Preliminary study of ring artifact detection in SPECT imaging using Jaszczak phantom

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Abstract. Inspection of imaging SPECT system performance was controlled by Quality Control (QC) regularly. Tomographic imaging parameters in QC, i.e. homogeneity, contrast, and spatial resolution should be tested. These results make it reliable whether the SPECT system will be used. The modular Jaszczak phantom was used for that purpose, as it offers the investigation to all three parameters with a single measurement. Compared to the contrast and spatial resolution, an objective identification of possible ring artifact in the homogeneity is challenging. Artifact simulation of SPECT images which have been generated by disturbance of 4 × 4 cm² copper sheet located on surface LEHR collimator have been conducted to study the detectability of ring artifact. Uniformity section of Jaszczak phantom which filled with ⁹⁹mTc was used for acquisition. The confirmed ring artifact was analyzed by Edge Detection and Circle Hough Transform provided by imageJ, and students t-test statistically. From the evaluation by edge detection and circle Hough transform, the present of ring artifact only detected in artifact SPECT images using 1.00, 0.75, and 0.50 mm copper sheet thickness, while in t-test method all copper sheet thickness (including 0.25 mm) detect ring artifact in images.

1. Introduction
The performance of clinical imaging devices in nuclear medicine is critically dependent on the accurate of radionuclide counting and imaging instrumentation. Quality control (QC) is a important component to ensure the performance of a procedure of instrument is within a predefined acceptable range for routine nuclear medicine practice. An extensive series of parameters for checking the acceptance test and performance characterization of gamma cameras, SPECT and PET scanners, and other nuclear medicine instrumentation in the QC procedures and methodology has been developed over the years [1–3].

Inspection of tomographic imaging properties of SPECT system, i.e. homogeneity, contrast, and spatial resolution, were performed and tested in regular intervals, which is using the QC protocols developed by international organizations and professional body [4, 5]. The modular Jaszczak phantom, which contains homogeneous cylinder for measurement of homogeneity, cold spheres for measurement of sphere contrast, and cold rods for measurement of spatial resolution, was widely used for QC of SPECT system.

The acquisition of high-quality SPECT images in routine performance of QC procedures requires big attention to detail for detection the present of artifacts. Artifacts are normally
came from a number of sources; that are the source of radiopharmaceutical, the gamma camera and its computer system, the procedure of acquisition, the patient, or from the result of an error in the reconstruction of the raw data. Most of artifact will occur on the complexity of modern systems in gamma camera and its computer system [6, 7].

In the QC of SPECT using Jaszczak phantom, detectability of possible ring artifacts in the uniformity section of the Jaszczak phantom is challenging compared with the defined calculation of sector cold rods and cold sphere. From a camera utilizing parallel hole collimation, the centered ring artifacts around the axis of rotation was occured by nonuniformities of planar field-of-view camera as explained by Gullberg et al [8]. In addition by O’Connor et al [9], the possible ring artifacts was investigated thoroughly from the measurement of the uniformity SPECT system. Detection of ring artifacts in SPECT field uniformity was determined by using annular sampling method in a study by Madsen et al [10], where the uniformity image was sectioned into rings and ring artifacts are nonuniformity section in the image. Detectability limits for ring artifacts have been investigated using Monte Carlo simulations in a study by Hirtl et al [11]. In a study by Bashir et al [12], a SPECT artifact consisting of dark and light concentric rings appeared consistently in all images because of gradual leakage of optical coupling grease, possibly by increased local temperature.

In this work, a homogeneity measurements for studying detection of ring artifacts from SPECT imaging system were conducted based on Hirtl work. $^{99m}$Tc used as radionuclide sources, and a material copper sheet was used for masking the surface of LEHR (Low Energy High-Resolution) collimator as part of photomultiplier tube (PMT) failure. Two SPECT images, artifact and non-artifact, have been generated. Reconstruction of ring artifact from SPECT images then analyzed using edge detection and circle Hough transform provided by imageJ software. Histogram of ring artifact and non-artifact area were calculated statistically to determine $t$-value of each image. From these $t$-value, the present probability of artifact can be detected.

2. Methodology
2.1. Materials
Simulation of ring artifact was conducted using Siemens Symbia E SPECT system, which equipped by two detector heads, using LEHR collimator. Jaszczak Deluxe Flangeless phantom (Figure 1) was used for the measurements of homogeneity. The geometry of the Jaszczak phantom consists of radius 20.4 cm, height 18.6 cm, and volume 6.4 L, without inserts (cold spheres and sector cold rods). The phantom was aligned parallel along the z-axis orientation to the axis-of-rotation of the SPECT system.

Simulation artifacts were designed by masking small areas at collimator surface with a $4 \times 4$ cm$^2$ copper sheet, and variation thickness of 1.00 mm, 0.75 mm, 0.50 mm, and 0.25 mm. The

![Figure 1. The modular type of Jaszczak Deluxe Flangeless phantom without inserts.](image)
copper sheet was positioned on one of the detector heads at 8 cm below its center. Acquisition of artifact image was carried out in 15 minutes and repeated 3 times using one part of Jaszczak phantom particularly for uniformity observation. This phantom filled with $^{99m}$Tc ± 3 mCi solution mixing with water (resulting in an activity concentration of ± 16 kBq/mL).

2.2. Inhomogeneity
Artifact images was investigated using imageJ software. Prior to calculation all images were filtered for each detection using Shepp-Logan filter. The images matrix computed by using edge detection with using Sobel operator $3 \times 3$ matrix. The potential ring shaped artifact was determined using circle Hough transform based on the highest pixel value of the ring throughout the image area.

Two generated SPECT images, artifact and non-artifact, was compared statistically using student t-test method for a thorough investigation whether there are the possibility of ring artifact or not. The ROI (Region of Interest) shaped ring of two images with same position was taken and the histogram from these ROI was computed to find $t$-value using equation:

$$t = \frac{\bar{D}}{s_d/\sqrt{N}}$$

(1)

where $\bar{D}$ is the mean intensity from difference ROI pixel value of non-artifact image and artifact image, $s_d$ is the standard deviation of $D$, and $N$ is the number of pixels per ring. Equation (1) can be generalized to:

$$t = \frac{(\Sigma(D)/N)}{\sqrt{\frac{\Sigma(D)^2-(\Sigma(D))^2}{(N-1)N}}}$$

(2)

Assuming the null-hypothesis, which means no difference between the artifact image and non-artifact image by investigating these mean values from histogram of ROI shaped ring (as there is no artifact on the artifact image), the distribution histogram of the pixel values in the homogeneity area should be very close to a normal distribution. The non-artifact image (Figure 2a) used as an example of acceptance test of a homogeneity test SPECT system without artifact. By using t-table for checking the confidence level of one-tailed t-test with degree of freedom ($df = N - 1$) is 139 from $t$-value, a $p$-value of larger than 0.025 was interpreted as a detection of potential ring artifact on SPECT images.

3. Results
Figures 2 to 5 explained the results of reconstructed SPECT images artifact and the evaluation by edge detection and circle Hough transform. Those images were reconstructed in slice which artifact visible visually. Full ring artifact are appeared at the center of images with width of ring at about 1 cm. For circle Hough transform, the detection of ring artifact was indicated by the symbol of ” + ” from the center of image phantom followed by a threshold-based decision criterion. The potential visible of ring artifact are identified with quantifying student’s t-test. In the case of student’s t-test method, Figure 6 and Table 1 shown that $t$-value explain the existence of artifact by investigating $p$-value and confidence level in t-table statistics.

4. Discussion
From the edge detection and circle Hough transform, reconstruction images shown the potential ring artifact was indicated by copper sheet with thickness 1.00 mm, 0.75 mm, and 0.50 mm, on
Figure 2. The non-artifact SPECT image as an acceptance test of homogeneous image (a) with artifact SPECT image results of (b) reconstructed image raw, (c) edge detection, and (d) circle Hough transform, by thickness of copper sheet 1.00 mm.

Figure 3. Artifact SPECT image results of (a) reconstructed image, (b) edge detection, and (c) circle Hough transform, by thickness of copper sheet 0.75 mm.

Figure 4. Artifact SPECT image results of (a) reconstructed image, (b) edge detection, and (c) circle Hough transform, by thickness of copper sheet 0.50 mm.

Figure 5. Artifact SPECT image results of (a) reconstructed image, (b) edge detection, and (c) circle Hough transform, by thickness of copper sheet 0.25 mm.
Table 1. p-value for each varied copper sheet thickness corresponding to t-value calculated in t-test method.

| Cu Thickness (mm) | t-value | p-value |
|-------------------|---------|---------|
| 1.00              | 3.65    | 0.0002  |
| 0.75              | 3.03    | 0.0015  |
| 0.50              | 2.43    | 0.0082  |
| 0.25              | 2.09    | 0.0193  |

Figure 6. t-value calculation results for each thickness of copper sheet, as shown in the graph t-value will increased along with more thickness the copper sheet. The more larger t-value means the more clear visible of ring artifact is.

the other hand, the artifact at copper sheet of 0.25 mm could not be clearly indicated. It means that the image was not significantly different with homogeneous image (non-artifact SPECT image). The result supported the Monte Carlo simulation by Hirtl et al, where SPECT artifact image resulted by 0.4 and 0.3 mm copper sheet is not different as homogeneous SPECT image. According to NIST [13] said that absorption photon should have less equal to 10%, so that the artifact disappeared, while those results only have 8% (for 0.4 mm) and 6% (for 0.3 mm). By the imageJ calculation using the same method, the absorption for 140 keV photon for 0.25 mm were around 5 %, so that proved the artifact disappeared using 0.25 mm copper sheet.

Contrary, the result from statistical t-test shown the artifact presented in the images because all artifact images have the p-value results are greater than 0.025. It because the t-test method using ROI histogram from ring artifact and homogeneous image, so those difference of pixel value between them will make clear the detection of artifact. The artifact detection using edge detection and circle Hough transform only detect the present of artifact by detecting in transforming image circle by circle. Of course that method not include pixel value, only detecting from the circle form that formed in transformation. The mixing technique of $^{99m}$Tc and water in the Jaszczak phantom affected the result of reconstruction images [14][15]. By having carefully
and well preparation for mixing water and $^{99m}$Tc before measurements, probably the artifact in reconstructed image will be appeared clearly.

Also these results make false result of the width measurement of the ring and the cause is still not yet been identified. Logically, if the size is $4 \times 4 \text{ cm}^2$, the reconstructed image should display 4 cm, yet it displays only a fraction of it, i.e. 1 cm. The possible reason comes from the absense of the copper sheet on the surface collimator of one of the detectors, hence the particular detector detect more photons than it is assumed.

5. Conclusion

The reconstructed SPECT images displayed the possibility of ring artifact visually caused by the disturbance of a copper sheet masking on surface collimator. Though from the edge detection and circle Hough transform result, it only clearly presented on thickness of 1.00 mm, 0.75 mm, and 0.50 mm. For the thickness of 0.25 mm, it still not clearly whether it appeared the ring artifact on images. It contrary with the results using t-test method, while shown all artifact image in all thickness detect ring artifact. So the t-test method is very significant than using edge detection and circle Hough transform. Further study of the variation positioning copper sheet on collimator must be conducted to understanding the appeared ring artifact. Hopefully as the more investigation of ring artifact on detector systems for the image acquisition and analysis, it can be easily for the technologist and the physician be able to recognize some artifact that can impact on clinical studies.

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