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Impact of radiation dose and iterative reconstruction (IR) level on low-contrast detectability with 4-AFC approach

Indah R. Ilham, Choirul Anam*, Heri Sutanto, Ariij Naufal, Riska Amilia
Department of Physics, Faculty of Sciences and Mathematics, Diponegoro University, Indonesia

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ABSTRACT

This study evaluated impacts of dose and iterative reconstruction (IR) level on low-contrast detectability in images of AAPM CT Performance phantom using a 4-alternative forced choice (4-AFC) approach. Five medical physicists detected low-contrast and small objects having size of 3.0 mm with the 4-AFC method. The tests were conducted at three different radiation doses (35.8 mGy, 54.1 mGy, and 72.1 mGy) at various IR levels from 0% to 100%. The total number of 4-AFC questions was 330 questions in which each observer answered the questions in 60 minutes. Percent correct answers increase as the IR level increases from 0 to 100%. The percent correct answers also increase as the dose increases from 34.8 mGy to 72.1 mGy. 100% correct answers start at IR levels of 70, 60, and 40% for doses of 34.8, 54.1, and 72.1 mGy, respectively. Conclusions: Increasing IR level and dose improve image quality, i.e., higher average percent correct answers. At IR levels around 50%, the average percent correct is close to the maximum (around 100%) for all radiation doses. An optimal combination of IR and radiation dose can produce good image quality with lower radiation dose.

Keywords: Iterative reconstruction, radiation dose, low-contrast detectability, 4-AFC, image quality

I. INTRODUCTION

Computed tomography (CT) is a modern medical imaging modality that is mostly used for diagnosis of various diseases [1]. One of the main challenges in CT imaging is detection of low-contrast objects having very small size [2]. This case is often appeared in the clinical facts [3, 4]. Low-contrast objects are usually more visible if image noise is very low [5], but this low noise is always accompanied with a higher dose received by the patient [6, 7]. Therefore, dose optimization is very important [8]. In addition, breakthrough efforts to improve low-contrast detectability from existing CT imaging systems are very much appreciated. This dose optimization and technological development (either in software or hardware) need an accurate and objective quantification of low-contrast detectability. Currently, quantification of low-contrast objects is mostly carried out by human observers on low-contrast phantoms with various small sizes. This method is very useful, but it has weaknesses, because the observers can be influenced by the low-contrast pattern of objects arranged in a certain pattern [9]. Nowadays, several low-contrast phantoms are designed with random patterns, so that the observer is not biased by the pattern. However, this type of phantom is still very limited in CT centers.

One method that can be used to minimize an influence of low-contrast pattern on the human observers is by alternative forced choice (AFC) approach. In this case, the human observer is asked to choose several images, but only one of them contains a low-contrast object (the other images do not contain low-contrast object, but only contain a background). The number option (n) in AFC can be 2, 4, 9, or more. However, if number option (n) gets bigger, then it will become more complex and time consuming. The most widely used n-AFC is 2-AFC or 4-AFC [5].

Currently, one effort to improve low-contrast detectability in the software aspect is by an alternative image reconstruction, i.e., the iterative reconstruction (IR) method [6, 10]. Each CT vendor has its own approach to this IR concept, and there is no universal method to evaluate the IR method [9]. Several vendors also provide IR strength level options, from 0% (still filtered back projection (FBP)) to as high as 100%. Typically, many vendors set IR at a level of around 50%. However, very few studies have been carried out to evaluate setting IR strength levels [11-13], especially if they are related to various radiation doses.

Detection of low-contrast in CT images using the n-AFC method has been performed by Yu et. al. [14]. The study used a torso-shaped phantom with a contrast of 15 HU which had objects with diameters of 3, 5, and 9 mm [14]. However, that study was only using 2-AFC and the contrast was still fairly high. Therefore, low-contrast evaluation at lower contrast on more accessible phantoms (e.g. AAPM CT performance phantom) using higher n-AFC is necessary. The current study evaluated low-contrast detectability on the AAPM CT performance phantom image (having a contrast of 10 HU) using the 4-AFC method.

II. METHODS AND MATERIAL

A. AAPM CT Performance Phantom

Figure 1 shows an example image of module 610-06 of the AAPM CT performance phantom used in this study. The module is made of epoxy material with a CT number of ~10 HU with a diameter of 20.3 cm and a height of 3 cm. The module also has eleven holes with different diameter sizes of 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, and 7.5 mm. Each diameter size consists of 4 to 5 objects [15]. In this study, we only focused on the object size of 3.0 mm. The phantom was filled with water. Hence, the contrast was around 10 HU.

The module was scanned with GE brand with Revolution Evo 128 Slice CT scanner. The input scanning parameters were 120 kV tube voltage, revolution time of 1 s, 5 mm slice thickness, 298 mm field of view, and with axial mode. The module was scanned with three tube currents of 200, 300, and 400 mA corresponding to the volumetric computed tomography dose indices (CTDIvol) of 35.8, 54.1, and 72.1 mGy. Images were reconstructed by Adaptive Statistical Iterative Reconstruction (ASIR) (one of the IR approaches) software with strength level from 0% (FBP) up to 100%.

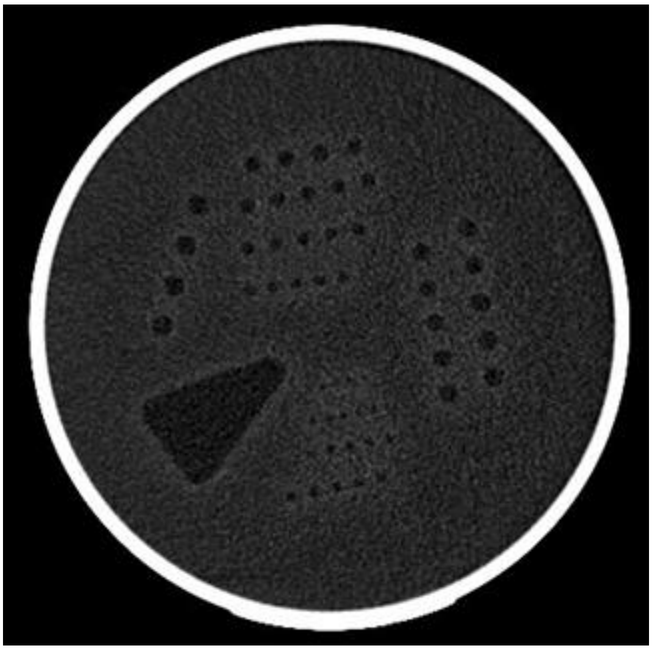

Figure 1. Example image of module 610-06 of AAPM CT performance phantom.

B. 4-AFC Method

The 4-AFC was carried out using IndoQCT software. There were two steps for this test. The first step was development of 4-AFC questions (Figure 2). Object size was set 3 mm. Region of interest (ROI) number was set 4, indicating that it is 4-AFC. ROI size was set 21 pixels. IndoQCT automatically finds out one object with size of 3 mm and locates an ROI covering the object, and randomly locates three ROIs in the homogeneous regions as the background. Each variation contains 10 question. So, all questions are 330 (3 (doses) × 11 (IR level) × 10 questions). Example of the 4-AFC questions can be seen in the Figure 3.

The second was the step of answering the available questions. This was performed by five medical physicists in same conditions. It was conducted in a dark room on an AMD Ryzen 7 7000U processor laptop, 14-inch screen size, FHD (1920 × 1080) resolution, and 300 nits brightness. Each observer was given 60 minutes to answer all 4-AFC questions. After all observers have answered the questions, the correct answers were averaged from five observers.

III.RESULTS AND DISCUSSION

Figure 4 shows the percent correct answers against the variation of IR levels for three different radiation doses: 34.8 mGy, (b) 54.1 mGy, (c) 72.1 mGy. It can be seen that the percent correct answers increase as the IR level increases from 0% to 100%. The percent correct answers also increase as the dose increases from 34.8 mGy to 72.1 mGy. 100% correct answers starting at IR levels of 70, 60, and 40% for doses of 34.8, 54.1, and 72.1 mGy, respectively.

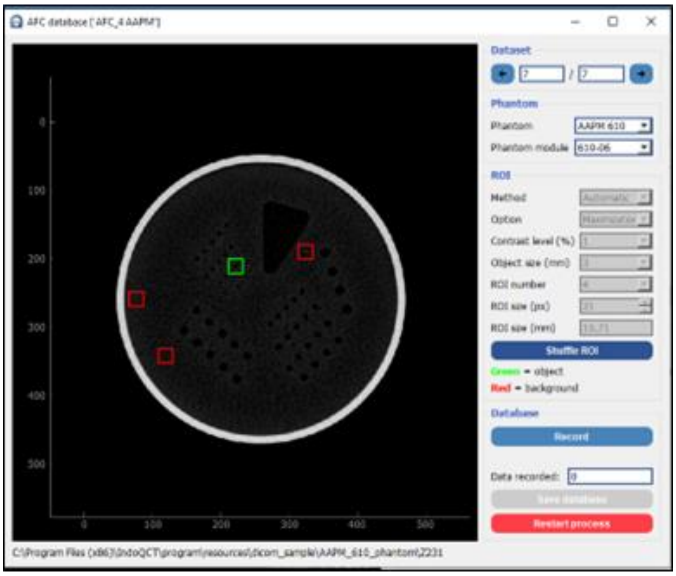

Figure 2. Development of 4-AFC questions using the IndoQCT software.

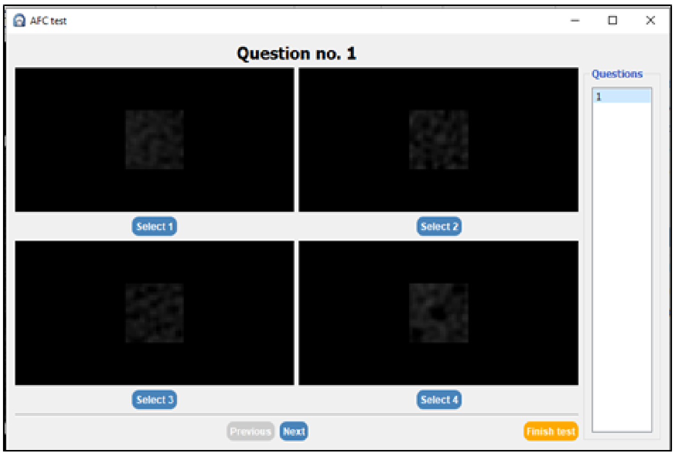

Figure 3. Example of 4-AFC questions displayed on IndoQCT software. There are four options (four cropped images). Only one image contains the low-contrast object with size of 3 mm, while the three other images contain background.

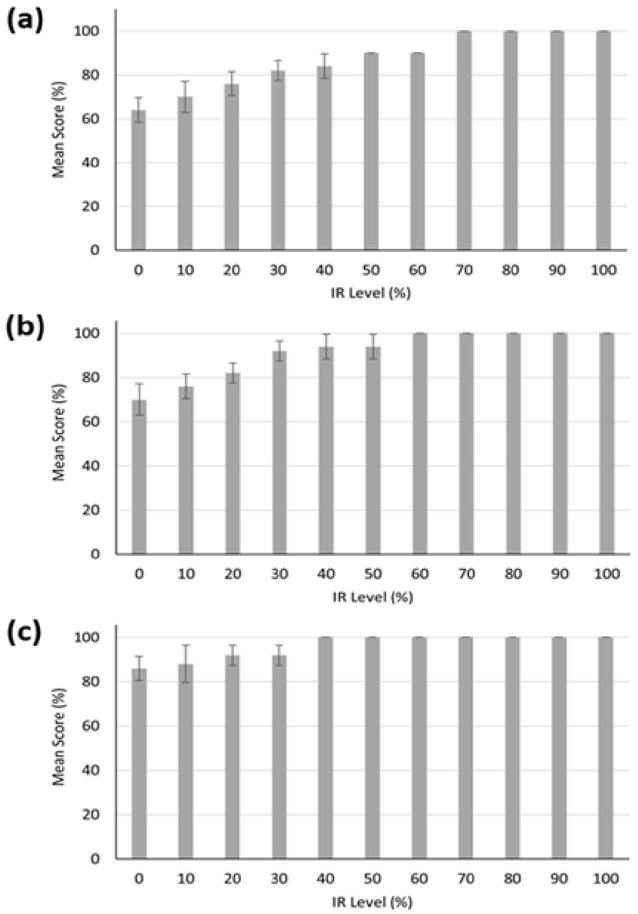

Figure 4. Graphs of the mean score of percent correct answers for the variation of IR levels for three different radiation doses: (a) 34.8 mGy, (b) 54.1 mGy, and (c) 72.1 mGy.

This study evaluated impacts of radiation dose and iterative reconstruction (IR) level on low-contrast detectability in the 10 HU contrast objects of the AAPM CT performance phantom images. The assessment utilized the 4-AFC approach, which enables objective evaluation by the medical physicists to select one of four options that they believe to be the most correct. The results showed that increased dose and increased IR level contributed positively to an increase in the percent correct answers. This means that low-contrast detection became more visible if the dose and IR level increase.

These findings are in line with the previous studies [16, 17]. These trends are correlated to the image noise level. The increase of radiation dose is due to the increase of tube current. The tube current correlates well with the number of photon of X-ray beams. If number of photon reaching the detector increases, then the image noise level decreases. If the image noise level decreases, the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) increase [18]. It means that the low-contrast detectability will increase [12, 19]. These phenomena were confirmed in this study.

In addition, at higher IR levels, reconstruction algorithms are also able to reduce more noise that affects low-contrast detectability [20, 21]. These results indicate that the IR level on the CT system is working as expected. IR itself has various approaches. Some use a statistical approach and others use a model-based approach [22-25]. Meanwhile, the details of each vendor's algorithm are proprietary by the vendor. Thus, it is necessary to carry out evaluation on IR strength at every CT center.

The results of this study are interesting, i.e., 100% correct answers occur when the IR level is around 40-60% (depending on the dose used) [26, 27]. This is relevant to most settings carried out by many vendors, i.e., setting the IR level to around 50%. However, this study was only carried out on low-contrast objects with a size of 3 mm and a contrast of 10 HU. Studies on object sizes other than 3 mm and a contrast of 10 HU may produce different results.

It is noted that if IR levels are too high, then the careful consideration should be paid as they can reduce noise excessively [28]. Too much reduction can cause the image to be over-smoothed and plastic-looking image [3]. In addition, this may minimize fine details in anatomical structures [20, 29]. This makes the boundaries of objects are less clear [30].

Although the 4-AFC approach is more accurate compared to traditional direct assessment on the images of low-contrast objects, however this approach remains subjective. A more objective approach is quantity of d-prime (d') which can be obtained by combining modulation-transfer function (MTF) and noise-power spectrum (NPS). Further studies are needed to correlate between n-AFC reading results and d-prime.

IV. CONCLUSION

It can be concluded that increasing IR level improves image quality, i.e., higher average percent correct answers. In addition, higher radiation dose also increases the average percent correct answers. At IR levels around 50%, the average score is close to the maximum (around 100%) for all radiation doses. An optimal combination of IR and radiation dose can produce good image quality with lower radiation dose.

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