Effect of Iterative Reconstruction Algorithm Associated with Low Contrast Detectability Performance from CT Pulmonary Angiography Examinations

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Abstract. Iterative reconstruction (IR) in Computed Tomography (CT) scan examinations are known for noise reduction to achieve a higher level of diagnostic. This study aims to evaluate the radiation dose and image quality performance in different iterative reconstruction levels on CT Pulmonary Angiography (CTPA) examination and to establish a figure of merit (FOM) between both parameters. Thirty adult patients who underwent CTPA examinations were retrospectively included in the present study. Scanning acquisition protocol and radiation dose information, together with patient habitus information, was collected and recorded. The vessel attenuation was measured in five consecutive areas surrounding the pulmonary artery for each iterative reconstruction image. Results of radiation dose were presented in terms of Computed Tomography Dose Index (CTDI\textsubscript{vol}) obtained from CT-console and SSDE that was calculated by the AAPM report 204 recommendation method. Meanwhile, image quality was estimated by contrast-to-noise ratio (CNR) on average from five consecutive areas of CNR. The mean values of CTDI\textsubscript{vol} and SSDE were 13.79 ± 7.72 mGy and 17.25 ± 8.92 mGy, respectively. The amount of CNR was significantly different within the iterative reconstruction level (p <0.001). There was a significant difference in the figure of merit for both CNR\textsuperscript{2}/SSDE and CNR\textsuperscript{2}/CTDI\textsubscript{vol} attained in different iterative reconstruction levels, (p <0.001) and (p <0.001), respectively. In conclusion, we successfully evaluate the value of radiation dose and image quality performance and establish a figure of merit for both parameters to aid further verification of scanning protocols by radiology staff.
1. Introduction
Computed Tomography Pulmonary Angiography (CTPA) is one of the imaging modalities used to rule out pulmonary embolism (PE). It has been a gold standard for detecting PE due to its high sensitivity and specificity. However, in 2001, the International Commission on Radiological Protection (ICRP) said that the use of CT was increasing, and there was a possibility that the radiation dose from CT examinations was high compared to other imaging modalities [1]. CTPA has become a preferred diagnostic imaging method for suspected PE due to its availability and its potential to assess mediastinal and parenchymal structures with sensitivities and specificities of more than 90% [2]. The issue of radiation dose draws full attention since it is reported that exposure to ionizing radiation during diagnostic imaging has a significant impact on the cancer risk, and most of the collective patient dose is under the CT examination’s responsibility [3].

Iterative reconstruction techniques can be applied to the reduced-dose CT examination to generate images with lower noise and high image quality by iterating the image reconstruction several times. The different CT scanners with various iterative reconstruction techniques have shown the potential in lowering the radiation dose and image noise, thus producing images with higher resolution by maintaining the edges and lower artefacts [4]. High quality of CT images is needed to get maximum diagnostic information for clinical interpretation while retaining the radiation dose as low as possible [5].

An accurate representation of the attenuation values of the x-ray beam by the body tissue, as displayed on the CT images, can determine the image quality. The precise reproduction of fine detail and small differences in attenuation in the image also can define the CT image quality [6]. The main parameters that can characterize the quality of the digital images are low contrast detectability (LCD), noise, contrast-to-noise ratio (CNR), and spatial resolution [7]. Low contrast detectability (LCD) is the ability to differentiate between materials with similar attenuation properties [8]. This study aims to evaluate the radiation doses and image quality performance of various iterative reconstruction levels of CT Pulmonary Angiography (CTPA) examination.

2. Methodology
2.1. Study Design and CTPA Acquisition Protocol
The records of 30 adults who were being clinically indicated for CTPA examination for suspected pulmonary embolism were retrieved between February 2019 until May 2019. A 128 MDCT (Philips Brilliance) scanner located at Hospital Kuala Lumpur, Malaysia, was used in the present study. The patients’ size was measured by effective body diameter using digital calipers in the CT-system at the mid-slice of the 3D CT images, which is shown in Figure 1 as the anteroposterior (AP) and lateral (LAT) body lengths.

![Figure 1. Patients’ effective diameter measurement at the mid-slice of the 3D CT images.](image-url)
Figure 2. (a) The distribution of radiation dose (SSDE and CTDI$_{vol}$), (b) FOM with a fraction of CTDI$_{vol}$, (c) FOM with a fraction of SSDE, and (d) comparison between the two FOM approaches in CTPA examination.

Table 1. A comparison of CTDI$_{vol}$ and SSDE value with different patients’ effective diameter.

| Effective diameter (cm) | CTDI$_{vol}$ (mGy)* | SSDE (mGy)* | p-value  |
|------------------------|---------------------|-------------|----------|
| 20–24 (Group 1)        | 9.39 (8.76)         | 12.31 (10.7)| < 0.001  |
| 25–28 (Group 2)        | 12.74 (7.35)        | 16.24 (9.12)| < 0.001  |
| 28–38 (Group 3)        | 17.60 (7.49)        | 26.30 (10.7)| < 0.001  |

*mean (SD)
Table 2. A comparison of CNR value obtained from different iterative reconstruction levels.

| Variable          | iDose⁴ | p-value |
|-------------------|--------|---------|
| CNR* (HU)         |        |         |
| Level 1           | 100.50 |         |
| Level 2           | 108.88 | <0.001  |
| Level 3           | 119.77 |         |
| Level 4           | 131.93 |         |
| Level 5           | 149.04 |         |
| Level 6           | 172.40 |         |

*mean value of five consecutive areas (pulmonary trunk, right pulmonary artery, left pulmonary artery, ascending aorta and descending aorta)

Table 3. A comparison of FOM values obtained from different patient’s effective diameter.

| Variable          | Effective diameter (cm) | iDose⁴ | p-value |
|-------------------|-------------------------|--------|---------|
| FOM               | 20–24 (Group 1)         | 2171.37| 7322.01 |<0.001  |
|                   | 25–28 (Group 2)         | 1570.32| 5035.68 |<0.001  |
|                   | 28–38 (Group 3)         | 1016.34| 2502.31 |<0.001  |
| CNR²/C TDIvol      | 20–24 (Group 1)         | 1599.32| 5403.38 |<0.001  |
|                   | 25–28 (Group 2)         | 1124.16| 3567.11 |<0.001  |
|                   | 28–38 (Group 3)         | 751.38 | 1846.18 |<0.001  |
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2.2. Radiation dose
CTDIvol, AP, and LAT lengths, recorded as provided by the CT system, were used to calculate SSDE based on the AAPM report 204. The patient size was determined by the equation below:

\[
\text{Effective Diameter (cm)} = \sqrt{AP \times LAT}
\]  (1)

The effective diameters (patient size) were converted to body size-dependent conversion factor (f-size) tabulated in the AAPM report 204. Then, SSDE was calculated by multiplying the f-size with the CTDIvol displayed on the scanner system.

2.3. Image Quality Assessments
Circular regions of interest (ROIs) were placed at the following five areas: the pulmonary trunk, right pulmonary artery, left pulmonary artery, ascending aorta, and descending aorta in axial sections to
measure the attenuation and standard deviation (SD) in Hounsfield units (HU). The SD of the left pectoralis major muscle was recorded as a background. The contrast-to-noise ratio (CNR) of each artery was calculated by using the following formula:

\[
\text{CNR} = \frac{2(HU_{\text{artery}} - HU_{\text{muscle}})}{SD_{\text{artery}} + SD_{\text{muscle}}}
\]  

(2)

The mean CNR was calculated by averaging the CNR value of all arteries. The initial ROI was placed on the image reconstructed with iDose\(^4\) level 1 and was then copied and pasted onto the corresponding data sets of iDose\(^4\) for level 2 until level 6 to ensure measurement accuracy. If PE was present, ROI circles were meticulously drawn without incorporating the embolic material.

2.4. Statistical Analysis

All data were analyzed using SPSS V17.0 (SPSS, version 17.0 for Windows, Chicago, Illinois, USA) for statistical analysis. A p-value of <0.05 indicated statistically significant differences. One-way ANOVA test and Kruskal-Wallis test were both used for analyzing CTDI\(_{\text{vol}}\), SSDE, CNR and FOM, respectively, and tabulated in the tables and boxplots.

3. Result

The mean CTDI\(_{\text{vol}}\) and SSDE are significantly different between the three groups of patients’ effective diameter. SSDE was found up to 30% higher compared to CTDI\(_{\text{vol}}\), especially in the smaller patient’s effective diameter. The comparison of CNR, FOM (CNR\(^2\)/CTDI\(_{\text{vol}}\)) and FOM (CNR\(^2\)/SSDE) of iterative reconstructions level was presented in Tables 2, 3 and Figure 1. There was a significant difference observed in the CNR, FOM (CNR\(^2\)/CTDI\(_{\text{vol}}\)) and FOM (CNR\(^2\)/SSDE) for all levels of iterative reconstructions (p <0.001). For CNR iDose\(^4\) level 1 showed the lowest value of CNR while iDose\(^4\) level 6 showed the highest value. As for both FOM, there was a high significant difference between iterative reconstructions level (iDose\(^4\)), and the value decreased with higher patient’s effective diameter. Meanwhile, FOM (CNR\(^2\)/SSDE) showed more top compared to FOM (CNR\(^2\)/CTDI\(_{\text{vol}}\)).

4. Discussion and Conclusions

The variation of SSDE and CTDI\(_{\text{vol}}\) was expected since the CTDI\(_{\text{vol}}\) used a 32-cm body phantom as the values of coefficients in dose exposure estimation. Unlike CTDI\(_{\text{vol}}\), SSDE value is patient-size dependent, as mentioned in the AAPM report 204. Some research found that when the automated exposure control (AEC) system was activated, both CTDI\(_{\text{vol}}\) and SSDE values were reported higher in bigger-sized patients compared to those who were standard-sized [2,7,9].

Our results showed there is a higher CNR value with increasing the IR level because iDose\(^4\) allows the adjustment of noise in the increasing iDose level [10]. The noisy data are penalized while edges are preserved through this technique, which will retain the attenuation gradients of underlying structures and maintain the spatial resolution. This technique brings an advantage in the CTPA examination since a better image quality has been reported with a higher level of iDose for imaging the vascular structures than for pulmonary vasculature [11].

There were some limitations to this study. The present study involved a small retrospective patient cohort and sole reliance on objective image quality. Further work should seek to compare subjective image quality by experienced radiologists to ensure in line relationship between the objective and the subject measurement. Moreover, it was performed on a single manufacturer’s scanner, so it may not be generalizable to other scanner types that are configured differently on the scanner parameter and IR algorithm. Patients were assigned to the high (120 kVp) or low tube voltage (100 kVp) with some degree of radiographer discretion rather than strict prospective weight or size measurements, leading
to potential selection bias. It can decrease the CNR value by lowering the tube voltage for higher patient’s effective diameter with high attenuation factor or vice versa. Lastly, some intervention study needs to be done by reducing the radiation exposure to identify the acceptable level of image quality performance based on the CNR approach.

As a conclusion, there was a significant difference between CTDI<sub>vol</sub> and SSDE value for all patient’s effective diameter groups. Significant differences were observed in the CNR, FOM (CNR<sup>2</sup>/CTDI<sub>vol</sub>) and FOM (CNR<sup>2</sup>/SSDE) for all levels of iterative reconstructions. As expected, the increase in image noise reduction was attained in the higher level of iterative reconstruction.

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