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Evaluation of Metal Artifact Reduction software in Computed Tomography

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ABSTRACT

Introduction: The image quality of computed tomography (CT) can be seriously lowered by metal implants of patients. These implants are known to exert a significant impact on diagnostic accuracy due to artifacts. The current study aimed to assess the usefulness of Metal Artifact Reduction (MAR) software in the reduction of metal artifacts, in comparison to iterative reconstruction algorithm (IDREAM).

Material and Methods: Water phantom with raw chicken leg underwent CT scan (Sinovision, Insitum 16) before (reference group (GP_{ref}) and after metal implantation: ((GPA (IDREAM without MAR) and GPB (IDREAM with MAR)). A total number of 30 patients [GP1 (instrumented spine (n=15)), GP2 (Brain clips (n=15))] underwent CT scan (Sinovision ,Insitum 16). GP1 and GP2 were reconstructed using two procedures including IDREAM without MAR vs. 2: IDREAM with MAR. All images were evaluated using subjective and quantitative assessment.

Results: In subjective image quality assessment, the scores of MAR images were higher than IDREAM images ($P<0.05$) as indicated by four radiologists. The absolute CT difference (ΔCT) and Artifact index (AI) demonstrated that MAR appeared to be superior for the reduction of metal artifacts ($P<0.05$).

Conclusion: As evidenced by the obtained results, MAR software can be efficiently used for metal artifact reduction in computed tomography (instrumental spine and brain clips).

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Introduction

Computed tomography is used for the evaluation of patients' post-operative condition. The use of metal implants is known to reduce image quality as a result of photon starvation and beam hardening artifact. Therefore, the researchers should turn their close attention to the reduction of metal artifacts [1]. Many solutions have been suggested for the reduction of metal artifacts, such as the increase in both tube peak voltages (kVp) and tube current (mA).The increase in kVp and mA leads to higher patient dose without exerting a considerable impact on image quality [2].

CT Metal artifacts can be reduced by iterative reconstruction method and the algorithm of metal artifact reduction [3–7]. However, the efficiency of these techniques depends on the metal material composition. High attenuation coefficient materials (e.g. dental fillings and hip implants) cause huge artifact that cannot be efficiently reduced. There are different metal artifact reduction software, such as orthopedic metal artifact reduction (OMAR), smart metal artifact reduction software (SMAR), and Metal Artifact Reduction (MAR) algorithm [8, 9]. MAR algorithm is a commercial algorithm produced by Sinovision (Insitum, CT 16 slice).The present research aimed to evaluate the usefulness of MAR software in the reduction of metal artifacts, in comparison to an iterative reconstruction algorithm (IDREAM).

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Materials and Methods

Phantom study

Water phantom with raw chicken leg (Figure 1) was scanned before (reference group (GP_{ref})) and after metal implantation (metal group) using CT-acquisition protocol (Sinovision ,Insitum 16 ,kVp =120; mA =200; pitch=1.0; rotation time =0.75 sec; matrix 512x512). The images of GP_{ref} were reconstructed by IDREAM. On the other hand, the images of metal group were assigned to two groups (GPA and GPB) according to reconstruction technique (A: IDREAM without MAR vs. B: IDREAM with MAR).

Patient Study

A total number of 30 patients [Group 1 (GP1 (instrumented spine (n=15)), GP2 (Brain clips (n=15))] underwent CT scan (Sinovision, Insitum 16) acquisition Protocol (kVp=120; pitch=1.0; rotation time=0.75 sec; matrix size 512x512), while mA was 280 and 300 for GP1and GP2, respectively. All images were reconstructed twice (1: IDREAM with MAR and 2: IDREAM without MAR).

Figure 1. Computer tomography scout image of chicken leg phantom

C B A

Figure 2. Computer tomography demonstrating the drawing of 2 regions of interest at the surrounding soft tissue and bone: A) the normal side joint. B) iterative reconstruction algorithm (IDREAM) with Metal Artifact Reduction (MAR) (GP_A), and C) IDREAM without MAR (GP_B)

Four radiologists (R1, R2, R3, and R4) used a scale of 0-3 to measure the degree of image quality. Score 0 reflects the higher impact of metal products on bone and soft tissue structures to be treated. Score 1 is demonstrative of a mild artifact that affects the diagnosis. Score 2 suggests a weak artifact; however, it has been detected. Score 3 indicates that no items exert an impact on the accuracy of the diagnosis.

The location and size of ROIs were consistent. The sizes of ROIs were measured at ROI1:238mm^2 andROI2:3 mm^2 for phantom and ROI: 3 mm^2 for patients.

Each ROI was calculated for the CT value and the standard deviation (SD). The image quality was evaluated using a CT value differential and artifact index(AI) , in contrast to IDREAM and MAR frames.

The ΔCT and AI were calculated using the following formula [8]:

$$\Delta CT = |CTart - CTref| \quad (1)$$

Where , CTart is the Hounsfield unit (CT number) of artifact.

CTref is the hounsfield unit (CT number) of normal side.

$$AI = |SDart - SDref| \quad (2)$$

Where , SDart is the standard deviation of artifact .

CTref is the standard deviation of normal side

Image quality indices (noise (N) and Signal to Noise Ratio (SNR)) were calculated for IDREAM and MAR groups applying the following formula [10]:

$$N = \pm\sigma \quad (3)$$

$$\%SNR = (1/\sqrt{\sigma})\ x100 \quad (4)$$

Where σ is the standard deviation of region of interest.

Statistical analysis

Data were analyzed in SPSS software (version 19.0). All test results are depicted by ±SD .A p-value less than 0.05 was considered statistically significant.

Results

Metal materials developed significant artifacts which indicated both photon starvation and beam hardening effects (figure 3A, 4A, and 5A), and artifacts decreased with the application of MAR (figure 3B, 4B, and 5B). The objective analyses which compared IDREAM (GPA) and MAR (GPB) are presented in tables 1 and 2, while tables 3 and 4 are related to GP1 and GP2. The ΔCT and AI values of IDREAM reconstructed images were statistically significant (P<0.05), in comparison to IDREAM-MAR reconstructed images.

A B

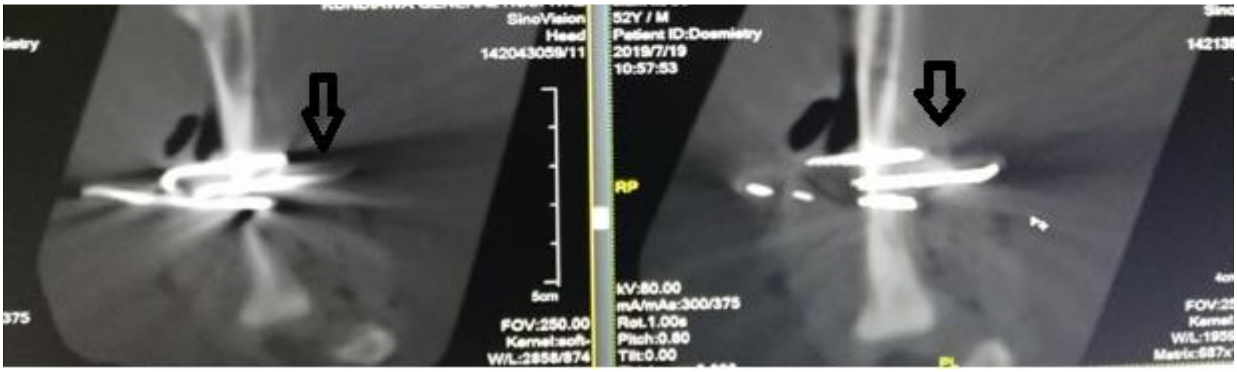

Figure 3. Computer tomography demonstrating the image of chicken leg with metal artifacts (dark and bright streaks): A) IDREAMwithout MAR (GPA) and B) IDREAM with MAR (GPB)

A B

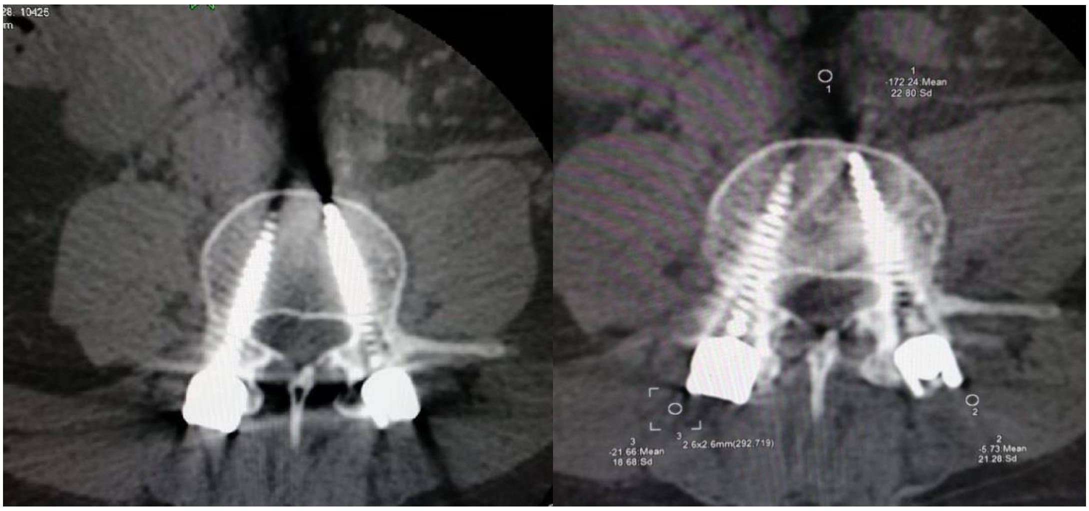

Figure 4. Computer tomography demonstrating the dropping of 3 regions of interest at the surrounding soft tissue of spine (GP1): A) IDREAMwithout Metal Artifact Reduction (MAR), and B) IDREAM with MAR

A B

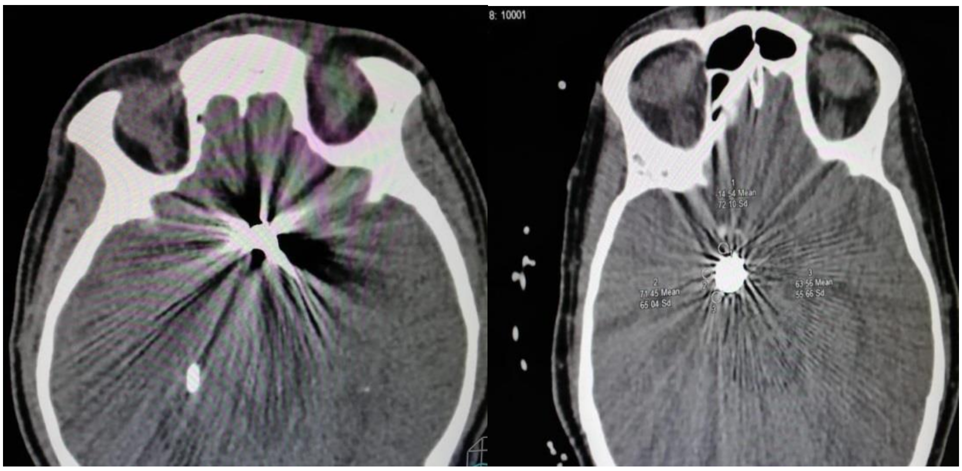

Figure 5. Computer tomography showing the dropping of 3 regions of interest at the surrounding soft tissue of brain clips (GP2): A) iterative reconstruction algorithm (IDREAM) without Metal Artifact Reduction (MAR), and B) IDREAM with MAR

Table 1. Objective analyses of Phantom comparing GPA against GPB in terms of ΔCT and AI

ΔCT			AI	
	IDREAM	MAR	IDREAM	MAR
ROI1	31	14	22.85	10.38
ROI2	263	54	21.63	4.57
P-value	P<0.05		P<0.05	

IDREAM: iterative reconstruction algorithm, MAR: Metal Artifact Reduction

As illustrated in Table 2, for phantom, the noise (N) and SNR of IDREAM group were significantly different, as compared to IDREAM in MAR group, where (N: ROI1=35.3 vs. 24.25; $P<0.05$, ROI2=11.79 vs. 9.1; $P<0.05$) for IDREAM and MAR group, respectively. The SNR of GPB were highly significant, as compared to GPA, where (SNR: ROI1=30% vs. 20%; $P<0.05$, ROI2=33% vs. 16%; $P<0.05$) for GPA and GPB, respectively.

Four radiologists (R1, R2, R3 and R4)scored MAR images higher than IDREAM images (R1:2.2 ± 0.50 vs. 0.5±0.3, P< 0.05; R2: 1.5±0.5 vs. 0.21±0.2, P<0.05; R3: 2.00±0.4 vs. 0.4±0.5, P < 0.05 and R4: 1.4 ± 0.2 vs. 0.3±0.2).

Table 2. Objective analyses of Phantom comparing IDREAM (GPA) and MAR (GPB) in terms of Noise and SNR

Noise= ±σ			%SNR=(1/√σ) x100	
	IDREAM (GPA)	MAR (GPB)	IDREAM (GPA)	MAR (GPB)
ROI1	35.3	24.25	20 %	30 %
ROI2	11.79	9.1	16 %	33 %
P-value	P<0.05		P<0.05	

IDREAM: Iterative reconstruction algorithm, MAR: Metal Artifact Reduction

Table 3. Objective analyses of GP1 (Lumber spine) comparing MAR and IDREAM in terms of ΔCT and AI

ΔCT			AI	
	IDREAM	MAR	IDREAM	MAR
ROI1	744.9	110	103.05	39.55
ROI2	484.1	278.95	428.55	210
ROI3	588.7	169.7	280.65	76.95
P-value	P<0.05		P<0.05	

IDREAM: Iterative reconstruction algorithm, MAR: Metal Artifact Reduction, ROI: region of interest

Table 4. Objective analyses of GP2 (Brain Clips) comparing MAR and IDREAM in terms of ΔCT and AI

ΔCT			AI	
	IDREAM	MAR	IDREAM	MAR
ROI1	652.37	129.31	336.03	138.8
ROI2	608.2	128.2	210.13	166.09
ROI3	341.3	67.6	305.79	92.66
P value	P<0.05		P<0.05	

IDREAM: iterative reconstruction algorithm, MAR: Metal Artifact Reduction, ROI: region of interest

Discussion

The presence of metallic implants in the CT scanned volume caused an artifact which appeared as dark and bright streaks across the reconstructed image (figures 3, 4, and 5) [11]. Metallic artifacts can significantly degrade the quality of CT images to a point of making them diagnostically unusable [12].

When the X-Ray beams hit a high attenuation material (e.g. metal implants), less photons reach the detectors resulting in noisy images [13,14].This effect is called photon starvation; however, beam hardening means that large amount of high energy photons pass through the scanned object and cause dark streaks [15] .When the beam travels through high-density materials, this effect will be magnified.

For phantom, the use of MAR algorithm in GR_B reduced the noise which in turn led to the enhancement of SNR (Table 2), in contrast to IDREAM (GP_A). Therefore, MAR algorithm demonstrated a significant improvement in ΔCT and AI for phantom (tables 1, 2) and patients studies (tables 3, 4), in comparison to IDREAM. The efficiency of MAR algorithm can be attributed to iterative process the obtained data went through. These data are used as input into an iterative loop, where the corrected image (output) is subtracted several times from the input to get the final corrected image. MAR identifies the metal points through segmentation process and replaces data points with interpolated values [16, 17].

In the present study, the qualitative assessment of the four radiologists suggests that the image quality substantially increased with the application of MAR algorithm in all patients with metal implants. Although Wang et al. [18] reported that prior Metal Artifact Reduction System (MARS) is unable to demonstrate the details of the structure around the metal, MAR (Sinovision ,Insitum 16) causes an artifact reduction which allows for the recovery of soft tissue and bony structure [18-20]. The present study shows the effect of MAR software in enhancing the clinical diagnosis in contrast to Wang et al. To the best of our knowledge, no study has so far been conducted on the assessment of MAR software (Sinovision, Insitum 16). Therefore, it is recommended that further studies be carried out on the efficiency of MAR for different positions of metal implants and with greater sample size.

Conclusion

As illustrated by the obtained data, MAR software (Sinovision , Insitum 16) can reduce the artifacts around the metals that allow anatomic visualization of soft tissue and bony structures. The application of this finding can increase the accuracy of diagnostic tests in patients with metal implants.

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