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Beam Hardening Artifact and Image Noise in Single and Dual Energy Computed Tomography Applications

Marwan Alshipli*[1] and Norlaili A. Kabir[1]

[1]School of Physics, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia

Abstract: *Computed tomography (CT) employs X-ray radiation to generate cross-sectional images. This article is concerning the ImageJ software and statistical analysis to aid CT image analysis. In this particular study, the ImageJ software and the Independent t-test were used as the combined methods to analyze the beam hardening artifact and image noise in dual energy images compared to the images acquired in single energy CT. High attenuation material (gypsum) had inserted in the peripheral holes of CT dose index phantom. The phantom was scanned using routine head protocol parameters for both single and dual energy CT. The quantitative analyses were carried out using the Image J software and Independent t-test. The results showed that the beam hardening artifact ($p < 0.05$) is observed in single energy CT images, but did not in images acquired by dual energy CT. The t-test results also showed that were no significant difference in image noise between single and dual energy CT images ($p = 0.1$). Therefore, ImageJ software and statistical results demonstrate the utility of single source dual energy CT technique to reduce the beam hardening artifact without improving the image noise.*

Keywords: *Computed Tomography, Beam Hardening Artifact, Statistical Analysis.*

1. Introduction

Computed tomography scan (CT) is a cross-sectional medical imaging technology that uses computer to scan the inner parts of the body. This technology creates data depending on the variation in attenuation levels of the scanned area. CT devices are generally founded in diagnostic radiology departments and might be accessed in the therapy department. Diagnostic and classification of disease by CT imaging depends on structural and morphologic standards such as, texture, tissue attenuation and size [1, 2]. Therefore, CT provides accurate localization and characterization of findings that lead to increase the clinical applications of CT. For example, CT can diagnose different types of diseases such as; gastric pathology, vascular diseases, lung and renal diseases, head injuries and various types of tumours and lesions [3-5]

CT is classified according to the energy technology into; single energy CT (SECT) and dual energy CT (DECT). The DECT produces two attenuation levels that construct of two datasets information for the same scanned area. These images will be created by low and high X-ray energies [6]. In single source DECT, different two datasets will be reconstructed algorithmically for 80 kVp and 140 kVp to create the final image which approximately equivalent to image of 120 kVp [7]. As a result, the single source DECT has more advantages to improve image quality over SECT. For example, the DECT has been developed additional techniques to reduce the radiation dose level and increase image quality at the same time by reduction the number of slices and correct beam hardening artifact [6, 8-10].

Beam hardening artifact and image noise impact the image quality and the diagnostic information in CT images. The beam hardening artifact appears as streaks distributing area that surround high attenuation material. It is the result of variation in mathematical algorithm between low and high density objects in the area of scan.

The DECT constructs two datasets information for the same anatomical region. This information can be used to derive virtual monochromatic images, which do not suffer from beam hardening artifact [11, 12].

Image noise is one of the most important indexes that express the CT image quality. It is based on the variation in CT number values for uniform anatomical area. Therefore, the noise can be defined statistically based on standard deviation (SD) for pixel intensity values in a physical uniform region [13, 14]. Consequently, the noise decreases as the SD for pixel value decreases. There are a number of studies have been conducted to study the image noise in the SECT and DECT examinations [11, 15-18]. Therefore, the main aim of this study is to investigate and compare the beam hardening artifact and the image noise in SECT and DECT images using the ImageJ software and t-test function.

2. Materials and Methods

This study was conducted at the CT scan unit, Hospital Perubatan dan Pergigian Termaju (IPPT), Malaysia. The study was used the CT Adult Head Dose Phantom (CTDI) as shown in Figure 1. The phantom was designed according to standards and criteria of Food and Drug Administration (FDA). It was made from solid acrylic in circular cylinder shape (160 mm diameter and 150 mm in height). The high attenuation material (gypsum) was inserted at two peripheral holes of the phantom. The phantom was scanned with a single source dual energy CT scanner (SOMATOM Definition AS, Siemens 2014 serial number: 95187,Germany) to produce different DICOM CT images. Afterward, the phantom was placed in the center of the field to scan a topogram image and set the protocol parameters that they are shown in the table 1. The DECT head adult protocol parameters were employed to generate axial DECT images at 80 & 140 kVp. On the other side, the DECT scanner was used as a SECT by adapting the SECT adult head protocol to create axial images at 120 kVp. The DICOM images were collected and ImageJ software program, which established at the National Institutes of Health (NIH) based on java application, was performed to determine the pixel intensity at slice number 20 with depth 7.6 cm. However, the ImageJ was performed in our study to calculate the pixel intensity and the SD values for each of DECT and SECT images at regions of interest (ROIs) as shown in Figure 2.

The statistical analysis was performed using independent t-test to compare the effect of beam hardening artifact an image noise in SECT and DECT images. The t-test was employed to find out the significance in variability between means of samples. The probability value (*p*) equals to 0.05 is considered as the significant level value. Afterward, The CT images were collected and the software program ImageJ was used to determine the pixel values at the ROIs. In this study, all measurements that were obtained by the ImageJ program were keyed in Microsoft Excel 2010 sheets. Then, the statistical analysis to compare between the acquired data was done using t-test function.

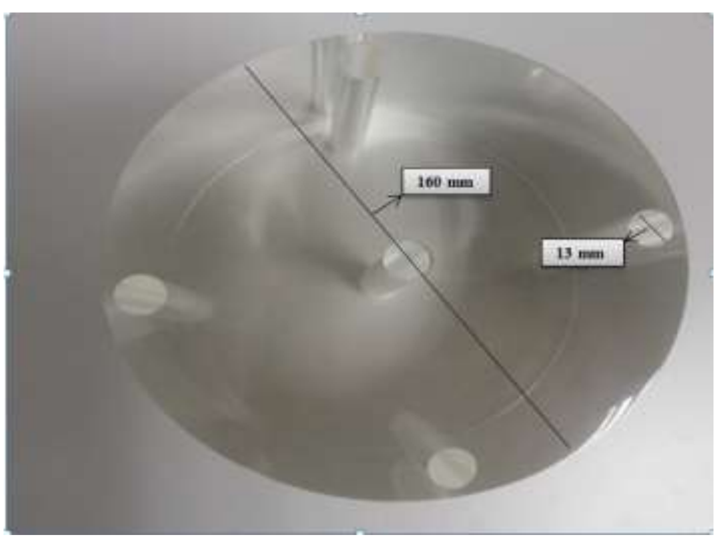

Fig. 1: Adult head CT dose phantom (CTDI) (IPTT-CT department).

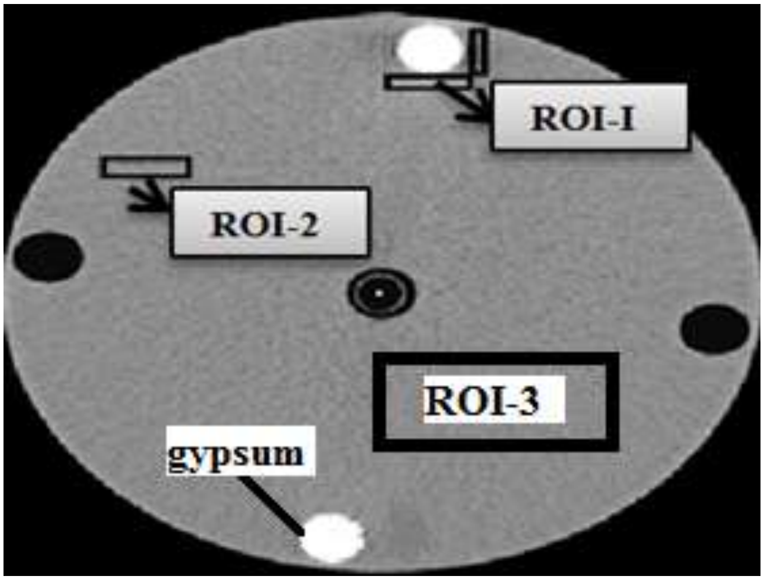

Fig. 2: Regions of interest: ROIs-1 and ROI-2 were used for beam hardening artifact assessment. ROI-3 (400 mm²) was used to measure the standard deviation (Image noise measurements).

TABLE 1: Dual and Single Energy CT Head Protocols

Parameters	Head Protocol Dual Energy CT	Head Protocol Single Energy CT
Scan mode	Spiral	Spiral
Tube voltage (kVp)	80 and 140	120
Tube Current (mAs)	Auto [a]	Auto [a]
Pitch	1.2	0.55
Slice Thickness (mm)	5	5
Rotation time (s)	0.5	1
Acquisition Collimation (mm)	40 x 0.6	40 x 0.6
Window	Base Orbita	Base Orbita
CARE Dose type	CARE Dose4D	CARE Dose4D

[a]Automatic Tube Current Modulation

3. Results and Discussing

The gypsum has high atomic number which provides high pixel intensity value in comparison with the material of CTDI phantom. As a result, the region which surrounded the gypsum shows dark streaks artifact and the region at the homogeneous area of phantom did not show the artifact. As shown in Fig.2 (previous section), the ROIs-I represent samples taken from where the beam hardening artifact is possible to appear. While ROI-II represents samples taken from where the beam hardening does not appear. The quantitative results demonstrated that *p* value between ROIs for SECT image was less than 0.05. This means there is a significant difference between the pixel intensity values for region of beam hardening artifact and region of the homogeneous area in SECT image. The variation within and between the ROIs-1 and the ROI-2 for SECT image statistically indicated that the SECT image suffers from the beam hardening artifact. On the other hand, the *p* value of DECT image between ROIs-I and ROI-II was greater than 0.05, so there are no significant differences between the pixel intensity values for the two regions. In other words, the regions which surrounded the gypsum materials did not show dark streaks in DECT image, but they were apparent in SECT image. Thus, this part of our study indicated that single source DECT solves the beam hardening artifact in comparison with SECT.

This experiment investigated the differential of impact noise levels by comparing the SD values in DECT and SECT images. The imageJ calculated the image noise in CT images by measuring the mean SD values at region of interest (ROI-3: Fig 2). The calculated SD values were 3.71 and 3.87 for DECT and SECT images, respectively. These results showed that no major variation between SD values and there is a slightly difference in image noise level between the two images. Statistically, two statistic samples were taken at two regions of interest (ROI-3) for DECT and the SECT images. The result of p value between ROI-3 DECT and ROI-3 SECT is 0.1 (greater than 0.05). Therefore, there is no significant difference between the pixel intensity values for the two regions. Thus, this part of our study demonstrates that single source DECT technique does not reduce the CT image noise significantly.

4. Conclusions

This study statistically investigated the role of dual energy technique to improve the image quality in CT examinations. The first major finding of our experiment is that DECT corrects the beam hardening effect. The artifacts are shown in the images of SECT and it is noticeable that they do not appear on the images of DECT. The quantitative results have indicated that the DECT improve the CT image by reducing the beam hardening effect. Based on statistical results and standard deviation measurements, the second finding in our study is that the single source DECT stills have approximately the same image noise level in SECT. Therefore, the overall study's results demonstrate the role of single source DECT in correction the beam hardening artifact without make a significant improving on the image noise.

5. Acknowledgements

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6. References

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