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The Impact Of Noise On The Results Of Automated Slice Sensitivity Profile Measurements In Computed Tomography

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Abstract

Purpose: This study was aimed to investigate the impact of noise on full-width at half maximum (FWHM) of slice sensitivity profile (SSP) of computed tomography (CT) images which was automatically calculated using Matlab-based software on the AAPM CT performance phantom. Methods: The slice thickness part of AAPM CT performance phantom was scanned by the 128 slice GE Healthcare CT scanner with four different tube currents of 50 mA, 100 mA, 150 mA and 200 mA. The noise calculation was carried out on the homogeneous region of the phantom which contains water. The noise was calculated as the standard deviation (SD) within the region of interest (ROI). The automated measurement of FWHM of SSP was carried out on the middle stair object of the image. Results: The noises were 7.67, 5.95, 4.98, and 4.00 HU for tube currents of 50, 100, 150, and 200 mA, respectively. The FWHMs of SSPs were 5.5 ± 0.1, 5.3 ± 0.3, 5.4 ± 0,0, and 5.2 ± 0.1 mm for noises of 7.67, 5.95, 4.98, and 4.00 HU, respectively. The result of automated FWHM of image with noise of 7.67 HU was 5.5 mm and the difference from the nominal slice thickness was 10%. The FWHM of image with noise of 4.00 HU was 5.2 mm and the difference from set slice thickness was 4%. The automated FWHM results tended to be similar to the nominal slice thickness for lower noise. Conclusions: The automated FWHM results tends to be similar to the nominal slice thickness for lower noise. Although the noise of 7.67 HU still produces an accurate FWHM of SSP, the results suggested to use low noise for measuring FWHM and SSP.

Keywords – Noise, SNR, automated SSP measurement, AAPM CT performance phantom, CT scanner.

I. INTRODUCTION

The multi-slice CT (MSCT) utilizes many row detectors in *z*-axis to produce multiple slices in one rotation of X-rays tube [1]. MSCT implements a sophisticated computer to perform reconstruction of sinogram data to produce axial images depicting a map of linear attenuation coefficient of the tissues within patient's body [2]. Due to the complexity of modern CT scanner and its high workload in the clinical environments, a routine quality control (QC) must be regularly carried out [3]. In QC program, evaluation of image quality is important to ensure that the image quality is appropriate and readable so that it can be used by radiologists to provide a precise and accurate diagnosis [4].

There are several parameters to evaluate the quality of the images, including spatial resolution [5] and noise [6,7]. There are two types of spatial resolutions in CT image, i.e. in-plane resolution (in *xy*-axis) and cross-plane resolution (*z*-axis). In-plane resolution is described using the point spread function (PSF) and corresponding modulation transfer function (MTF), while cross-plane resolution is described using the slice sensitivity profile (SSP). Noise is an important image quality parameter produced from fluctuation of the pixel values within image [8]. Interestingly, image qualities may be affecting each other, such as noise affecting cross-plane resolution. Measuring noise in images is generally carried out by measuring the standard deviation (SD) within homogeneous area of region of interest (ROI). Comprehensively, noise is described by a noise power spectrum (NPS). The NPS is calculated by Fourier transformation of the image pixel within homogenous ROI. Noise of the image changes with the changes of the input exposure factors, such as tube voltage, tube current, and pitch [9, 10]. In clinical setting, the image produced should contain low noise within the acceptable standard limits [11]. The allowable noise tolerance limit is ≤ 2 HU according to the regulation of Indonesian Nuclear Energy Regulatory Agency (BAPETEN) No. 2, 2018 [12]. A parameter describing both noise and the mean pixel value within ROI is generally expressed in terms of a signal-to-noise ratio (SNR).

The SSP measurement of the image is commonly related to the determination of appropriate ROI and its pixel profile to define the FWHM of the image [13]. Previous studies have measured SSP using various input parameters [14, 15]. An automated measurement of SSP using MATLAB-based software has been shown to provide more objective and accurate results compared to manual measurement [16]. However, the automated SSP measurement may be affected by noise in the image. The pixel fluctuation (noise) will have a high effect on the pixel profile [17] of the stair objects within the phantom. There is currently no study that has discussed the relationship between noise and SSP using automated measurement methods. Therefore, the aim of the current study is to investigate the impact of noise on FWHM of SSP of CT images which was automatically calculated using the Matlab-based software. The noise and SSP are measured on AAPM CT performance phantom.

II. Methods

This research was conducted at the Radiography Installation at Indriati Hospital, Solo, Indonesia. The AAPM CT performance phantom with a slice thickness part made of aluminum plate was scanned by the 128 slice GE Healthcare CT scanner. The phantom was scanned with four different tube currents of 50 mA, 100 mA, 150 mA and 200 mA. The acquisition parameters were shown in Table 1. The images of aluminum plates produced were used to automatically determine the SSP. The images were saved and processed in DICOM format.

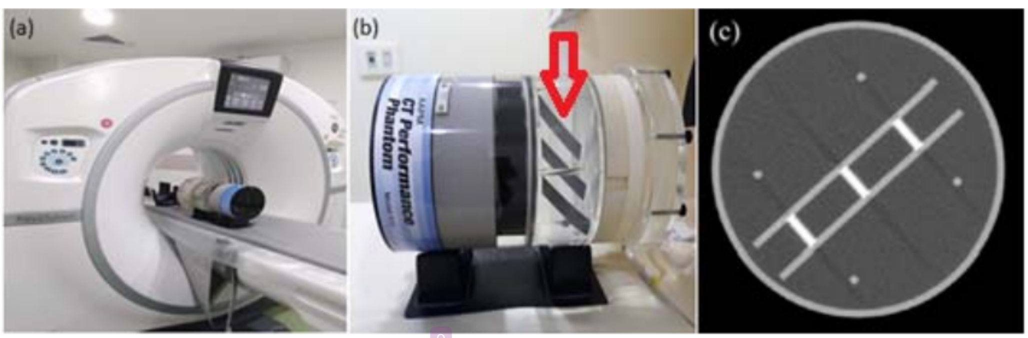

Fig. 1 (a) CT-scanner of GE Healthcare 128 slice; (b) AAPM CT performance phantom, and (c) image of phantom's image for SSP determination.

Table 1. Acquisition parameters of 128 slice GE Healthcare CT scanner.

Acquisition parameter	Unit	Quantity
Tube potential	kV	120
Tube current	mA	50, 100, 150, and 200
Pitch	-	0.984
Field of view (FOV)	mm	255
Rotation time	s	2
Filter reconstruction	-	Filtered-back projection (FBP)
Nominal slice thickness	mm	5

Noise measurement

The noise calculation was carried out on the homogeneous region of the phantom which contains water. Figure 2 shows the image containing a region of interest (ROI) within the water part of the phantom. The noise was calculated as the standard deviation (SD) within the ROI. The signal-to-noise ratio was also calculated. The SNR was calculated as the mean pixel values within ROI divided by the value of the noise. The measurements were performed at three different slices.

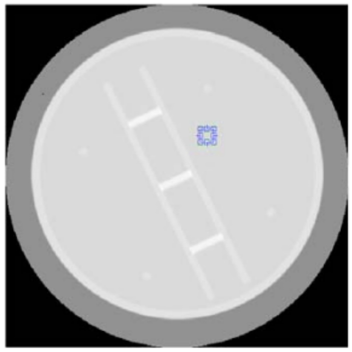

Fig. 2 Region of interest (ROI) location for noise and SNR measurements.

SSP measurement

The automated measurement of SSP was carried out on the middle stair object of the image (Figure 3a). The algorithm of the automated measurement of SSP was proposed [18] which consisted of several steps. The first step was to segment the stairs object image based on the threshold value to produce a binary image. The second step was to calculate the angle of the stair object using the Hough transformation. The third step was to crop the stair object and rotate it based on Hough transformation results. The fourth step was to generate pixel profile across the stair object and calculate the full-width of half maximum (FWHM) of the profile (Figure 3b).

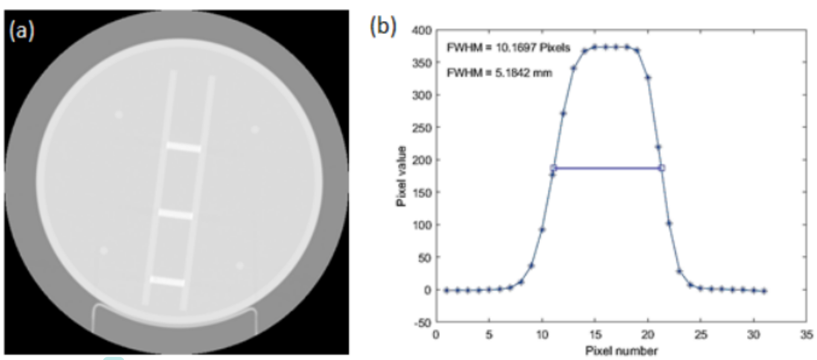

Fig. 3 The automated SSP measurement process: (a) the original image of stair object for SSP measurement; (b) the profile of pixel values across the stair object depicting the SSP. The FWHM of SSP was displayed in the units of pixels and mm.

III. RESULTS

Noise

Table 2 shows the results of the mean pixel value, noise, and SNR of the images for various tube current from 50 mA to 200 mA. Mean pixel values are within ± 4 HU. Table 2 indicates that mean pixel value tends to approach to the 0 HU for the increase of tube current. The noise increased when the tube current was decreased, agreeing with our hypothesis. Due to the mean pixel value was closer to 0 HU along with the increase of tube current, the SNR tended to approach 0 with the increase of tube current.

Table 2. Mean pixel and noise values for various tube currents.

Tube current (mA)	Mean pixel value (HU)	Noise (HU)	SNR
50	-3.18	7.67	-0.40
100	-2.46	5.95	-0.40
150	-1.79	4.98	-0.34
200	-1.20	4.00	-0.30

SSP measurement

Figure 4 shows the AAPM CT performance phantom images for tube current variations of 50, 100, 150, and 200 mA. The SSPs and FWHM values for tube current variations are shown in Figure 5. The FWHM value of each SSP is represented in unit of pixels and mm. The x-axis of SSP represents the pixel number (pixel) and the y-axis represents the pixel value (HU). Table 3 shows the mean and standard deviation values of the FWHM of SSP from automated measurement. The automated measurement of FWHM of SSP had accurate measurement results and similar to the nominal slice thickness. However, the automated FWHM results tend to be similar to those of the nominal slice thickness for lower noise. The FWHM of image with noise of 7.5 HU was 5.5 mm and the difference from the nominal slice thickness was 10%. The FWHM of image with noise of 4.3 HU was 5.2 mm and the difference from the nominal slice thickness was 4%.

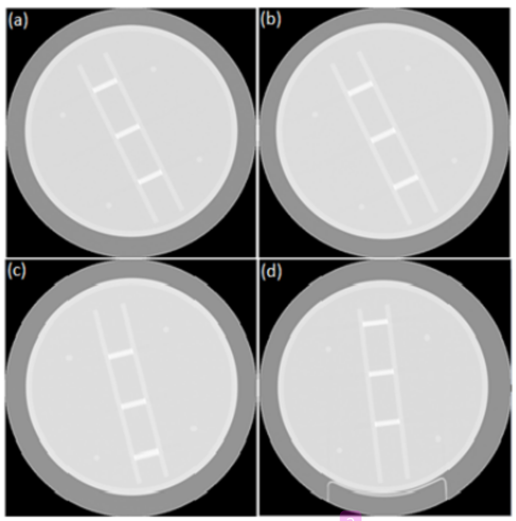

Fig. 4 AAPM CT Performance Phantom images for the tube current of (a) 50 mA; (b) 100 mA; (c) 150 mA; and (d) 200 mA.

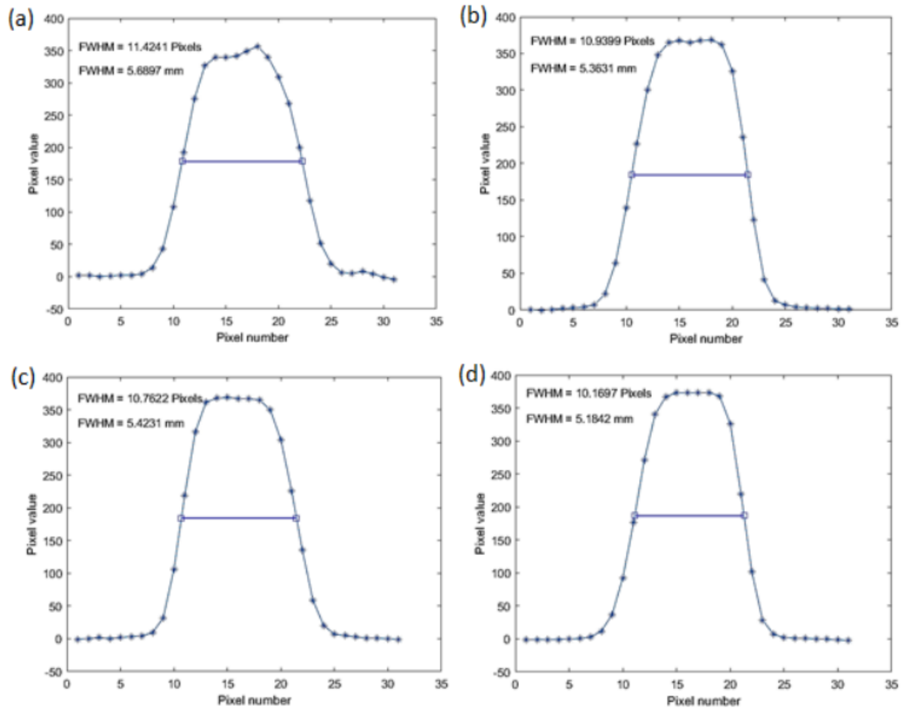

Fig. 5. SSPs and their FWHM values for various noises of (a) 7.67 HU, (b) 5.95 HU, (c) 4.98 HU, and (d) 4.00 HU.

Table 3. Results of automated slice sensitivity profile measurements for the tube current variations

Noise (HU)	FWHM of SSP from automated measurement (mm)	Difference from the nominal slice thickness (%)
7.67	5.5 ± 0,1	10
5.95	5.3 ± 0,3	6
4.98	5.4 ± 0,0	8
4.00	5.2 ± 0,1	4

IV. Discussions

We investigated an impact of noise on resulted FWHM of SSP. We found that for four image noises from 4.00 to 7.67 HU, the FWHMs of SSPs were ranged from 5.2 mm up to 5.5 mm. It means that the differences of FWHM from the nominal slice thickness are still within 0.5 mm. However, we found that the FWHM closer to the nominal slice thickness for lowest noise. It is understood that if noise increases, the fluctuation of pixel values also increases [19], and this leads to more fluctuating SSP. Therefore, FWHM of SSP is less accurate compared to the lowest noise.

Although the FWHM is less accurate for highest noise, however the FWHM is still within tolerance limit, i.e. its difference from the set slice thickness is within 0.5 mm [20]. Based on this finding, the results indicated that a use of lower noise in the automated SSP measurement is preferable. However, this investigation has limitation since the investigation of impact of noise on SSP is limited with maximum noise of 7.67 HU. Hence, investigation of impact of noise on SSP for higher noise than 7.67 HU is interesting, since in clinical setting the noise is often higher than 7.67 HU [21] and it will be conducted in the next study.

In addition, the noise in this study is limited from tube current variation. Many other parameters impacted on noise level, such as tube voltage, type of filter, and size of phantom [22]. Investigation of impact of noise from these parameters may provide different perspective. Moreover, the slice thickness also directly affects the noise. If the slice thickness is getting smaller, the noise increases [23]. Based on this fact, accurate measurement of FWHM of SSP for small slice thickness, for instance sub millimeter, may need a greater tube current. Therefore, the investigation of SSP for slice thickness less than 5.0 mm should be performed.

It is noted that automated SSP measurement is only based on AAPM CT performance phantom. However, this finding may be applicable for other phantoms. Therefore, the investigation of impact of noise on SSP for other phantoms should be performed in the future study.

V. Conclusions

The impact of noise on automated results of FWHM of SSP with AAPM CT performance phantom have been investigated. The noise values of 4.00-7.67 HU were found from different tube currents from 200 mA down to 50 mA. It was found that in the range of noises used, the different FWHMs of SSPs from the nominal slice thickness of 5 mm are still within limit of 0.5 mm. However, the automated FWHM results tend to be similar to those of the nominal slice thickness for lower noise. Therefore, the use of low noise for measuring FWHM and SSP may be more preferable.

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