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Evaluation of a new method for metal artifact reducing in computed tomographic images

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ABSTRACT

Background: The common streak artifacts in computed tomographic (CT) images result from metal implants in patients. Metal artifact suppresses and obstructs diagnosis or misdiagnoses as it occurred in ten percent of the patients' tomographic images.

Objectives: To develop the method for metal artifact reduction in CT images using MATLAB software and implement it in phantoms with the metal artifact as well as in patients with the metal artifact in the head and neck region.

Materials and methods: The new method of metal artifact reduction in CT images using MATLAB software. The homogeneous polymethylmethacrylate (PMMA) phantom, the Alderson Rando phantom, and patients with a metal implant in the head and neck region were scanned by the Philips Brilliance Big Bore CT system. Commercial orthopedic metal artifact reduction (OMAR) software and a new method software were applied to the CT images of phantoms and patients. The quantitative analysis of image quality on a metal artifact of the head and neck region was evaluated in the percent noise. The qualitative analysis in clinical imaging was evaluated in scoring by two radiologists with the same experience.

Results: In the Alderson Rando phantom, the new algorithm indicated higher efficiency in metal artifact reduction than OMAR software. In contrast, for the patient at head and neck CT images with metal artifact reduction, OMAR, and the new method showed comparable results. The new method suppressed the artifact in homogeneous PMMA, Alderson Rando phantoms, and patients with a metal implant in the head and neck region with approximately 40%, 40%, and 60% percentage of noise reduction, respectively. The qualitative analysis by two radiologists showed comparable results of OMAR and the new method.

Conclusion: The efficiency of metal artifact reduction of the new method is better than no correction and OMAR in homogeneous PMMA phantom and Alderson Rando phantom. However, the efficiency of OMAR is better than the new method, and no correction regarding the percent noise.

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Introduction

Computed tomographic (CT) imaging was introduced in clinical practice in the early 1970s.[1] The evolution of the X-ray CT system resulted in high image quality and improved diagnostic capabilities. Since normal tissues are not superimposed on the image as is the case in conventional X-ray imaging, CT has become one of the most important modalities for diagnostic imaging, nuclear medicine, and radiation therapy because it provides cross-sectional images of the whole body. The clinical potential of

CT became evident during its early period, and the output solidified the role of computers in medical imaging. Recent advances in acquisition geometry, detector technology, multiple detector arrays, and x-ray tube design have led to scanning time now measured in fractions of a second.[2-7]

One common artifact in CT images results from metal implants by multiple mechanisms related to the metal itself and some to the reconstruction algorithm. The metal implant can cause beam hardening, scattered effect, photon starvation, and increased Poisson noise. Metal artifact suppresses and obstructs diagnosis or misdiagnoses as it occurred in ten percent of the patients' tomographic images.[8] The source of artifacts in the oral cavity of CT images is metal fillings in the teeth. It suppresses the diagnosis, causes misdiagnoses, and hampers organ delineation in CT images.

Several methods for reducing the metal artifact in the CT images include the iterative reconstruction technique and dual-energy technique.[9] Orthopedic metal artifact reduction (OMAR) is the first commercial product available that implements a robust algorithm to mitigate artifacts caused by metal implants in CT images. The crux of the OMAR implementation is an iterative loop where the output correction image is subtracted from the original input image. The resultant image can then become the new input image and the process can be repeated.

OMAR can induce some minor artifacts when the metal implant is close to the body surface or the low-density tissue. A spine with metal screws can create a problem when using OMAR. Similarly, a pacemaker can also create a problem in an orthopedic implant. Its proximity to the lung with metal wires entering the heart and lung area can cause the streaking artifacts when using OMAR which is not present in the non-corrected image.

In this work, the new metal artifact reduction method was developed to improve the images of metallic artifacts using MATLAB software. This study aims to evaluate the new method of metal artifact reduction in head and neck CT images and compare the resulting images with no correction and those obtained using a commercially available metal artifact reduction algorithm.

Materials and methods

Study of phantom

The concept of a new method of metal artifact reduction is the B-spline and averagely weighted interpolation techniques by MATLAB software. The new method of metal artifact reduction is shown in Figure 1. The B-spline curve is a piecewise polynomial curve whose shape is controlled by control points and the degree of its polynomial basis. In practice, the metal artifacts appear in only one or two slices. The information lost due to the artifact can be inferred from the slices immediately above and below (inter-slice) and within its slice (intra-slice). The information from inter-slices and intra-slice is fused to estimate the missing information in our method. The metal artifact causes very bright and dark streaks in an image to be easily detected by thresholding for the area with very high and low intensities. B-spline interpolation is used to find the intra-slice information. The intensity lost by the artifact is interpolated from the intensity within the same slice. The weighted average between the intensities of the slices above and below is used as the inter-slice information. The missing intensity is estimated according to the following equation.

$$I_{interslice,k}(x,y)=\alpha I_{k-1}(x,y)+(1-\alpha)I_{k+1}(x,y)$$

where I (inter-slice, k) (x,y) and I_k (x,y) are the weighted average and the original intensities at (x,y) in the k-th slice, respectively. α is the weight and has a value between 0 and 1. The weighted average is then applied

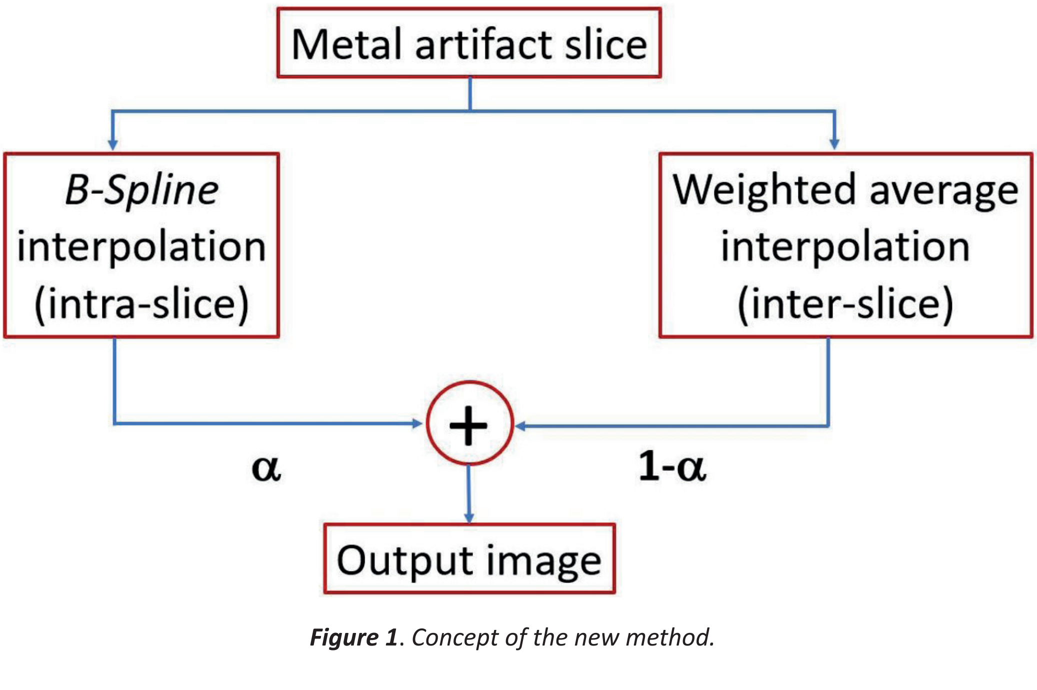

Figure 1. *Concept of the new method.*

to fuse the intra-slice and the inter-slice information. Since only a few slices are degraded by metal artifact, α for information fusion is manually set (all case set to 0.5). The concept of the new method was a simple and effective method to suppress the metal artifact in the CT image because the image space-based method in image processing was used together with the DICOM file format from CT.

The scanning parameter of Philips Brilliance CT Big Bore was 120 kVp, 3 mm slice thickness, helical mode, 512×512 matrix size, and field of view covering the body contour of the patient. In this study, a CT image from filtered back projection (no correction) was used as the original image. Upon completion of the algorithm development, the homogeneous PMMA phantom and Alderson Rando phantom images with and without amalgam inserts were used to evaluate the algorithm's utility in phantoms. The homogeneous PMMA, cylindrical phantom is 16 cm in diameter and 14 cm in length. Alderson Rando phantom incorporates the materials to simulate various body tissue muscle, bone, lung, and air cavities. It is made of tissue-equivalent material based on synthetic isocyanate rubber. The phantom material is processed chemically and physically to achieve a density of 0.985 g/cm^3 and an effective atomic number of 7.3 based on the International Commission on Radiation Units and Measurement (ICRU). The phantom is shaped into a human and sectioned transversely into slices 2.5 cm thick. Both phantoms were scanned by 16 detector rows Philips Brilliance Big Bore CT simulator with OMAR.[10] The tube voltage was fixed at 120 kVp, and the tube current time was varied at 100, 150, 200, and 250 mAs respectively for all phantom studies. The acquisition was repeated three times per mAs setting. The quantitative analysis of image quality in the phantom was obtained from the percent noise (standard deviation divided by the mean of CT number at the region of interest). The region of interest in the area of 1 cm^2 in rectangular shape was close to the metal artifact region.

Clinical study

This study was approved by the Institutional Review Board (IRB), Faculty of Medicine, Chulalongkorn University (IRB 627/60). Fifty-two head and neck CT images with metal artifact images from cancer patients were subjected to the metal artifact reduction method. All patients were acquired by a 16 detector rows Philips Brilliance Big Bore CT simulator with OMAR software. The efficacy of the metal artifact reduction method was assessed using quantitative and qualitative analysis. The quantitative analysis of image quality in patients was obtained from the percent noise. The qualitative image quality was determined by two independent radiologists to score the images. Both had the same experience in CT image interpretation (10 years of experience). This study was blind observations for two radiologists, and the weighted Kappa for inter-observer reliability was analyzed by SPSS version 22. The guidelines of image quality criteria are score 1 = very dissatisfied, score 2 = dissatisfied, score 3 = satisfied, and score 4 = very satisfied.

Result and discussion

Study of phantom

Examples of the transverse axial images from the homogeneous PMMA phantom and Alderson Rando phantom with and without artifact reconstructed by no correction, OMAR, and the new method algorithms are shown in Figure 2, 3, 4, and 5 respectively. The no correction, OMAR, and new method showed the same image quality in the homogeneous phantom and Alderson Rando phantom without metal which is shown in Figure 2 and Figure 4. The image quality of the new method showed better than no correction and OMAR in the homogeneous phantom and Alderson Rando phantom with metal as shown in Figure 3 and Figure 5.

The average percent noise of the homogeneous phantom and Alderson Rando phantom with and without artifact of no correction, OMAR, and the new method are shown in Table 1 and Table 2, respectively. As expected, the percent noise of the homogeneous phantom and Alderson Rando phantom with and without artifact decreased when mAs increased.

The new method's effectiveness in reducing the average percent of noise in homogeneous and Alderson Rando phantoms was slightly better than no correction and OMAR 17.4% and 9.7%, respectively. The results were consistent when compared with Wagenaar D *et al*. regarding the percentage of noise reduction.[9]

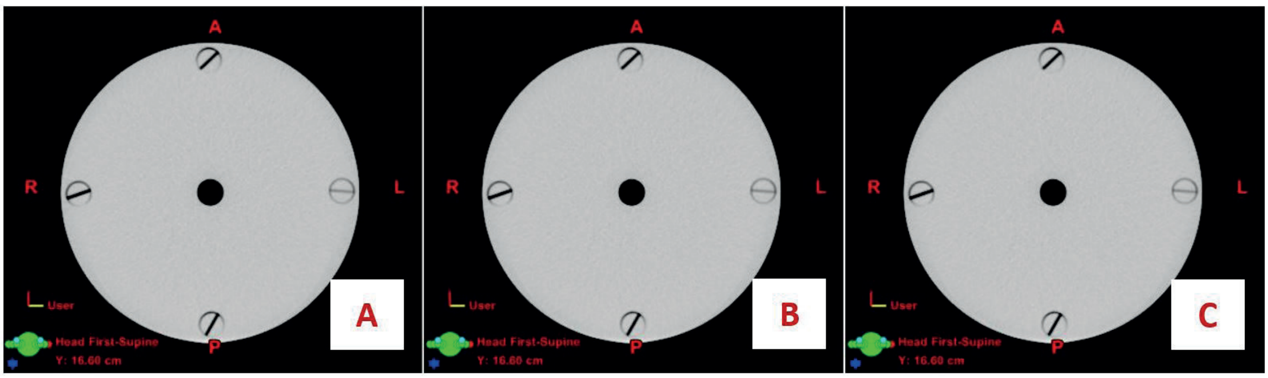

Figure 2. *Homogeneous phantom without metal artifact reconstructed by 3 different methods. A: FBP, B: OMAR, C: new method.*

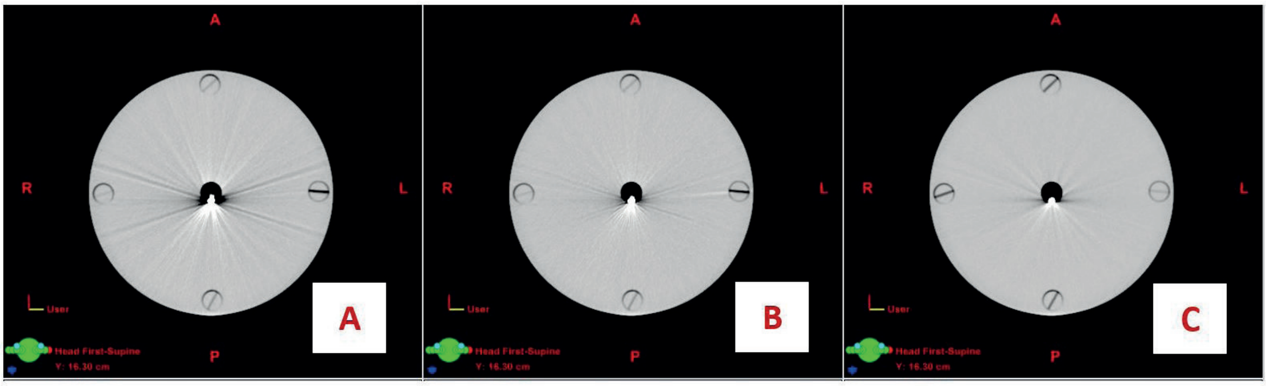

Figure 3. *Homogeneous phantom with metal artifact set close to the center of phantom reconstructed by 3 different methods. A: FBP, B: OMAR, C: new method.*

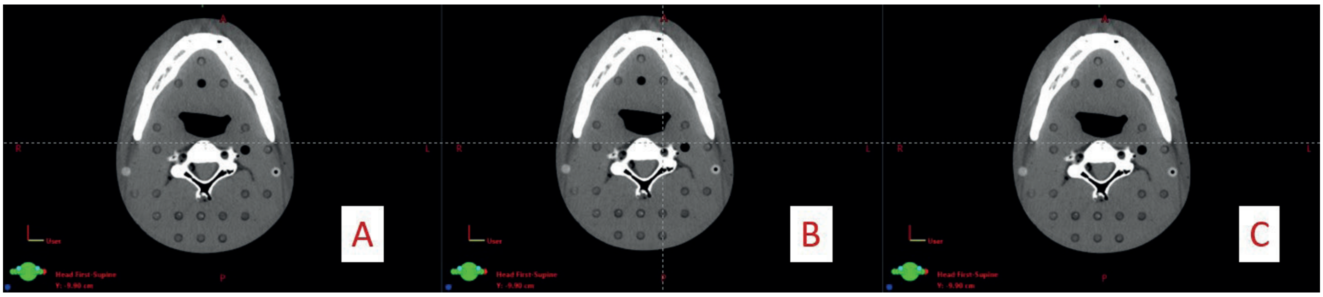

Figure 4. *Transverse axial image of Alderson Rando phantom, head, and neck part, without metal artifact reconstructed by 3 different algorithms. A: FBP, B: OMAR, C: new method.*

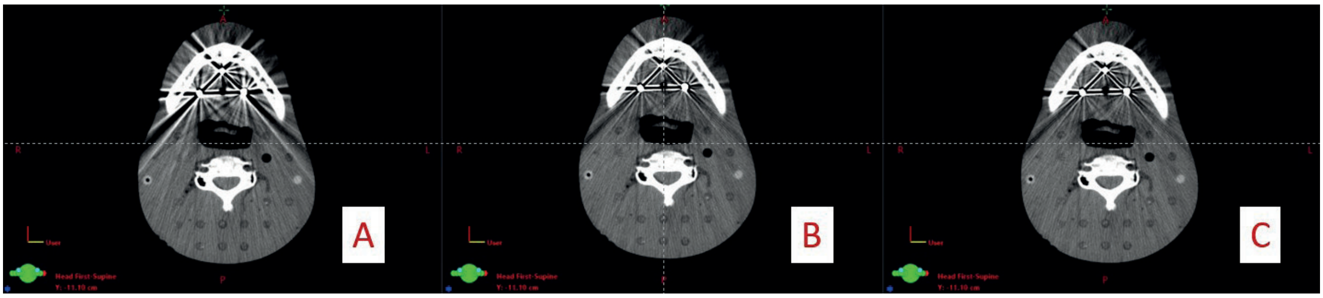

Figure 5. *Transverse axial image of Alderson Rando phantom, head, and neck part, with metal artifact reconstructed by 3 different algorithms. A: FBP, B: OMAR, C: new method.*

Table 1 Average percentage of the noise of homogeneous phantom with increasing tube-current time.

mAs	Average %noise (without metal)			Average %noise (with metal)		
	FBP	OMAR	New method	FBP	OMAR	New method
100	8.3±0.6	8.3±0.6	6.4±0.7	34.7±5.3	26.4±2.5	12.1±1.4
150	7.6±0.9	7.6±0.9	5.4±0.2	32.6±3.7	21.2±1.5	12.0±0.3
200	5.9±0.6	5.9±0.5	4.5±0.3	24.8±3.9	19.2±2.1	11.6±1.7
250	5.6±0.5	5.6±0.5	4.2±0.3	23.8±3.6	18.2±1.0	10.5±0.6

Table 2 Average percentage of the noise with increasing tube current time studied in Alderson Rando phantom without and with the metal artifact.

mAs	Average %noise (without metal)			Average %noise (with metal)		
	FBP	OMAR	New method	FBP	OMAR	New method
100	66.3±31.0	66.0±30.5	27.9±2.0	290.0±38.7	288.4±22.3	162.6±22.0
150	62.5±38.2	62.6±38.2	22.4±3.2	281.6±44.4	286.8±21.4	105.6±30.0
200	60.1±36.1	59.9±36.2	18.9±1.9	277.3±34.7	283.5±27.6	1.7±31.7
250	54.2±32.1	54.5±32.1	18.9±1.5	264.3±29.6	264.3±28.1	92.4±30.0

Clinical study

Three of fifty-two CT images of head and neck cancer patients with metal artifacts reconstructed by no correction, OMAR, and the new method are shown in Figure 6. The percent noise of CT patient images with a metal artifact of no correction, OMAR, and new method are shown in Table 3. The average percentage noise of CT patient images of the new method was less than no correction and more than OMAR. Twenty of fifty-two CT images of the new method showed better image quality than no correction and OMAR, but two of fifty-two were worse than no correction and OMAR.

The performance of both metal artifact reduction methods is shown regarding the percent of metal artifact reduction in CT patient images as in Table 4. The OMAR was slightly better, 55.5±0.15% reduction of the percentage of noise than a new method of 41.2±0.23% reduction percentage of noise. The performance of a new method showed better image quality than no correction and OMAR in Figure 6.

Two independent radiologists with similar experience evaluated the image quality by scoring the CT images among no correction, OMAR, and the new method for metal artifact reduction. The image quality scoring is shown in Table 5. Both radiologists' evaluation confirms the agreement on the new method and OMAR has better image quality than no correction image. Two of fifty-two CT images that resulted from a new method show more artifacts than no correction and OMAR because of many streak artifacts from metal in adjacent CT images.

The result in homogeneous PMMA phantom and Alderson Rando phantom with metal artifact shows that the metal artifact suppressed by a method is better than no correction and OMAR. In contrast, the clinical study indicated that the suppression of the metal artifact using OMAR is better than the new method and has no correction. The major limitation in clinical application is that OMAR could not be used in DICOM file format when processing the images. Therefore, the CT images from other vendors could not be processed by OMAR. Therefore, it is necessary to develop a new method using the DICOM file format for CT images from other vendors. A new metal artifact reduction method can be used in several CT scanner vendors because it uses the DICOM format in image processing.

Several publications reported the performance of the metal artifact reduction algorithm by sinogram technique.[3-6,11-13] and forward projection metal artifact reduction technique.[3] Most new methods show much better performance than no correction images in qualitative and quantitative evaluations. Most publications studied in the phantom or simulation phase without clinical applications. This study shows both phantom and clinical applications in which the new method could reduce metal artifacts

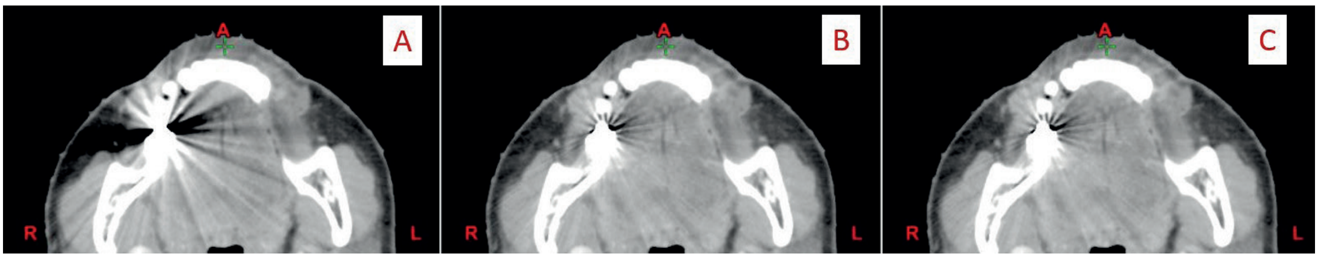

Figure 6. *Patient computed tomographic images with metal artifacts reconstructed by 3 algorithms. A: FBP, B: OMAR, C: new method.*

Table 3 Average percentage of the noise of computed tomographic patient images of three algorithms.

Average %noise (FBP)	Average %noise (OMAR)	Average %noise (new method)
111.2±65.8	46.6±30.0	63.8±54.7

Table 4 The percent of metal artifact reduction in computed tomographic patient images.

Percent of metal artifact reduction (%)	
OMAR	New algorithm
55.5±0.15	41.2±0.23

Table 5 Image quality of patients with metal artifacts using three methods, scored by two radiologists.

	Average scores on image quality, with metallic artifacts		
	FBP	OMAR	New method
1st Radiologist	1.2±0.4	2.5±0.8	2.3±1.0
2nd Radiologist	1.5±0.5	3.5±0.5	3.0±1.0

in phantoms and patients. The performance of the new method shows better image quality than the no-correction image. However, the new method does not perform better than OMAR in a heterogeneous environment. It improves the image quality regarding metal artifact reduction, but it underperforms the current commercial metal artifact reduction algorithm. There is an unexpected new artifact consequence where a new method may modify more artifacts due to metal artifacts in the previous and next CT images. The radiologist and radiation oncologist should always compare filtered back projections and a new method dataset in clinical applications.

Conclusion

The efficiency of metal artifact reduction of the new method is better than no correction and OMAR in homogeneous PMMA phantom and Alderson Rando phantom in the clinical range of mAs. However, the efficiency of OMAR is better than the new method, and no correction regarding the percent noise. The image scoring by two independent radiologists with the same experience shows comparable efficiency results of the new method and OMAR.

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