Evaluation of efficacy of metal artefact reduction technique using contrast media in Computed Tomography

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Abstract. The aim of this study was to evaluate the efficacy of metal artefact reduction using contrasts media in Computed Tomography (CT) imaging. A water-based abdomen phantom of diameter 32 cm (adult body size) was fabricated using polymethyl methacrylate (PMMA) material. Three different contrast agents (iodine, barium and gadolinium) were filled in small PMMA tubes and placed inside a water-based PMMA adult abdomen phantom. The orthopedic metal screw was placed in each small PMMA tube separately. These two types of orthopedic metal screw (stainless steel and titanium alloy) were scanned separately. The orthopedic metal crews were scanned with single-energy CT at 120 kV and dual-energy CT at fast kV-switching between 80 kV and 140 kV. The scan modes were set automatically using the current modulation care4Dose setting and the scans were set at different pitch and slice thickness. The use of the contrast media technique on orthopedic metal screws were optimised by using pitch = 0.60 mm, and slice thickness = 5.0 mm. The use contrast media can reduce the metal streaking artefacts on CT image, enhance the CT images surrounding the implants, and it has potential use in improving diagnostic performance in patients with severe metallic artefacts. These results are valuable for imaging protocol optimisation in clinical applications.

1. Introduction

Computed Tomography (CT) is an imaging modality that combines multiple x-ray projections taken from different angles and produce detailed image views of all types of body tissues. However, one of the CT imaging limitations is the difficulty in evaluating the image with the artefacts arising from metallic implants in patient's body [1]. Metal implants such as shrapnel, surgical clips, pacers, joint prostheses, wires, pedicle screw placement, stenting, and so on usually undergo follow-up CT imaging [2-4]. These metallic implants lead to severe streak and shadow artefacts in CT images that superimpose the structures of interest and deteriorate image quality, which is important for diagnostic imaging [4, 5]. This is because the metallic objects is a high density material, which is strongly scattered to the transmitted x-ray beam during CT examination. It results in the production of severe image artefacts due to the lack of the output data projection in CT images [6]. Therefore, it is difficult for radiologists to interpret the CT images with metallic implants due to the artefacts problem. This situation hampers the diagnostic interpretability of the implants themselves, metallic-bone interfaces, and adjacent soft tissue itself. These diagnostic criteria are important to prevent cracking or loosening and sufficient verification with adequate protection of the implant [7] and ruling out of hematoma, evaluation of blood vessels near implants or inflammation in the adjacent soft tissue. However, due to the occurrence of metal artefacts, the diagnosis on CT images remains challenging with many cases rendered uninterpretable, even with hard convolution kernels and widened CT density ranges [1].

Various metal artefact reduction techniques have been developed to reduce metal artefacts, and most commonly used reconstruction algorithm for CT are filtered back projection (FBP), interpolation methods, and iterative reconstruction methods. These methods involve in identification and replacement of the metal-corrupted data in CT images. However, the limitations are most of the techniques do not remove all sources of streaking artefacts, cause loss of spatial resolution in images and introduce the secondary artefacts that may lead to misinterpretation [8-10]. Other than reconstruction technique, the use of contrast media is also proposed as metal artefact reduction technique [11-13]. Contrast media are a group of medical drugs used to improve the visibility of internal organs and structures in imaging techniques. Contrast media commonly used to visualise vessels, tissues, organs, urinary tract and so on. They are helpful in distinguishing between the normal and the pathological areas. The use of contrast media is usually safe, and adverse effects are usually mild and limited. Side effects range from contrast media range from a mild inconvenience, such as itching, delayed allergic reactions, anaphylactic reactions, and cutaneous reactions, to life-threatening emergencies [14]. Lambert et al. (2015) study on the complementary of contrast media using bismuth, tantalum, and tungsten for patients with metal implants in dual-energy CT. They found that metal artefact severity was reduced in high-keV images across changes in the metal artefact types [11]. Other study done by Pjontek et al. (2015) found that contrast media and metal artefact reduction software (MARS) in angiographic CT is significantly improves image quality in patient after coiling or clipping [12]. Saake et al. (2012) use intravenous contrast media in angiographic CT follow-up imaging of intracranial flow diverting device. They found that result of digital subtraction angiography and intravenous contrast media images scored identically in all patients with stent deployment [13].

Therefore, the purpose of this study was to evaluate the efficacy of the metal artefact reduction method using clinical contrast media in abdomen CT scan to produce high image quality.

2. Materials and Methodology

2.1. Phantom Design

A water-based abdomen phantom of diameter 32 cm was designed and fabricated using polymethyl methacrylate (PMMA) materials. The PMMA consists of five small tubes with diameter of 5 cm. The contrast media were filled in these small tubes. The small tubes were mounted in a circular pattern in abdomen phantom, which was then filled with water. A 100 ml of three clinical contrast materials (iodine, barium and gadolinium) with a clinical concentration of 350 mg/ml, 49 mg/ml, and 340 mg/ml were used respectively. Orthopedics metal screw represents the prototype of a high attenuation material that causes streak artefacts in CT imaging. Two type of metal implants materials with 6 mm diameter were used in separate phantom configuration to produce different artifact types.

The first configuration for non-contrast based phantom, used 316-grade stainless steel orthopedic screws, attached along the small PMMA tubes. The second configuration used 5-grade titanium alloy orthopedic screws. While for contrast based phantom, the first configuration used 316-grade stainless steel orthopedic screws, attached along the small PMMA tubes. The small PMMA tubes contain contrast media and orthopedic screw material each scan. The other remaining two tubes were filled with water with orthopedic screws. The second configuration used 5-grade titanium alloy orthopedic screws. The phantom configuration was shown in Figure 1.

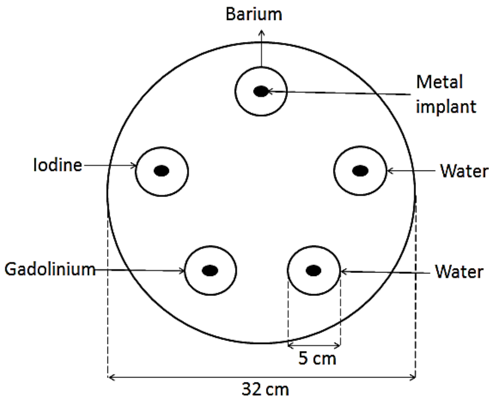


Figure 1. Axial image of the CT abdomen phantom.

2.2. CT scan parameters
All CT examinations were performed using CT scanner SOMATOM Definition AS, Siemens Healthcare, Forchheim, Germany (128 slices system) for abdomen routine scan. Table 1 shows a summary of CT parameters used in this study.

Table 1. Summary of CT scan parameters

	Single-energy CT	Dual-energy CT
Tube voltage (kV)	120	Fast kV-switching between 80 and 140
Tube current (mAs)	Tube current modulation (care4Dose setting)	
Pitch (mm)	0.35, 0.60, 1.20	
Slice Thickness (mm)	1.0, 3.0, 5.0	

2.3. Image Analysis
The signal-to-noise ratio (SNR) before and after applying metal artefacts reduction technique using contrast media were evaluated. The analysis of SNR was performed by drawing the five region-of-interest (ROI) using circular area of 50 mm^2 at the surrounding of each small PMMA tubes. The location of ROIs was standardized in the image analysis. The SNR was calculated with respect to the background (water). An average from five ROIs and background were used to calculate the SNR. The SNRs were calculated by dividing average of mean CT numbers by standard deviation of the background as shown in equation 1 [15].

$$\mathrm{SNR} = \frac{S_0\,(HU)}{\sigma_0\,(HU)} \tag{1}$$

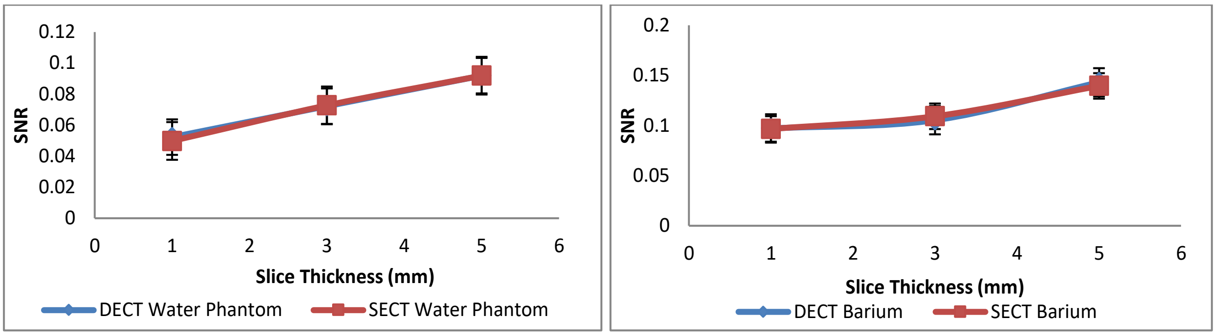
where, S_0 is the signal intensities, and σ_0 is the standard deviation of the background.

2.4. Statistical Analysis
The qualitative scales of image quality were reported based on SNR measurement. The students't-test was performed to determine the significant differences between the results. A p-value < 0.05 was accepted as statistically significant.

3. Results and Discussions

3.1. Single-energy and dual-energy CT
Figure 2 shows SNR against slice thickness for non-contrast based phantom and contrast based phantom in single-energy and dual-energy CT. SNR for single-energy CT and dual-energy CT for non-

contrast based phantom is not significantly different with p-value of 0.547. The contrast based phantom is also not significantly different with p-value of 0.982. Same findings was found by Exhibit et al. (2016) stated that image quality of blended images of dual-energy CT is similar to the conventional single-energy 120 kV acquisitions [16].

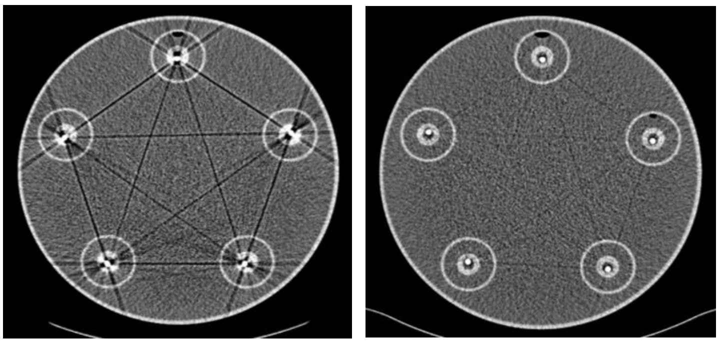


(a) (b)

Figure 2. SNR against slice thickness for (a) non-contrast based phantom and (b) contrast based phantom.

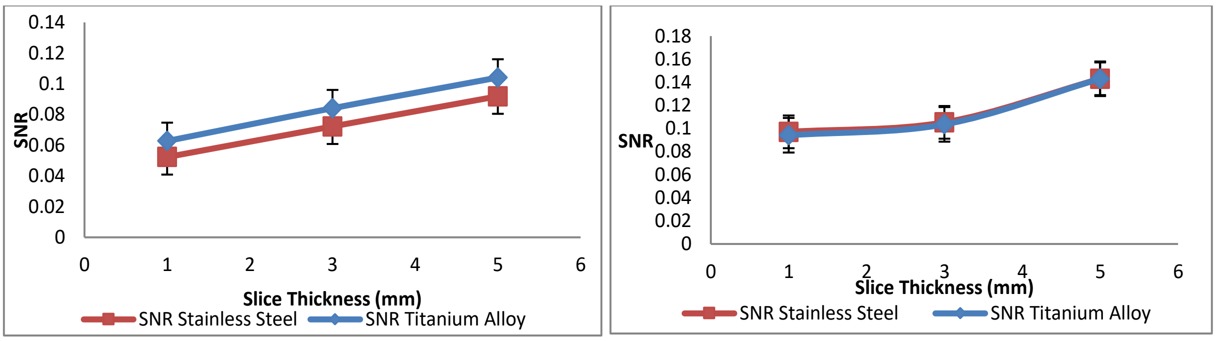
3.2. Stainless steel and titanium alloy

The severity of streaking artefacts on CT images varied with the presence of orthopedics screws depending on the material type. The streak artefacts are present between the orthopedic screw and elsewhere in the phantom (background). However, the streaking artefacts are more pronounced with the use of stainless steel screw compared to titanium alloy screw as shown in Figure 3.



(a) (b)

Figure 3. CT images with metallic artefacts in the presence of (a) stainless steel and (b) titanium alloy.



(a) (b)

Figure 4. The SNR against slice thickness for (a) non-contrast based phantom and (b) contrast based phantom.

Figure 4 (a) shows the SNR against slice thickness for titanium alloy and stainless steel in non-contrast based phantom. Titanium alloy shows higher SNR values compared to stainless steel (p-value = 0.002). The SNR is inversely proportional with the noise in the CT images [15]. The higher the SNR, the lower the noise appears in the images. Higher noise in CT images was obtained with the use of stainless steel. This is due to the higher of atomic number of stainless steel compared to titanium alloy. The atomic number of stainless steel (Z=26.7) is higher than the titanium alloy (Z=21.4). Thus, it causes higher scattered x-ray radiation.

Figure 4 (b) shows the SNR against slice thickness for titanium alloy and stainless steel in contrast based phantom. SNR of stainless steel and titanium alloy is not significantly difference with p-value of 0.204. This is because the x-ray attenuation of contrast media is higher compared to the orthopedic screw [11, 17]. Thus, the SNR value calculated for stainless steel and titanium alloy for contrast based phantom is not significantly difference.

However, the SNR values obtained with non-contrast based phantom appear higher when compared to SNR values of contrast based phantom. This shows that the CT images with contrast based phantom have less image noise compared to non-contrast based phantom. Furthermore, the use of contrast media helps to reduce metallic artefact, increase edge detection of soft tissue and enhances the image quality at the area of implants.

3.3. CT data acquisition

Pitch and slice thickness that used will also affect the quality of the CT image obtained. Figure 5 shows that the SNR results obtained at different pitch. The SNR values increase with the increment of slice thickness. The SNR decreases when the pitch increases as shown in Figure 6.

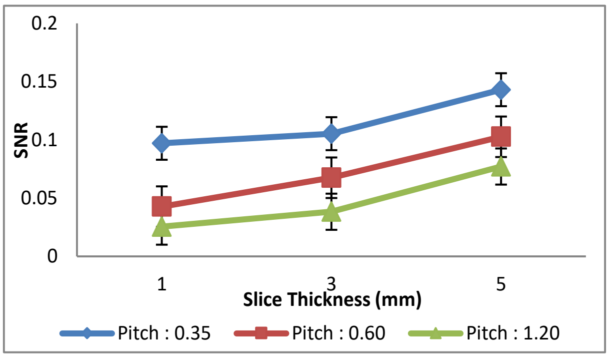


Figure 5. SNR against slice thickness.

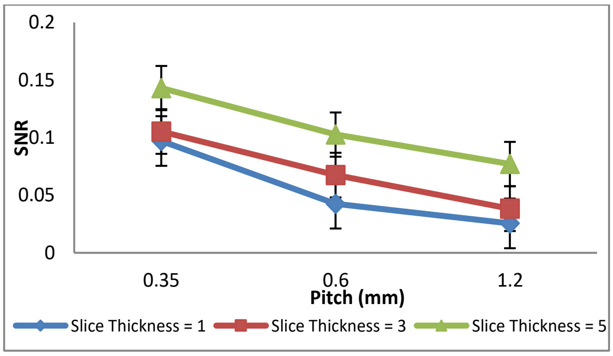


Figure 6. SNR against pitch.

Figure 5 shows the SNR value increases when the slice thickness increases. Thinner slice thickness reduces the size of the voxels. Smaller voxels absorbs or captures less number of x-ray photons. Thus, this will increase image noise; due to greater spatial resolution. Although thicker slice thickness have lower spatial resolution, they also have lower noise in CT images. However, if the slice thickness is too large, the CT images obtained will be affected by partial volume effect (PVE). The PVE occurs when different tissues or objects are represented by the same voxel. PVE is also known as partial volume averaging [19]. Thus, slice thickness of 5 mm shows optimum parameters for orthopedic implant with higher image quality with higher SNR value.

Figure 6 shows that the SNR value decreases when pitch increases. This is due to high noise in the images [18]. Pitch is defined as table distance traveled in one 360^{o} gantry rotation divided by beam collimation. However, pitch affects both image quality and patient dose. Increasing the pitch value increases the speed of moving patient through the x-ray beam and reduces the time required to cover an anatomical area. Higher pitch of 1.20 mm results in decreased patient dose, but, it also decreased the image quality (lowest SNR value). This is because there are gaps in the x-ray beams where the tissue is not irradiated. However, lowest pitch (0.35 mm) resulted in better image quality, but it gave high patient dose due to x-ray beam overlap and it causes a volume of tissue is irradiated more than once per scan.

Thus, pitch of 0.60 mm shows an optimum parameters with higher image quality (higher SNR value), and give optimum patient dose. The higher pitch and lower slice thickness settings resulted in the degradation of contrast and diagnostic image quality of the CT images. The use of thinner slice thickness settings resulted in a noisy image due to the greater spatial resolution. Therefore, the SNR values increase as slice thickness increases, and decrease as pitch increases. Thus, the use contrast media was able to enhance the CT images and reduce artefacts from the metallic implants, where the contrast-based materials provided higher x-ray attenuation that caused the high atomic number of iodine (Z=53), barium (Z=56) and gadolinium (Z=64).

3.4. Comparison for contrast media.and non-contrast media

Figure 7 shows a graph of SNR against slice thickness for non-contrast based phantom and contrast based phantom. The graphs shows that the higher SNR value was obtained with the use of contrast based phantom compared to non-contrast based phantom (p-value = 0.015). Murakami et al. (2010) stated that the SNR value is inversely proportional with the noise in the images [15]. Lower SNR value have higher noise appears in CT images. This explained that contrast based phantom has lower noise and streaky image than non-contrast based phantom in CT images. This is because the x-ray attenuation of contrast media is higher compared to the orthopedic screw [11, 17].

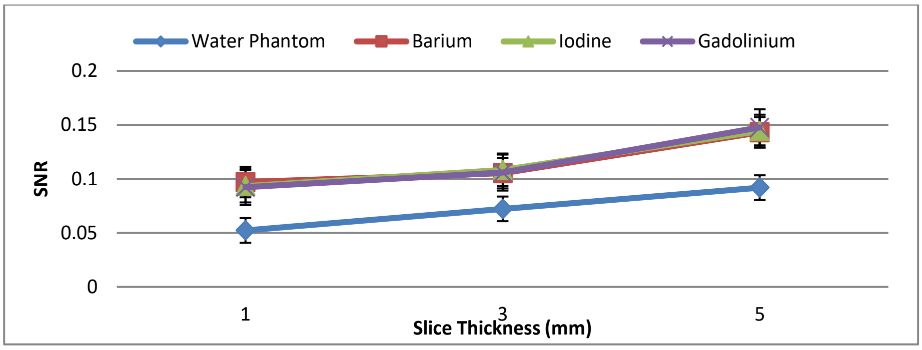


Figure 7. SNR against slice thickness in contrast based phantom and non-contrast based phantom.

4. Conclusion

In conclusion, our phantom study of water-based abdomen phantom in single-energy and dual-energy CT, we found that excessively low slice thickness and high pitch settings resulted in degradation in diagnostic image quality. Although an increase in pitch setting leads to decrease radiation dose towards patient, however these will an increase noise in CT images. Attenuation of contrast material may cause an increase in backround noise in addition to the beam hardening artefacts. Thus, our results suggest that it is desirable to use pitch of 0.60 mm, and slice thickness of 5.0 mm. The use of clinical contrast media is able to reduce metallic artefacts from implants (19 to 46%), and improved image quality in the area of metallic implants. Furthermore, the contrast media also improves the relative convergence in the area of metallic implants (edges and attenuation values) than the image without contrast media. The result of this study can be translated to clinical imaging, and contrast administration can be done by intravenous injection for iodine and gadolinium, while administrated orally for barium.

5. References

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