol}$) and dose length product (DLP) values were considered as baseline values. Furthermore, the influence of rotation time was also investigated by changing the rotation time from 0.4 seconds to 0.50 and 0.75 seconds while keeping tube voltage constant to 80 kVp.

The obtained phantom images were reconstructed into 5 mm thickness for calculating quantitative image quality (attenuation value, image noise and Signal to noise ratio) in head phantom and body phantom by drawing circular region of interests (ROI's) using Philips IntelliSpace Portal (ISP) v9.0.4.31010 (area of 99 – 101 mm^2). ROI's were place in 4 peripheral locations of the phantom and center location for all the obtained images (Fig. 1). Mean attenuation values in Hounsfield unit (HU) for each scan were obtained from all the four peripheral and center locations and averaged. To calculate image noise, standard deviation of the attenuation values from all the four peripheral and center locations were obtained and averaged. Signal to noise ratio (SNR) was calculated by dividing averaged values of mean attenuation and image noise (SNR = mean attenuation/image noise). The values for quantitative image quality obtained using standard dose were used as baseline values.

Table I: Standard protocol and dose reduction strategies parameters for head phantom

Parameters	Standard Protocol	Scan Length Reduction	Protocol A	Protocol B	Protocol C
kVp	120	120	120	100	80
mAs (mA)	314 (503)	314 (503)	200 (319)	230 (319)	260 (414)
Scan length	300 mm	150 mm	300 mm	300 mm	300 mm
Scan time	5.63 sec	5.63 sec	5.63 sec	5.63 sec	5.63 sec
Slice thick-ness	0.9 mm	0.9 mm	0.9 mm	0.9 mm	0.9 mm
Rotation time	0.4 sec	0.4 sec	0.4 sec	0.4 sec	0.4 sec
Pitch	1	1	1	1	1

Table II: Standard protocol parameters for body phantom.

Parameters	Value
kVp	120
mAs (mA)	254 (628)
Scan length	150 mm
Scan time	2.185 seconds
Slice thickness	0.9 mm
Rotation time	0.4 sec
Pitch	1

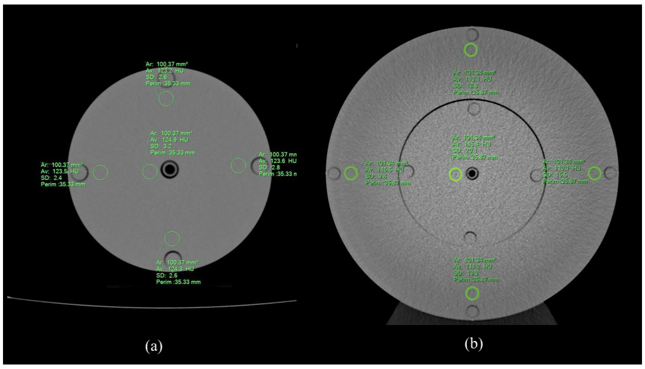

Figure 1: CT (a) head phantom, and (b) body phantom image showing the placement of ROI's for calculating quantitative image quality.

RESULTS

Head Phantom

The $CTDI_{Vol}$ and DLP values noted for standard protocol was 44.32 mGy and 1599.53 mGy*cm, respectively. Reduction of scan length to half, resulted in 41% reduction in radiation dose in terms of DLP, whereas the $CTDI_{Vol}$ value remained unchanged. DLP value noted was 947.18 mGy*cm. The $CTDI_{Vol}$, DLP, and quantitative image quality values noted for Protocol A, B and C are tabulated in table III. When comparing the result with baseline dose, low dose protocol was able to achieve 37%, 55% and 75% reduction in radiation dose for Protocol A, B and C, respectively. In contrast, the attenuation values and SNR shows reducing trends and images noise values increased with lower dose.

Reduction of kVp showed reducing trend in radiation dose, attenuation values and SNR, whereas images noise values increased with lower kVp settings (table III). Similarly, mAs values were manipulated, and obtained values showed reduced $CTDI_{Vol}$ and DLP values for lower mAs settings, but very minimal changes were noted when considering quantitative image quality values (table III).

Body Phantom

The scan was performed using a standard protocol of 120 kVp and the obtained $CTDI_{Vol}$, DLP, and quantitative image quality values is tabulated in table IV. kVp was manipulated to 100 kVp and 80 kVp, and noted 40% reduction in radiation dose with 100 kVp and more than 70% reduction in radiation dose with 80 kVp protocol when compared to baseline dose. Quantitative image quality comparison showed increased image noise and reduced attenuation values and SNR for lower dose protocol.

Lastly, the influence of rotation time was investigated with constant kVp (80 kVp) and found that the change in rotation time influences the maximum mAs allowed. Maximum mAs allowed was 244, 311 and 475 for rotation time of 0.4, 0.50 and 0.75 seconds respectively. Since the increase in the rotation time increased the mAs, therefore the radiation dose and quantitative image quality also showed an increasing trend (table IV).

DISCUSSION

Demand of CT angiography has increased due to its minimally invasive techniques (16). However, there is a substantial increase in radiation dose due to multi-phase scanning protocol and longer scan length (17-19). To address the concern of increased radiation dose and associated cancer risk, the optimization of radiation dose was suggested. In this experimental phantom study, a positive effect of various dose reduction strategies on radiation dose was noted.

There are several parameters which the technologist can modify to achieve dose reduction in CT examination (17). In this study, manipulation of scan length, tube current, tube voltage and rotation time were considered to achieve a reduction in the radiation dose. The result of the present study on the effect of scan length to reduce radiation dose showed a reduction of dose in

Table III: Quantitative image quality values and radiation dose for head phantom.

Dose reduction strategies	Attenuation value (HU)	Image noise	Signal-to-noise ratio	$CTDI_{vol}$ (mGy)	DLP (mGy*cm)
Standard Protocol	123.48	2.44	50.60	44.32	1599.53
Scan Length Reduction	-	-	-	44.32	947.18
Protocol A	123.54	2.84	43.5	28.14	1015.97
Protocol B	115.72	3.96	29.22	19.87	717.46
Protocol C	102.36	4.94	20.72	11.21	404.58
mAs manipulation					
200	123.3	3.12	39.51	28.14	1015.97
300	123.68	2.64	46.84	42.21	1523.95
350	124.02	2.38	52.19	49.25	1777.95
kVp manipulation					
120	123.9	2.72	45.55	44.32	1599.33
100	115.72	3.32	34.85	27.22	982.61
80	101.94	4.98	20.46	13.58	490.17

Table IV: Quantitative image quality values and radiation dose for body phantom.

Dose reduction strategies	Attenuation value (HU)	Image noise	Signal-to-noise ratio	$CTDI_{vol}$ (mGy)	DLP (mGy*cm)
kVp manipulation					
120 (standard Protocol)	113.66	14.22	7.99	20.60	450.20
100	105.08	18.32	5.73	12.29	268.68
80	91.6	30.38	3.01	5.89	128.79
Rotation time manipulation					
0.40	95.32	26.64	3.57	5.89	128.79
0.50	103	24	4.29	7.38	161.24
0.75	101.44	19.76	5.13	11.26	246.04

terms of DLP values, where the scan length was reduced by 50% and achieved 41% reduction in the radiation dose. Pyong – Kon Cho et al., in their study reported the increase in the scan length on CT cerebral angiography is responsible for higher radiation dose where they observed increased radiation dose in the scan covering from arch of the aorta to vertex then base of the skull to the vertex (18). Therefore it is a technologist and radiologist duty to plan the scan so that only the anatomy required for the clinical diagnosis is scanned.

There are several studies performed to reduce the radiation dose while decreasing tube current and tube voltage in combination, or manipulating either tube voltage and keeping tube current constant and vice versa (6, 16, 20-23). ICRP 135, 2007 (24) in their report stated that it is not only the radiation dose reduction which should be considered but also the image quality should be adequate to make a clinical diagnosis. The present study showed up to 75% reduction in the radiation dose when the parameters kVp and mAs(mA) were manipulated in head phantom. Even by reducing only the mAs(mA) values from 314(503) (Standard Protocol) to 200(319) (Protocol A) with constant kVp of 120, dose reduction of 37% could be achieved with very minimal changes noted in quantitative image quality (Standard deviation of standard protocol to protocol A: for Attenuation value is 0.04, image noise is 0.28, and SNR is 5.02) (table III). However, the attenuation values and SNR shows reducing trends and images noise values increased with the lower dose protocols (Protocol B and C). Wei – Lan Zhang et al., (6) also reported a similar finding where they could reduce up to 50% radiation dose using 80 kVp technique in CT head and neck angiography compared with 120 kVp technique and similarly Iezzi et al., (20) could reduce radiation dose up to 61% while using 80 kVp technique. Furthermore, this was true for body phantom as well, where 70% reduction in radiation dose was achieved when the kVp was manipulated from 120 to 80. However, when considering quantitative image quality of the phantom images, the values showed increased noise and decreased attenuation values and SNR values with low kVp techniques (table IV). Since the mean photon energy of contrast material used during angiography, which is iodine, has the k-absorption of 33.2 keV, higher vessel enhancement can be achieved while using kVp factor other than 120 kVp (6). Therefore, with the use of lower kVp protocol, for example, 80 kVp technique for low body mass index (BMI) patient and 100 kVp for normal BMI patients, the difference in density can be achieved because the vessel filled with contrast will show higher attenuation values and surrounding vessels will demonstrate lower attenuation values. Also, the use of low tube voltage has an advantage in reducing contrast dose leading to the reduction of imaging cost as reported by Masayuki Kanematsu et al., (16). Similarly, Nakayama et al., (25) in their study reported that the radiation dose can be reduced up to 57% with reduced tube voltage and a reduced amount of contrast material used.

The concept of increasing the tube current while reducing the tube voltage is to maintain the image quality because while decreasing tube voltage there is the tendency of increase in noise which could compromise the diagnostic quality (26-28). In this present study using head phantom, the mAs values was increased while reducing the kVp factor and could still achieve good dose reduction. Similarly, W. Xia et al., (23) reported the reduction of dose by 54% when the authors changed the conventional dose of 120 kVp and 400 mAs to low dose protocol of 80 kVp and 600 mAs. The mAs was increased to compensate for the loss of image quality, and they could achieve a 50% increase in contrast to noise ratio (CNR). The increase in CNR achieved in W. Xia et al., (23) study might be due to the difference in density between contrast filled vessels and adjacent tissues obtained by the use of 80 kVp technique and also increased tube current to compensate for the loss of image quality due to reduced tube voltage. Reducing the tube current alone can also be beneficial. In this present study, 43% dose reduction was achieved when mAs value was reduced to 200 from 350 while keeping the kVp constant with minimal changes noted in quantitative image quality (Standard deviation of 200 mAs to 350 mAs: for Attenuation value is 0.50, image noise is 0.52, and SNR is 8.96) (table III). L. Jangland et al., (29) achieved dose reduction by the factor of 3 while, Srinivasa R. Prasad et al., (21) in their study achieved 50% dose reduction when they reduced mAs from a standard dose of 220-280 to a low dose of 110-140. Similarly, James G. Ravenel et al., (22) reported that the tube current can be reduced to 50% without compromising image quality, and also Nevzat Karabulut et al., (30) reported a similar finding.

In this present study, rotation time influenced the maximum mAs allowed. While reducing the rotation time from 0.75 to 0.40 seconds, system allowed the maximum mAs of only 244. Scan time and radiation dose reduction could be achieved while reducing the rotation time similar to the report of Mannudeep K. Karla et at., (17). However, in their study, they suggested that to maintain contrast image noise quality, tube current have to be increased, while the present study report showed limitation in the use of mAs value. This difference in finding may be due to the use of different CT scanner, and further research can be performed to answer this difference in opinion.

There are other factors as well, which can influence the radiation dose, and those are patient BMI and the type of CT scanner (29). Since the tube current is directly proportional to radiation dose, manipulating tube current with regards to the patient weight or body mass index would further optimize the radiation dose (21, 29). The model of CT scanner also plays a crucial role in optimizing radiation dose. The current model of CT scanner comes with the iterative reconstruction, which has started to replace conventional filtered back projection. The advantage of iterative reconstruction techniques is that the loss of image quality due to increase noise from the consequences of reducing tube current or tube voltage or both can be compensated using this technique. Masayuki Kanematsu et al., (16) in their study reported that they could achieve 20 – 51% reduction of radiation dose using iterative reconstruction with low tube voltage. Similarly, there are reports by other authors about the use of iterative reconstruction to maintain image quality while optimizing radiation dose (31-33).

The above mention strategies to reduce the radiation dose is from optimizing the technical parameters. There are other ways to control radiation dose in CT. The most effective way but a controversial method is the justification of the CT scan. Robert L. Zondervan et al., (7) in their study reported about the unnecessary use of CT scanning, and how little guidelines are developed to implement this method. Rebecca Smith et al., (19) also reported that more than 30% of the CT performed is unnecessary. Although the European Commission office of radiation protection and the Canadian Association of radiologist have developed the guidelines to address this issue, the utilization of the guidelines remains sporadic. In the end, it is the physician and radiologist duty to do a benefit vs risk assessment into a clinically relevant context so that the unnecessary use of CT can be controlled (7).

The benefit of using various dose reduction strategies to reduce radiation dose is high, but there is always a concern when it comes to the application of these strategies. Although the standard protocols used in this study are universally accepted protocol, and the image quality for both contrast and non-contrast images are excellent. Nevertheless, optimizing the technical parameters, mainly by lowering tube voltage yields better contrast for bone and iodine, leading to increased enhancement (3). Therefore the low dose protocol can be used in CT angiographic examination for better arterial enhancement. Christe et al., (34) in their study decreased tube current and could still detect solid pulmonary nodules. Jan-Erik Scholtz et al., (35) reported better tumor delineation with low kVp settings, however, according to Moses et al., (10) characterization of the tumor is inadequate with low dose protocol. Low dose protocol also introduces uncertainty in diagnosis for non-contrast images. Additionally, Moses et al., (10) stated the limitation in the use of low dose protocol for larger patients.

The findings of this experimental study showed increasing attenuation (HU) values when the tube voltage was increased. Similarly, Hashizume K et al, (36) reported increase in attenuation coefficient with the use of higher tube voltage from their phantom study. Whereas the general trend is that the attenuation decreases when the tube voltage increases. The answer to this different concept lies in the behavior of HU in the tissue equivalent material which depends on three factors, that is, photon energy, tissue density, and atomic number. Since the phantom used in this study is made of a tissue equivalent material with low atomic number similar to water (Z=7.5), therefore it is less attenuated with low tube voltage due to photoelectric interaction, but the attenuation increases when high tube voltage is used due to Compton scatter interaction (37). However, in case of high atomic number material, for example iodine (contrast material) the attenuation decreases with increase in tube voltage due to photoelectric effect. Likewise, Zhang WL et al, (6) and Y. Murakami et al, (38) suggested to use low kVp technique for contrast enhance examination for better vessel enhancement.

The limitation of this experimental phantom study was that the image quality analysis was only performed in tissue-equivalent phantom and the different size of the phantom was not considered since we used only head and body phantoms of 16 cm and 32 cm in diameter respectively. Other limitation was that the study was carried out only in one CT scanner which is Philips Incisive 128 Slice CT scanner.

CONCLUSION

The manipulation of various parameters showed an effective reduction of radiation dose. Though to increase the image quality of CT images, some factors can be further manipulated, such as increasing the tube current when the tube voltage is changed, however the amount of tube current increment is subjective which depends on the individual image quality preference. Changing the kVP settings depending on the patient body mass index (using low kVp setting for low BMI patients), reduction in the scan length by covering only the required anatomy can further optimize the dose and avoiding repeat examination, and performing follow up examination in low dose protocol could help in optimizing the radiation dose. Therefore, this study can be concluded by stating that the dose reduction strategies used is feasible and can be used clinically to optimize radiation dose.

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