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Evaluation of metal artefacts reduction by application of monoenergetic extrapolation of dual-energy CT: A phantom study with different metal implants

H A Saidun¹, I L Shuaib¹, N M Daud², N F M Sobri¹, N D Osman¹

¹ Oncological & Radiological Sciences Cluster, Advanced Medical and Dental Institute, Universiti Sains Malaysia, Kepala Batas, Penang, 13200, Malaysia ² Radiology Department, Hospital Universiti Sains Malaysia (HUSM), Kubang Kerian, Kelantan, 16150, Malaysia

E-mail: noordiyana@usm.my

Abstract. The aim of this study was to evaluate the application of monoenergetic (ME) extrapolation technique of dual-energy computed tomography (DECT) for metal artefact reduction using phantom study. This study involved phantom study with a customized phantom consisting different types of metal implant such as titanium and stainless steel. The phantom was scanned using a single-source DECT scanner (SOMATOM Definition AS+, Siemens Healthcare, Germany) with dual-energy mode of 140/80 kV spectrum. The commercially available post-processing software (Syngo DE, Siemens) was applied to generate ME image datasets with different extrapolated energies ranged from 55 to 160 keV. The reduction of artefacts was measured qualitatively and quantitatively using region of interests (ROIs) statistical analysis. The results show 60% of metal streak regions were reduced significantly at higher extrapolated energy which is 160 keV. Quantitative analysis also resulted in lower HU readings within the region of artefact for 160 keV. However, higher extrapolated energy resulted in higher noise and lower signal-to-noise (SNR) value. ME images at 160 keV appear noisier while ME images at 64, 70 and 80 keV appear smoother. Metal artefacts induced by both metal implants were reduced significantly using DECT ME extrapolation and diagnostic quality of CT images also improved. It can be achieved by using higher ME of DECT. However, image noise is higher, and SNR is reduced with higher ME extrapolated energy.

Keywords: Monoenergetic extrapolation; dual-energy CT; metal artefact

1. Introduction

For computed tomography (CT) imaging, metal-induced artefacts appearance is a major concern and limitation in diagnostic image evaluation [1-2]. The presence of artefacts can markedly impair the assessment of surrounding structures. The presence of metal artefacts is mainly due to the attenuation of high dense metallic implant that leads to missing projection data and beam hardening effects [2–3]. Due to absorption of x-ray quanta by the metallic objects, insufficient x-ray photons were detected (photon

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starvation) and thus generating incomplete projection profiles. As these missing data are reconstructed, it will result in bright and dark streaks appearance in CT image [4].

One of the most promising technologies in CT nowadays is dual-energy CT (DECT), where the CT data is acquired at two different x-ray spectra and the DECT image is reconstructed based on monoenergetic (ME) extrapolation [5]. The DECT image demonstrates the distribution of specific materials based on their attenuation properties at two different energies [2]. Following image reconstruction, the linear attenuation coefficients at low and high energy acquisition are expressed as a linear combination of the effective mass attenuation coefficients of the materials [6]. Thus, the ME extrapolated image at energy keV can be expressed as a weighted average of the images at both energies and the linear combination of two CT images with sum of the two factors equals to 1. The linear attenuation coefficients derived from the reconstructed ME extrapolated images can be expressed as:

$$(\mu^k) = \left(\frac{\mu}{\rho}\right)_1^k \rho_1 + \left(\frac{\mu}{\rho}\right)_2^k \rho_2 \tag{1}$$

where, μ refer to the mass attenuation coefficients, and ρ refer to the mass densities of the two materials. By solving the two linear equations, the mass density of the two basis materials can be obtained, and is used to calculate the monochromatic image at energy E.

Previous studies have explored the application of dual energy ME method and have proved its effectiveness in reducing metal artefact due to different orthopaedic implants in CT images [6–10]. The aim of this study is to further evaluate the potential of DECT imaging for metal artefact reduction induced by different metal through different ME extrapolation energies using phantom study.

2. Methodology

2.1. Phantom images acquisition

This study involved two phantoms study on two different phantom consisting various materials. The first phantom study is performed on CIRS electron density phantom for material characterisation acquired at different ME extrapolated energies. The second part involved a customized phantom that been proposed by Osman et al., (2014) [11]. The water bath phantom was designated with a dimension of 20 x 15 x 0.8 cm and was made of clear polymethyl methacrylate (PMMA) and has Stainless steel (ST) and Titanium (Ti) inserts to simulate metal artefacts appearance in post-operative spinal implants. All phantom scanning were performed with single-source DECT scanner (SOMATOM Definition AS+, Siemens Healthcare, Germany). For DECT acquisition, the CT scanner with a single tube operated at voltages combination of 80 kVp and 140 kVp through dual-spiral technique. Automatic exposure control (CareDose4D; Siemens Healthcare) was used for DECT acquisition. Beam collimation was 128 x 0.6 mm and pitch was 0.8.

2.2. ME extrapolation reconstruction

All the acquired data were reconstructed using DECT monoenergetic extrapolation technique on post processing workstation with specific software Syngo (Syngo workplace, Siemens Healthcare, Forchheim, Germany). The DECT image datasets were generated with different ME extrapolated energies such as 55, 64, 70, 82, 105, 132, and 160 keV by Syngo DECT software to assess the metal artefact reduction.

2.3. Image Analysis

For the first part, a CT number-to-mass density conversion curves were plotted for different ME extrapolated energies. In second part, quantitative analysis was performed to evaluate the reduction of metal artefacts by measuring the mean HU value and the noise (SD) using regions-of-interest (ROIs) statistical analysis. The ROIs measurement were defined on phantom images without the metal inserts as reference value and also

on phantom images with both metal inserts (Ti and ST) within the dark and bright streak regions. The reduction of artefacts was also evaluated by artefact index (AI), defined as [12–13]

$$AI = \sqrt{SD_{ROI(Metal)}^2 - SD_{ROI(Ref)}^2}$$
(2)

where SD is the standard deviation of the CT numbers measured phantom image with metal rods (ROI_{Metal}) and without the metal rods (ROI_{Ref}).

3. Results

Figure 1 shows the value of CT attenuation for different materials inserts of the CIRS phantom acquired at different ME extrapolated energies ranging from 55 to 160 keV. From the graph, it shows that materials with physical density between 1200 to 4000 kgm⁻³ were better differentiate using ME extrapolation reconstruction. However, the measured HU were constant for materials below and above that range of physical density for different ME energies.

In part 2, the reduction of metal artefacts in phantom images for both Stainless Steel and Titanium rods were shown in Figure 2. As shown in the figure, the presence of dark and bright streaks surrounding the rods were reduce at higher ME extrapolated energies such as 160 and 190 keV. The image quality is the worse with severe streak artefacts at lowest ME extrapolated energy, 40 keV. Qualitatively assessment shows phantom images consisting Ti rod induced smaller amount of streaks compared to Steel rod.



Figure 1. The CT number-to-physical density conversion curves of different tissue substitute materials acquired at different ME extrapolated energies.



Figure 2. Phantom images show metal streak induced by two different metal types, the stainless steel rod (above) and titanium rod (below) reconstructed at different ME extrapolated energies. Note that the image quality improves at higher DECT ME extrapolated energies.

In Figure 3, the plot shows the trend of mean signal-to-noise (SNR) for both Titanium and Steel rods measured within the streaking regions in phantom images extrapolated at different monoenergetic energies. The SNR decreased significantly in CT images with both Steel and Titanium rods). But, the reduction of SNR is much greater for Ti rod (almost half of original images). In monoenergetic energies of 82 keV, the value of HU readings on the streaking artefact location was approximately close to the standard linear blending dual energies. The ROIs reading around Stainless steel revealed that the HU reading of metal streak around stainless steel was the highest when viewed at 55 keV. In term of noise reading, images extrapolated at 160 keV energy yield the highest noise for both images. This suggested the presence of additional noise when applying the ME extrapolation algorithm. Rassouli et al., (2017) proved that the noise within the target organ area was smaller on ME extrapolated images compared to noise in images of standard 120kVp [10].

Figure 4 shows the artefact index (AI) values plotted at different ME extrapolated energies. A lower AI values specifies superior artefact suppression. From Figure 4, it can be seen that the AI values is decreased as the ME extrapolated energies increased for Steel rod, but increased over at the highest energy for Titanium rod.

In term of metal artefact reduction, 60% of metal streak around Titanium rod was significantly reduced at 160 keV. In contrast, the metal artefact is reduced by only 10% of the reference HU value and metal artefacts reduction was maximum at 105 keV for Stainless steel rod. Since the monoenergetic energies of 82 keV were the closest to 70 keV, we can compare that the noise of streaking artefact was minimized when using the extrapolated energies of 82 keV. While by applying the lowest and highest monoenergetic energies (55 and 160 keV), the noise was increased.



Figure 3. The graph of signal-to-noise ratio (SNR) at different ME energies (keV) for metal streak CT images induced by ST and Ti rods.



Figure 4. The artefact index (AI) plotted at different ME energies (keV) for CT images consist of Stainless steel and Titanium.

4. Discussion

In this study, the application of ME energies in DECT imaging was studied and the analysis was done by comparing the extrapolated ME energies images with the reference images (linearly blended DE images). The results of the image quality and artefact density analysis indicating beam hardening artefacts were reduced with increasing energy. However, reduction of artefacts was only present to a certain extent only. On the other hand, if metal inserts of low attenuating materials were present, visually no artefact reduction takes place.

The results show image reconstructed at 70 keV virtual ME has lowest noise but highest CNR. This is due to higher HU values within the bright streak region and lower HU values within the dark streak regions. In overall, the energy of 132 keV presented the optimum extrapolation setting with acceptable level of image quality of CT image. Although the HU reading of streaking artefact were minimized when extrapolated the energies at 160 keV, however the noise introduced were highest even though the SNR was small.

Although the application of mono-energetic energies brings lots of benefits in terms of image quality of CT images, the artefacts are not eliminated completely. They are only substantially reduced allowing better visualization of spinal implants. Now, with dual-energy CT and monochromatic image synthesis, yet another type of image can be provided to the interpreting physician. The results of this study provide important information for physicists, technologists, and imaging physicians regarding how the image quality at an optimal virtual monochromatic energy compares with the conventional CT and standard linear blending dual energy images.

5. Conclusion

Metal artefacts induced by metallic objects can be reduced using ME extrapolation of dual-energy method and the diagnostic quality of CT images also improved as compared to the standard liner blending dual energies (DECT) images.

6. References

- [1] Robertson D D, Weiss P J, Fishman E K, Magid D, and Walker P S 1988 Evaluation of CT techniques for reducing artifacts in the presence of metallic orthopedic implants *J of Comput. Assist. Tomogr.* 12 236–241.
- [2] Bamberg F, Dierks A, Nikolaou K, Reiser M F, Becker C R, and Johnson T R C 2011 Metal artifact reduction by dual energy computed tomography using monoenergetic extrapolation *Eur Radiol* 21 1424–1429.
- [3] Barret J F and Keat N 2004 Artifacts in CT: Recognition and avoidance *RadioGraphics* **24** 1679–1691.
- [4] Lee S H, et al. 2013 Additional value of dual-energy CT to differentiate between benign and malignant mediastinal tumors: an initial experience *Eur J Radiol* 82(11) 2043–2049.
- [5] Zhao L Q, et al. 2012 Improving image quality in portal venography with spectral CT imaging *Eur J Radiol* 81(8) 1677–1681
- [6] Yu L, Christner J A, Leng S, Wang J, Fletcher J G, and McCollough C H 2011 Virtual monochromatic imaging in dual-source dual-energy CT: radiation dose and image quality *Med Phys* **38** 6371–9.
- [7] Yazdi M and Beaulieu L 2007 Artifacts in spiral x-ray CT scanners: Problems and solutions *World Acad of Sci and Tech* **35** 96–100.
- [8] Matsumoto K, et al. 2011 Virtual monochromatic spectral imaging with fast kilovoltage switching: improved image quality as compared with that obtained with conventional 120-kVp CT. *Radiology* 259(1) 257–262.
- [9] Pessis E et al. 2013 Virtual monochromatic spectral imaging with fast kilovoltage switching: Reduction of metal artifacts at CT *RadioGraphics* **33(2)** 573–583
- [10] Rassouli N, Chalian H, Rajiah P, Dhanantwari A, and Landeras L 2017 Assessment of 70 keV virtual monoenergetic spectral images in abdominal CT imaging: A comparison study to conventional polychromatic 120kVp images Abdom Radiology 42
- [11] Osman N D, Salikin M S, Saripan M I, Aziz M Z A, and Daud N M 2014 Metal artefact correction algorithm based-on DSAT technique for CT images *IEEE Conference on Biomedical Engineering* and Sciences (IECBES), Kuala Lumpur, 2014, 324–327.
- [12] Dong Y *et al* 2015 Metal artifact reduction using virtual monochromatic images for patients with pedicle screws implants on CT *Eur. Spine J.* **25** 1754–63
- [13] Wang T et al 2017 Application of dual-energy CT to suppression of metal artefact caused by pedicle screw fixation in radiotherapy: a feasibility study using original phantom *Phys. Med. Biol.* 62 6226–6245

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