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Effects of Tube Voltage and Phantom Diameter on Noise Inhomogeneity of CT Image

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Abstract:- To investigate the effects of tube voltage and phantom diameter on noise inhomogeneity of computed tomography (CT) image. This study used a step-wedge water cylindrical phantom with four diameters (i.e., 8, 16, 24, and 32 cm). The phantom was scanned with GE 128-Slice CT scanner with tube voltage variation of 80, 100, 120, and 140 kV. Noise inhomogeneity was measured using IndoQCT software. The noise inhomogeneity measurement was started with creating noise maps on the image with kernel size of 11 pixels. After that, multiple region of interests (ROIs) with size of 15 pixels were placed at 85% of image area. The noise inhomogeneity was determined as difference between the highest and the lowest noises from each ROI. : It was found that the highest noise inhomogeneity is at phantom diameter of 32 cm and tube voltage of 80 kV (14.00 ± 0.93 HU), and the lowest noise inhomogeneity is at phantom diameter of 8 cm and tube voltage of 140 kV (0.40 ± 0.02 HU). The trends of the tube voltage and phantom diameter on noise inhomogeneity were similar to the trends of the noise level, i.e., noise inhomogeneity increases with increasing phantom diameter and with decreasing tube voltage. Effects of variations of tube voltage and phantom diameter on the noise inhomogeneity has been investigated. Trends of the noise inhomogeneity due to tube voltage and phantom diameter are the same as trends of the noise level.

***Keywords:-** Inhomogeneity Noise, Step Wedge Water Cylindrical Phantom, CT-Scan.*

I. INTRODUCTION

Computed tomography (CT) is a sophisticated medical imaging modality. CT uses X-ray technology to create detailed images of patient [1,2]. One of the main image quality parameters of CT image is image noise [3,4]. Noise is random fluctuation in pixel values of CT images (5), due to imperfections in the process of image acquisition, image reconstruction, and image handling (6). Image noise due to image acquisition is influenced by several factors, including tube voltage and size of the scanned object [7,8,9]. It was reported that the image noise increases when the tube voltage decreases or the object size increases [10,11].

Apart from the image noise, noise uniformity is also an important parameter the determines quality of CT image [8]. Noise uniformity is usually measured using five regions of interests (ROIs) placed in the center and at the peripheral area of the image. However, noise uniformity measurements using five ROIs are sometimes unable to completely detect image noise fluctuations across the field of view (FOV). This leads to the introduction of a new parameter called the noise inhomogeneity.

Noise inhomogeneity is obtained by creating a noise maps across the image [12]. Multiple ROIs are created on the noise maps across the FOV. Mean noise values from each ROI are calculated. Noise inhomogeneity is obtained as the difference between the highest and lowest average noise from each ROI. Li et al [13] suggested the multiple ROIs are created in an area of 85% of the image. It is reported that noise inhomogeneity is more sensitive to fluctuation in noise across the image compared to noise uniformity [13]. However, up to now, noise inhomogeneity evaluation is only carried out on images with a fixed tube voltage and phantom size. To our knowledge, there is no study evaluating the influence of tube voltage and phantom size on the noise inhomogeneity. Therefore, this study aims to evaluate the effects of tube voltage and phantom size on noise inhomogeneity of CT images.

II. METHODS

- *Scanning of the Step-Wedge Water Cylindrical Phantom*

This study used the step-wedge water cylindrical phantom having four diameters (i.e., 8, 16, 24, and 32 cm). The case of phantom is an acrylic material. The phantom was filled with the distilled water. The phantom was scanned using a 128-slice GE CT scanner installed at Indriati Solo Baru Hospital, Surakarta, Indonesia. The parameters of the scanning are shown in Table 1. The tube voltage was varied (i.e., 80, 100, 120 and 140 kV). The images were saved in the digital imaging and communications in medicine (DICOM) format. Examples of the axial phantom images for each diameter are shown in Figure 1.

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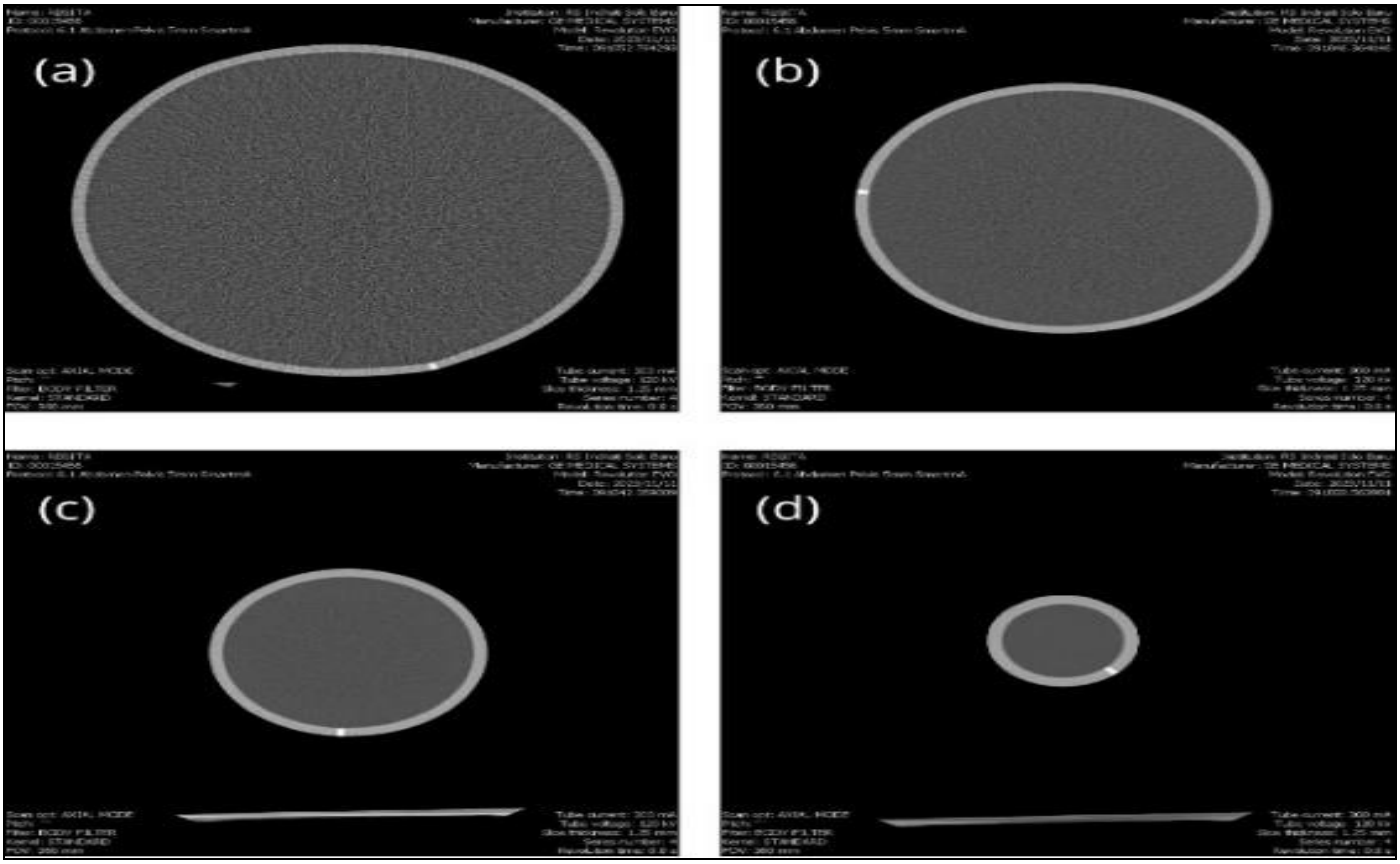

Fig 1 Examples of the Step-Wedge Water Cylindrical Phantom Images for Four Diameters: (a) 32 cm, (b) 24 cm, (c) 16 cm, and (d) 8 cm

Table 1 Scan Parameters

Scan Parameter	Input
Scan mode	Axial
Tube voltage (kV)	80, 100, 120, and 140
Rotation time (s)	1
Tube current (mA)	120
Slice thickness (mm)	5
Field of view (FOV) (cm)	36
Reconstruction	Filtered back projection (FBP)
Type of filer	Abdomen

➢ *Inhomogeneity Measurement*

In this study, noise inhomogeneity for each phantom diameter was measured. Noise inhomogeneity measurement was performed using IndoQCT software. Steps for measuring noise inhomogeneity consisted of five stages: segmentation, center point determination, standard deviation map development, multiple ROIs creation, and noise inhomogeneity calculation. Segmentation was performed on the image with a threshold value of -100 HU to produce a binary image. Standard deviation map was calculated using the equation (1) using a sliding window with a kernel size of 11 pixels. The center point within the image was determined using the centroid formula. Based on the center point, the multiple ROIs (with size of 15 pixels) were created across the 85% of the area of the image. Noise average was calculated in every ROI. Noise inhomogeneity (σ_h) was calculated as the difference between the largest and the smallest average noises (Equation (2)).

$$\sigma = \sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}} \quad (1)$$

$$\sigma_h = |(\overline{\sigma_{maks}} - \overline{\sigma_{min}})| \quad (2)$$

III. RESULT AND DISCUSSION

The standard deviation color maps for noise inhomogeneity measurements at tube voltage of 100 kV for diameters of 8, 16, 24, and 32 cm are shown in Figure 2. Visually, it appears that if the diameter becomes larger, the noise in the center of the image also becomes larger. Meanwhile standard deviations maps with multiple ROIs at a diameter of 16 cm for voltage variation are shown in Figure 3. Visually, there is no clear difference between the four images.

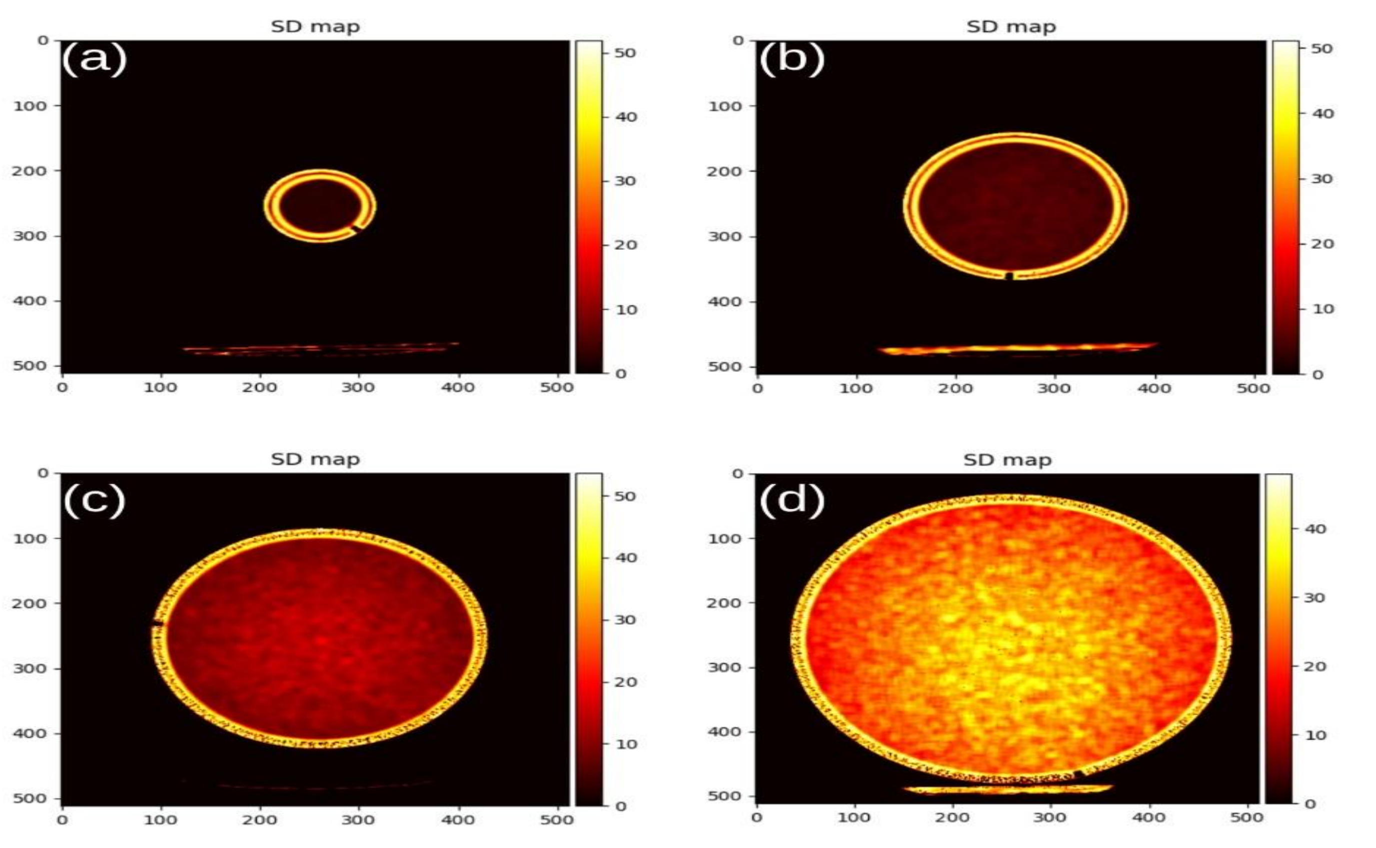

Fig 2 The Standard Deviation Calor Maps for Noise Inhomogeneity Measurements for Various Diameters: (a) 8 cm, (b) 16 cm, (c) 24 cm, and (d) 32 cm

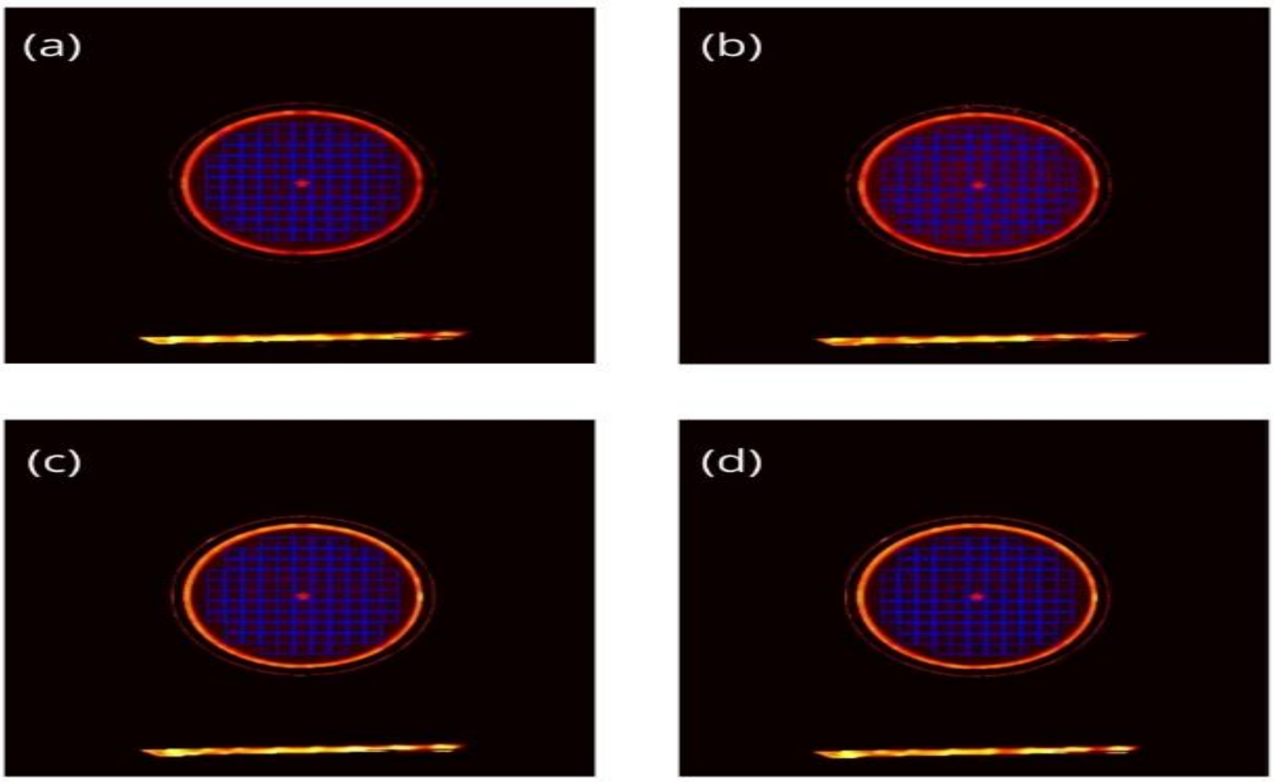

Fig 3 The Standard Deviation Maps with Multiple ROIs for Noise Inhomogeneity Measurements for Various Tube Voltages: (a) 80 kV, (b) 100 kV, (c) 120 kV, and (d) 140 kV

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The noise inhomogeneity values for variations in tube voltage and phantom diameter are shown in Figure 4. It is clear that the noise inhomogeneity increases with decreasing tube voltage and increasing phantom diameter. At the smallest tube voltage (80 kV) and the largest diameter (32 cm), the largest noise homogeneity was obtained, i.e., 0.91 ± 0.14 HU. At the largest tube voltage (140 kV) and the smallest phantom diameter (8 cm), the smallest noise homogeneity was obtained, i.e., 0.40 ± 0.02 HU

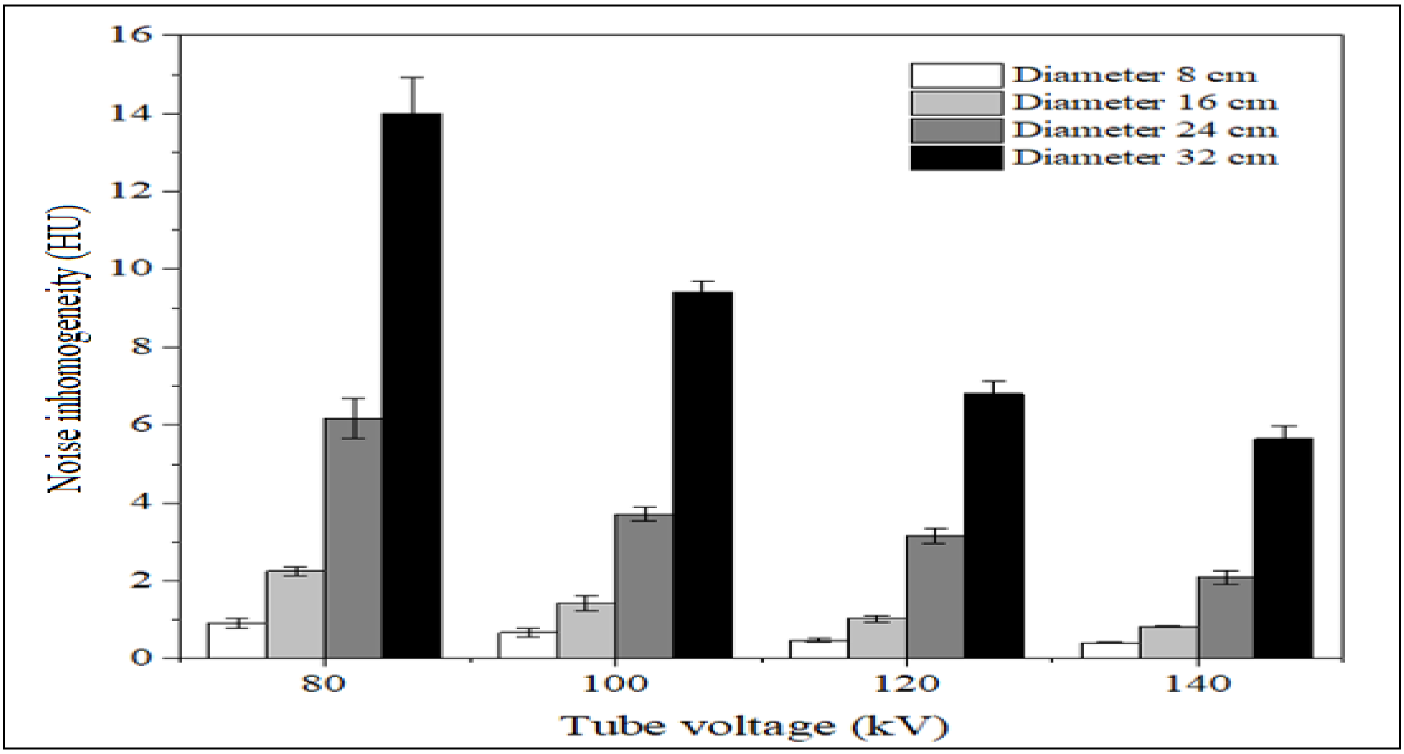

Fig 4 Noise Inhomogeneity Values for Variations of Tube Voltage and Phantom Diameter

From these results, it is found that the noise inhomogeneity pattern is similar to the image level noise pattern as reported by several previous studies [9,10]. The pattern is that the noise level increases with decreasing tube voltage and increasing phantom diameter. It is known that if the tube voltage decreases, then the number of X-ray photons decreases (in addition to the average X-ray energy). This decreasing number of X-rays leads to an increase in image noise. This is called as the quantum noise. On the other hand, if the phantom diameter increases, then the X-rays that can penetrate the phantom decrease. As a result, the X-rays captured by the detector decrease. This decrease in the number of X-rays arriving at the detector results in an increase of noise.

This study has several limitations: First, the investigation was only carried out on one type of CT machine and was only carried out on one type of image reconstruction (FBP) with only one type of the filter. However, the pattern of increasing noise inhomogeneity is predicted to be the same for other CT machines and also for other types of reconstruction such as iterative reconstruction (IR) or other types of filters. However, it should be noted that this pattern is only obtained when the CT machine does not implement the tube current modulation (TCM) technique. The CT number inhomogeneity pattern in the TCM technique will be very complex depending on the TCM level and the TCM algorithm used. Thus, noise inhomogeneity testing on CT machine with TCM needs to be carried out in future research.

IV. CONCLUSIONS

The noise inhomogeneity decreases as the tube voltage increases or the phantom size decreases. The smallest noise inhomogeneity value is found at 140 kV tube voltage and 8 cm diameter, which is 0.40 ± 0.02 HU. At the same time, the largest noise inhomogeneity is found at a tube voltage of 80 kV at a diameter of 32 cm, which is 14.00 ± 0.93 HU.

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