Original Article, PET/CT Physics.

Evaluation of computed tomography dose Reduction and image Quality in Ingenuity TOF PET/CT.

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ABSTRACT:

Objectives: The aim of this study is to evaluate the various automatic tube current modulation combined with iterative reconstruction (iDose4) in commercially available positron emission computed tomography/computed tomography (PET/CT, Philips healthcare) imaging scanner. **Methods:** A Rando phantom was scanned according to the high dose routine protocol (CTDI=19.3 mGy) using Atomic Exposure Control (Dose Right) with two different dose right modulation Z and 3D modulation.

At each modulation, four different values of Dose right index 5, 10, 15, 20 and 30 were applied. Raw data were reconstructed with 4 iDose4 levels (0, 2, 4 and 6).

Results: We found that no significant difference in image noise (SD) of bone, lung, liver issue between the two ATCM including 3D-DOM and Z-DOM ($p>0.05$). However, significant difference in SD measurements was found in soft tissue ($p<0.05$). A significant image noise improvement on iDose4 L2 images at DRI 5 and Z-DOM modulation represented by a reduction in SD of 10.1%, 18.5%, 12.8% and 17.5% for bone, soft tissue, lung and liver respectively.

The greatest reduction of image noise was observed when using iDose4 L6 by 20.9%, 39.3%, 40.7 and 72.7% for bone, soft tissue, lung and liver respectively. Z-DOM and 3D-DOM protocols were observed to lead significant reduction in CTDI vol, DLP and effective dose. The reduction in effective radiation exposure was between 15% and 63% according to the value of DRI used.

Conclusion: While maintaining a diagnostic level of image quality, combining AEC software with iDose4 levels can effectively reduce the radiation effective dose significantly (up to 60%) in comparison with constant tube current (AEC-off). The results demonstrate also that no significant reduction in radiation dose exposure between using Z-DOM and 3D-DOM modulation.

Key Words: patient dose optimization, iterative reconstruction algorithm (iDose4), Automatic exposure control, radiation exposure, Rando phantom.

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INTRODUCTION:

In the last 2 decades, hybrid imaging has seen significant developments [1]. The combined features of anatomical imaging like magnetic resonance imaging (MRI) and x-ray computed tomography (CT) with those of positron emission tomography described by molecular imaging have been well established and adopted in clinical institutions.

The hybrid PET/CT imaging techniques are one of the most impressive and successful implementations in radiology.

Both components should be necessary to approach specific requirements in order to accomplish a standard level of quality. The efficiency of the PET system utilizing standard procedures and also the national association of equipment and manufacturers (NEMA) is reported in the literature [2,3]. However, the CT component of the combined PET/CT is not widely technically examined in the nuclear medicine society.

Although the advantages of CT are many folds including but not limited to the correction of photon attenuation, scattered radiation and other corrections for image degrading factors as well as partial volume effects. In addition, the molecular imaging phase, including calcium score, cardiac angiography may also benefit from certain diagnostic tests.

Radiation doses of patients often are higher with CT than with nuclear medicine tests, particularly when diagnostic CT is received from the imaging scan [4,5 and 6].

Over the last two decades, there has been a recent interest in developing new approaches that allow dose reduction and minimization of individual patient radiation exposure .Among the techniques used in dose reduction are decreasing mA and tube voltage and also using higher helical pitch [7,8]. Nevertheless, with poor image quality, these methods increase the noise of the image. Especially for children the mA and kV can be reduced while maintaining the CT image Quality [9].

Iterative reconstruction based algorithms have also been introduced to rebuild images obtained at a low dose of radiation while at the same time being able to have a similar image quality for those images obtained at a high dose of radiation.

Design of CT scanners with automatic exposure control (AEC) techniques and iterative reconstruction algorithms has been devised to optimize CT exams. Two key techniques are used to apply AEC: Automatic Current Modulation (ATCM) and Automatic Current Selection (ACS) Which can be separately enabled or combined. In the ACS system, the scanner produces an optimized steady tube current to be applied to the scanned region for which a modulated tube current is given by ATCM. The scanner generates an optimized constant tube current in the ACS system to be applied to the scanned area for which ATCM gives a modulated tube current [10]. All these AEC techniques are based on mA modulation to optimize for variability in patient attenuation while aim to provide a full scan with maintaining image quality.

Moreover, when scanning with fixed mAs it results in variations in image quality and generally in over-irradiation of the areas of the body with low attenuation.

With advanced reconstruction algorithms, such as iterative reconstruction (iDose4), which is commonly used, image noise can also be minimized. IDose4 provides a groundbreaking approach in which both image domains the projection are processed iteratively [11,12].

In this study, we aimed to evaluate the image quality and radiation dose of CT images achieved at different Dose Right Index (DRI) levels using Z-DOM and 3D-DOM modulation and reconstructed with varies iDose4 levels.

MATERIALS AND METHODS:

The PET-CT Scanner: The scanner used in this study was a commercially available scanner namely Ingenuity TF 64 PET/CT (Philips Healthcare, Cleveland, OH, USA). The CT consists of 64 slice multi detector-array. The X-ray tube has rotating anode with a variable focal spot size with filtration of 1.0 mm Al equivalent with additional 1.2 mm titanium filter. The system is equipped with “Dose Right” the automatic exposure system and iDose4 (4^{th} generation of iterative statistical reconstruction) offering dose reduction and acceptable image quality.

The Philips AEC system, consists of three components: Automatic Current Selection (ACS) (dose right) for patient-based; D-DOM for angular AECs; and Z-DOM for longitudinal AECs [(13)]. Currently, these three tube current modulation methods cannot be used together; instead, ACS could be used with Z-DOM or D-DOM. To set the appropriate image quality standard, the Philips system utilizes the reference image definition. The operator chooses the protocol-specific mA value and, on the basis of each patient's attenuation information, mAs is automatically adjusted to maintain the same noise level roughly as for a predetermined reference patient.

Rando phantom: This phantom is manufactured of tissue-equivalent components that simulate the characteristics of an adult's radiation attenuation. The Rando phantom used here consisted mainly of thirty-five portions of 170 cm human stem and 70 kg body weight [(14)]. The phantom is a human skeleton embedded in an anthropomorphic material. The unique phantom density compartments are 0.32 g/cm^3 in the lungs, 0.98 g/cm^3 in the soft tissues and 2.70 g/cm^3 in the skeleton, which are closely linked to the absorption and dispersion of x-ray photons by human body tissues [(15)] ***Figure (1)***.

Acquisition and reconstruction parameters: To analyze the dose reduction efficiency developed by Philips healthcare and implemented in the Ingenuity TOF PET/CT scanner software package, the rando phantom was employed.

In data acquisition, the phantom was based on the gantry iso center according to the clinical routine of the CT examination, i.e. sagittal midline, the supine location and mid thickness of the phantom.

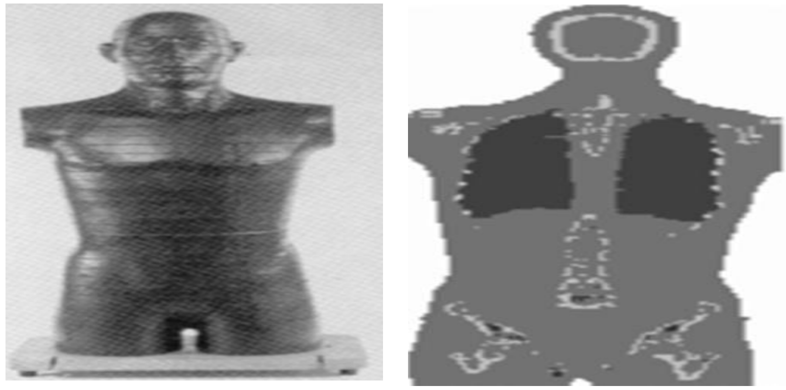

Figure (1): A photograph of the Rando phantom.

A Rando phantom was scanned according to the routinely used high dose protocol as shown in ***Table (1)***. Using Atomic Exposure Control (Dose Right) with two different ATCM Z-DOM and 3D-DOM. At each modulation, four different values of dose right index 5, 10, 15, 20 and 30 were applied. Raw data were reconstructed with 4 iDose4 levels (0, 2, 4 and 6).

The routine high dose protocol revealed CTDIvol of 19.3 mGy. The former is the typical data acquisition protocol used in diagnostic F18-FDG PET/CT oncologic examination employed in our daily routine and typically used in diagnostic chest/abdomen and pelvic CT procedures.

Image quality evaluation: To evaluate how the AEC modulation, dose right index and iDose4 levels affected image quality, the image noise values from scans performed by changing in these parameters were compared. Circular regions of interest (ROIs) of 0.5 cm^2 were drawn to measure SD and HU in four regions: soft tissue, bone, and lung region of the rando phantom.

Table (1): Scanning parameters for routine protocol.

Settings	protocol
Tube voltage	120 KV
Rotation time (S)	0.75
Collimation(mm)	64*0.625
Slice thickness(mm)	1
Increment(mm)	0.08
Filter	Standard
FOV(mm)	450
Matrix	512*512

RESULTS:

The image noise (SD) measurements from the bone, soft tissue, lung and liver for the four different DRI 5, 10, 15,20 and 30 with two ATCM modulation Z-DOM and 3D-DOM when iDose4 was activated with various levels are shown in ***Figure (2)***.

It illustrates the impact of iterative reconstruction algorithm iDose4 levels (0, 2, 4 and 6) on the SD at different DRIs (0, 5, 10, and 20). It provided information on how SD changes when two different modulations (Z-DOM and 3D-DOM) was activated.

A significant increase in image noise was noticed when DRI increase from 5 to 10 and decreasing again when DRI increase from 10 to 30 for bone and liver. But the SD of lung and soft tissue decrease with increasing DRI.

A Wilcoxon signed-rank test found that there was a significant difference in image noise (SD) between the 3D-DOM and Z-DOM ATCM modulations in the soft tissue region ($p<0.05$). No significant change in all SD measurements in the bone, liver and lung regions ($p>0.05$; $p=0.27$; $p=0.126$).

The impact of using iterative reconstruction algorithms (iDose4) with level 2 is shown in figure 2b. A significant image noise improvement on iDose4 level2 images at DRI 5 and Z-DOM modulation represented by a reduction of SD of 10.1%, 18.5%, 12.8%, and 17.5 % for bone, soft tissue, lung and liver respectively.

The greatest reduction of image noise was observed when using iDose4 level 6 compared to level 2 and 4. This has been translated into a reduction of the SD by 20.9%, 39.3%, 40.7 and 72.7% for bone, soft tissue, lung and liver respectively.

The measured HU at different regions of the rando phantom including bone, soft tissue, lung and liver for the five different DRI 5, 10, 15,20 and 30 using two different ATCM Z-DOM and 3D-DOM are shown in ***Figures (3)*** and 4. It provided also information on how HU changed when iterative reconstruction algorithm iDose4 was activated with different levels. No significant difference was observed in HU values of lung, soft tissue, bone and liver when iDose4 with different levels (0, 2, 4 and 6) was activated as shown in ***Figure (4)***.

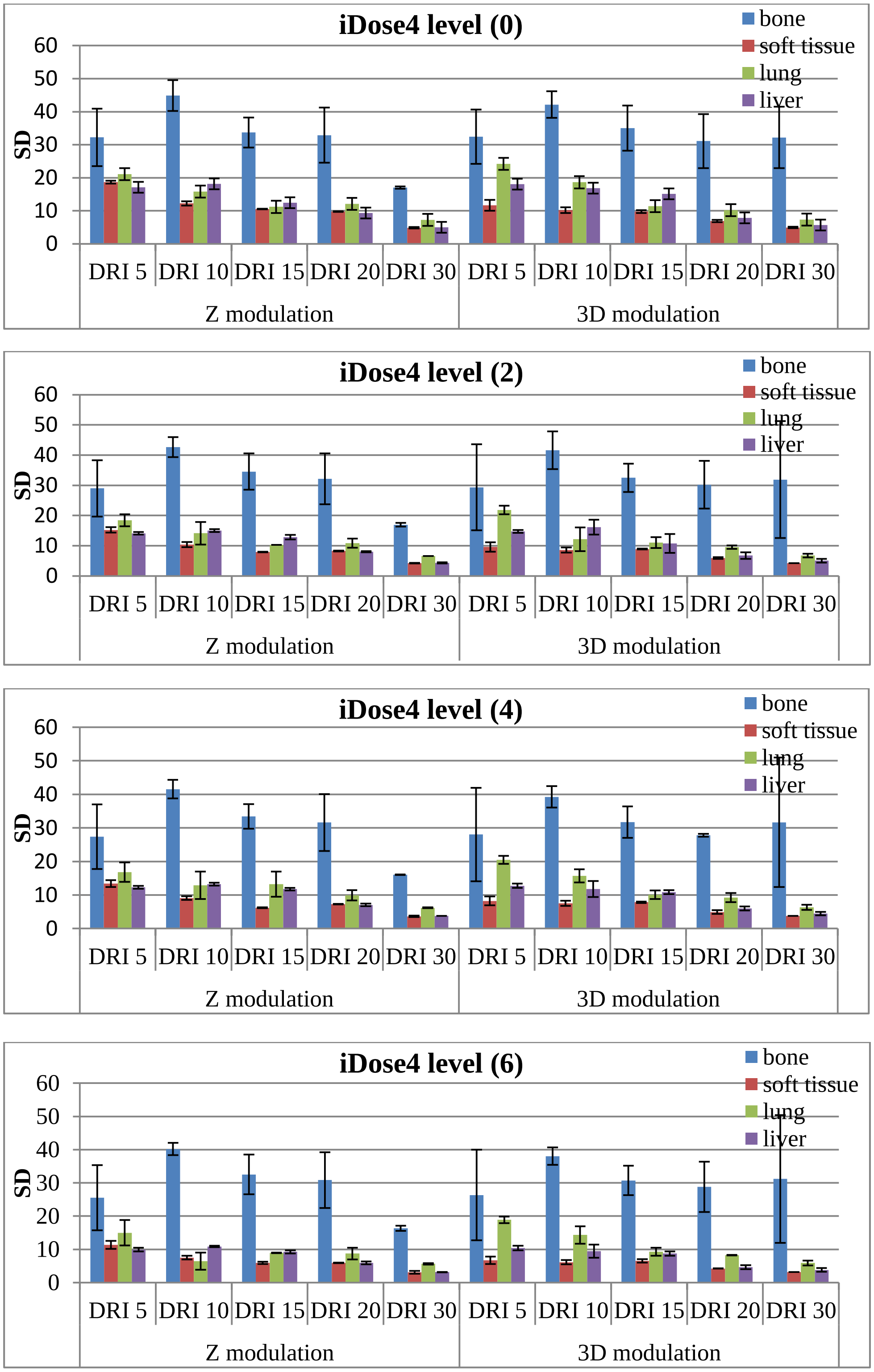

Figure (2): Measured SD (image noise) in the bone, soft tissue, lung and liver with different DRI and iDose4 levels (0, 2,4and 6) using two different AEC modulation Z-DOM and 3D-DOM.

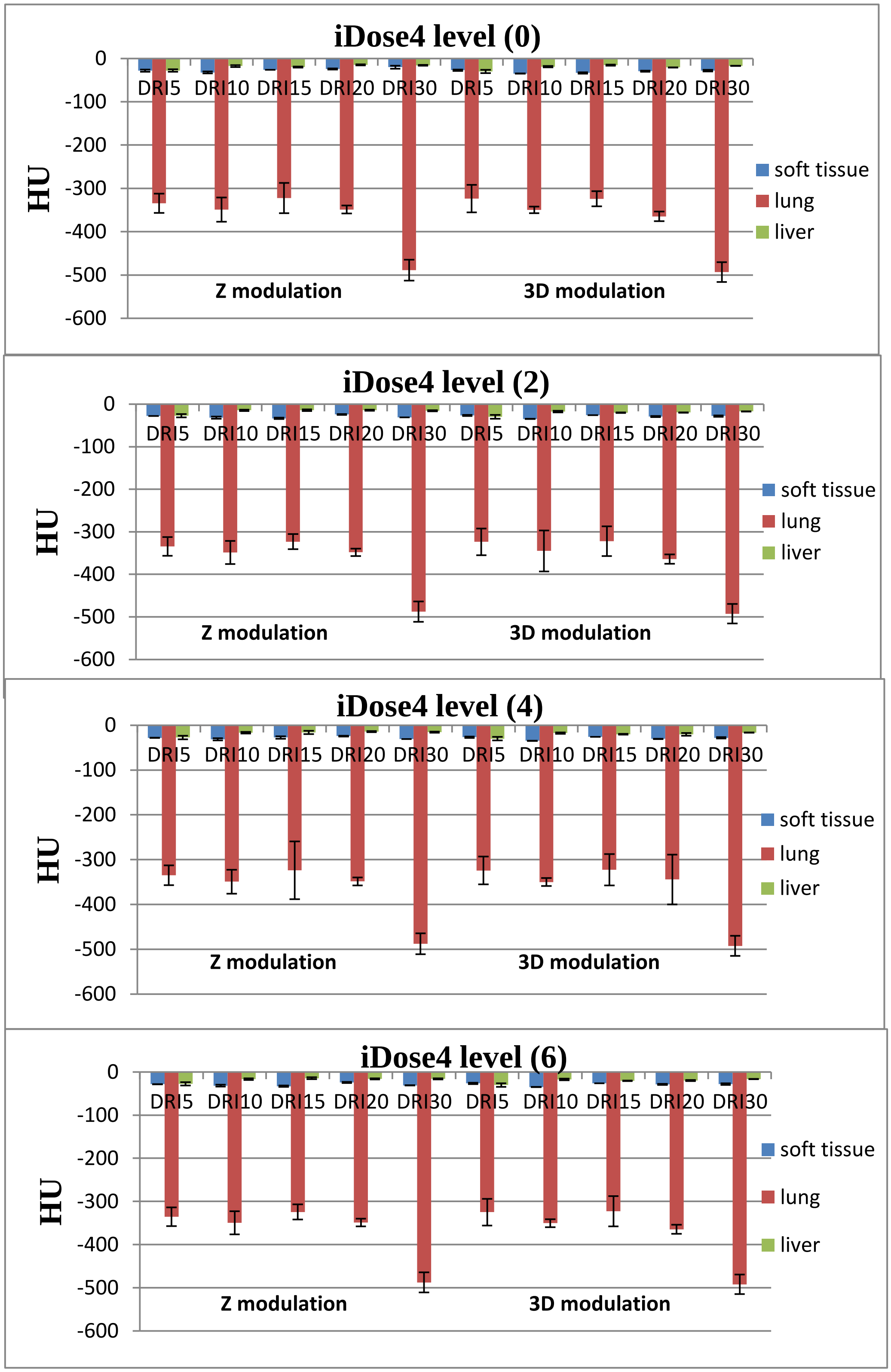

Figure (3): Measured HU in the soft tissue, lung and liver with different DRI and iDose4 levels (0, 2,4 and 6) using two different AEC modulation Z-DOM and 3D-DOM.

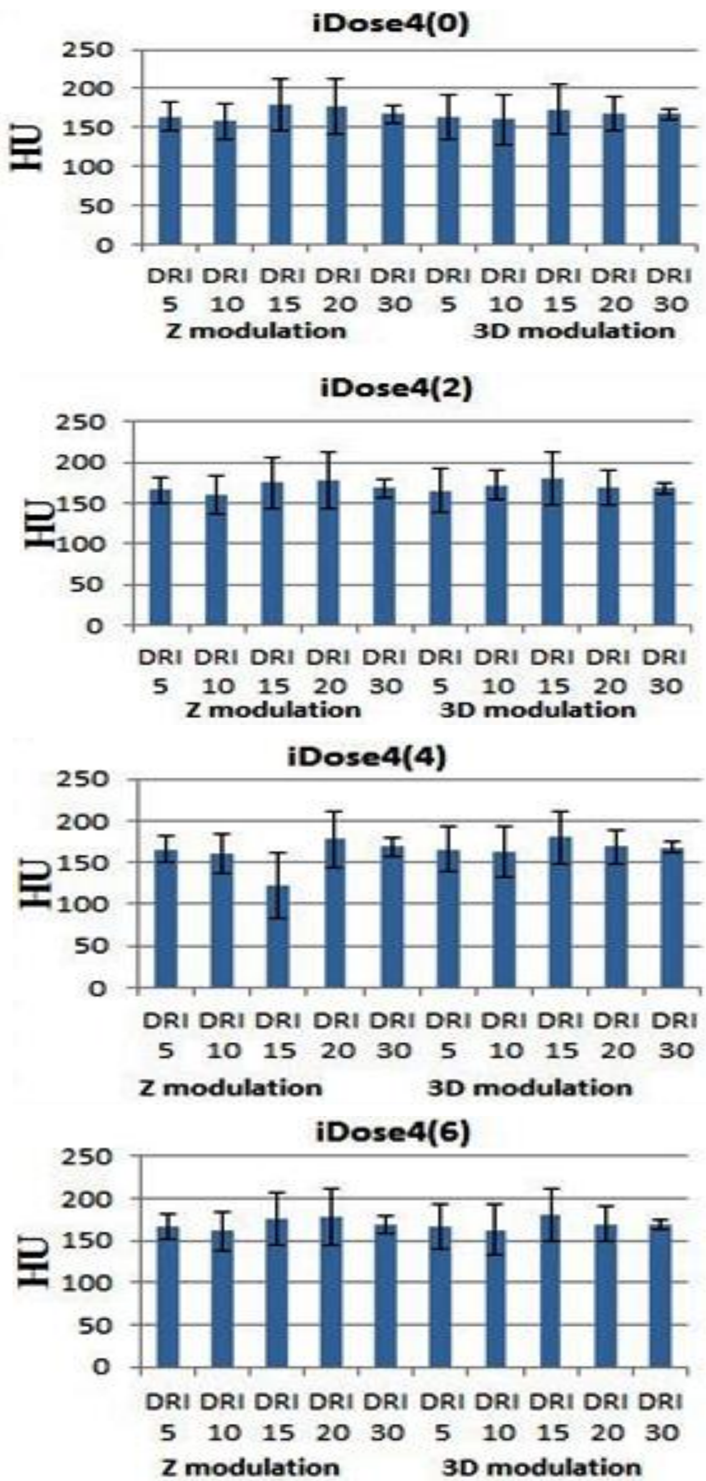

Figure (4): Measured HU in bone with different DRI and iDose4 levels (0,2,4and 6) using two different AEC modulation Z-DOM and 3D-DOM.

(Table 2) values indicate that using Z-DOM decreased the radiation exposure between 15.15 and 63.64% according to the value of DRI used. When using DRI 20 and above, this again has made an increment in the radiation dose exposure. The study results also found that there was no significant reduction in radiation dose exposure when using Z-DOM and 3D-DOM modulation providing that the same tube current was used in both techniques.

Table (2): CTDIVOL, DLP and Effective dose of Z-DOM and 3D-DOM protocols*.

	Z-DOM scan protocols			3D-DOM scan protocols		
	CTDIVOL(mGy)	DLP(mGy.cm)	E(mSv)	CTDIVOL(mGy)	DLP(mGy.cm)	E(mSv)
DRI5	1.2	115.6	1.734	1.3	125.2	1.878
DRI10	1.7	163.7	2.4555	1.8	173.3	2.5995
DRI15	2.8	269.6	4.044	2.9	279.2	4.188
DRI20	4.9	471.8	7.077	5	481.4	7.221
DRI30	14.9	1468	22.02	15.3	1508	22.62
*** DRI=0 CTDI=3.3mGy, DLP=312.6 mGy.cm and the E=4.68mSv**						

The Wilcoxon signed-rank test results showed a non-significant difference in HU values for the liver region. In addition, different regions such as bone, lung and soft tissue significant differences were observed in HU values when using two different ATCM Z-DOM and 3D-DOM.

The CTDIvol, DLP, effective dose values decreased in both of the two different protocols when the AEC system has been used especially in comparison with steady tube current (AEC-off). Dose right index resulted in a significant reduction in CTDIvol, DLP and Effective Dose Values and increased again for DRI 20 and 30 across Z-DOM and 3D-DOM scanning protocol For Z-DOM protocols, the influence of using DRI 5, 10 and 15 led to a decrease in the radiation exposure by 63.64%, 48.48% and 15.15% respectively. But when using DRI 20 and 30, this has made an increment in the radiation dose exposure again. The Wilcoxon signed-rank test results indicated that there was no significant reduction in radiation exposure dose between Z-DOM and 3D-DOM modulation ($p<0.05$).

DISCUSSION:

The recent developments in CT technology and usages over the past few decade have increased the medical applications of CT but with an increasing concern of radiation doses received by patients [16]. While the benefits of CT outweigh detrimental effects of exposure to radiation, the regulatory bodies were serious in reducing radiation dose to routine practice of radiological examinations [7].

This has enabled the development of several radiation reduction techniques that focus on the design of dose-efficient technology and optimization of scanning protocols.

There are several techniques that focused primarily on software as well as hardware optimization technologies that either improve the efficiency of the CT scanner or improve the image quality at low radiation doses [17].

Currently, AEC systems are used for dose optimization in most CT scans. AEC is applied to two techniques: ACS (right dose) and ATCM (Z-DOM & 3D-DOM). ATCM modulate the exposed radiation dose based on attenuation and patient size [18]. Dose right is rely on the use of reference image to control image quality level [19]. The results of the current study were achieved in a center where Z-DOM and 3D-DOM protocols activated. Dose reduction techniques used have included different DRIs (0, 5, 10, 15, 20, and 30) and ATCMs (Z-DOM & 3D-DOMs) and iDose4 for all study protocols adopted. ATCM was observed to lead significant reduction in CTDIvol, DLP and effective dose values across the two scanning protocols (using Z-DOM and 3D-DOM) in agreement with other studies [20,21,22,23 and 24].

This study showed that there was a non-significant change in image noise at soft tissue regions between the two different ATCM techniques (Z-DOM and 3D-DOM) whereas there were significant differences in noise measurements of bone, liver and lung regions. Nevertheless, HU measurements showed that there was a non-significant difference in liver region but showed significant difference at other regions including soft tissue, bone and lung. This may due to Liver is homogenous organ and little interface could be found with less contributions from heterogonous tissues of variable attenuation in comparison to other organs. Typically, the Iterative Reconstruction Algorithm has lower mean attenuation than FBP.

This technology has the potential to increase image quality in scans with minimal tube currents by reconstructing images with reduced image noise compared to the simpler mathematical model used in FBP techniques [25]. On both raw and image data, the hybrid iterative reconstruction algorithm iDose4 decreases noise. Several studies have also shown that CT dose estimates could be decreased by 40-60 %without reducing image quality using ATCM and we could further minimize CT doses to sub-mSV levels when using ATCM with iDose4 [26,10,27].

Our results indicated that iDose4 reconstruction increases the quality of images by decreasing the SD of images in line with literature [28].

However, reconstructed images of Z-DOM protocol and DRI 5 by iDose4 L2 demonstrated SD reduction up to 18.5% for soft tissue, 10.1% for bone, 17.5% for liver and 12.8% for lung. When images were reconstructed with iDose4 L6, this led to reduction in image noise by 39.3%, 20.9%, 72.7% and 40.7% for soft tissue, bone, liver and lung respectively.

To our knowledge, this is the first study using rando phantom to evaluate the effects of different levels of iDose4 on dose reduction in sub-mSv high-dose CT scanning by using ATCM (Z-DOM, ٣D-DOM) for different DRI setting.

We have been able to reduce the effective dose to 1.73 mSv at DRI of 5, and improve the image quality (produce least image noise) at DRI=5 while using iDose4 L6.

According to the presented results, for two protocols (Z-DOM & 3D-DOM), the higher improvement in image quality (reducing image noise) was observed at images reconstructed with iDose4 L6 compared to L2 and L4. SD improvement indicates that using iDose4 level 6 permit radiation dose reductions without compromising diagnostic level of image quality.

The results also demonstrated that various implementations of IR iDose4 levels did not have significant effect on HU measurements.

CONCLUSIONS:

While maintaining a diagnostic level of image quality, combining AEC software with iDose4 levels can effectively reduce the radiation effective dose significantly (up to 60%) in comparison with constant tube current (AEC-off). The results demonstrate also that no significant reduction in radiation dose exposure between using Z-DOM and 3D-DOM modulation.

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