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Effectiveness of orthopedic metal artifact reduction among patients undergoing computed tomography at a tertiary setting – A cross-sectional study

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ABSTRACT

Background: In computed tomography (CT), metal implants increase the inconsistencies between the measured data and the linear assumption of the radon transform made by the analytic CT reconstruction algorithm. **Aims and Objectives:** The aims of this study was to evaluate the effectiveness of orthopedic metal artifact reduction (O-MAR) among patients undergoing CT at a tertiary setting. **Materials and Methods:** A cross-sectional observational study was conducted on 30 subjects attending the department of radiology for CT scan for 1 year from December 2018 to 2019. The CT scan was performed in 64 detector row (PHILIPS INGENUITY CORE 128 slice) scanner. The patient was asked for the presence of metallic objects/history of implants, and the topo gram confirms it. Image noise was considered as the primary outcome variable. The statistical analysis was performed using the coGuide software and $P<0.005$. **Results:** All the thirty participants were analyzed finally. Image noise in plain image type was 79.5 SD of Hounsfield units, and in O-MAR image type, it was 44.01 SD of Hounsfield units denoting a higher percentage of SD in plain than O-MAR images. **Conclusion:** The O-MAR application helped in improving image quality of CT for patients in the aspect of metal artifact reduction and soft-tissue profile. However, it can also improve diagnostic quality in the evaluation of patients with severe metallic artifacts by decreasing the negative impacts of orthopedic metals.

Key words: Coiling; Dental implants; Phantom; Prosthesis; Techniques

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INTRODUCTION

Computed tomography (CT) serves as an essential imaging modality for a wide range of diagnostic and treatment planning applications, including the evaluation of post-operative orthopedic surgery patients.[1] Streak artifacts from high attenuation objects are a common problem in CT. This type of artifact typically occurs from metallic implants such as dental fillings, hip prostheses, implanted marker bins, branchy-therapy seeds, pacemakers, or implanted cardioverter defibrillators. When X-rays pass through metal objects, there is strong attenuation between them that originates artifacts in the dark shadows of the measured sonogram. These "metal shadows" are of less use in constructing an image. Removing metal artifacts during reconstruction require dealing with "missing data."[2]

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Forty years long history demonstrated that metal artifact reduction (MAR) is a general problem that has spawned numerous algorithmic approaches. Multiple contributions amplified in the presence of metal are the main reason for artifact origin that can be from incorrect assumptions in the CT reconstruction model that is related to the image coefficients arising from X-ray projection (sinogram).[3] Diagnostic ability and accurate distinction of tissue types in the image get affected due to errors in CT numbers. Due to this, dose calculation errors during radiation therapy for cancer treatment get affected as accurate tumor localization, and characterization of surrounding tissues get hindered, affecting treatment success. Such problems are encountered in orthopedics, where the specialty needs high image quality very close to metal implants for the success of treatment. For the past 40 years, extensive research and development efforts have been devoted to MAR to overcome artifacts in CT caused by metal objects.[4]

Multiple mechanisms such as photon starvation, beam hardening, scattering, partial volume effects, under-sampling, and patient motion are combined together to produce metal artifacts.[5] An increase in tube current is one of the common techniques used to prevent artifacts. The method has the disadvantage of providing a high radiation dose to the patient with compromised image quality. In the literature, various methods such as MAR algorithms have been developed to lower artifacts in surrounding tissues and at the bone-metal interface.[6]

Various MAR algorithms exist, some based on single-energy techniques and some on dual-energy (DE) techniques. The latter technique is characterized by simulating monoenergetic images. On the basis of the attenuation information obtained from the two different (low and high peak kilovoltage) energy spectra, the DE data set is decomposed into a linear combination of mass attenuation coefficients of two basis materials. Using these two data sets, virtual monoenergetic extrapolation (VME) is performed, and monoenergetic images for specific photon energies can be generated. Two Kiloelectronvolt levels for VME images for MAR for various types of metal implants are relatively high and range between 77 and 141 keV.[7]

The previous studies by Patel and Marin,[8] Zhang et al.,[9] and Chou et al.,[10] have demonstrated the effectiveness of various reconstruction techniques used in clinical practice in reducing metal artifacts, such as MAR algorithms, model-based iterative reconstruction, iterative MAR (iMAR, pre-commercial version, Siemens Healthcare), single-energy MAR, and virtual monochromatic imaging (VMI).[11]

The first commercialized iterative reconstruction method that can be applied to conventional CT data is the MAR algorithm for orthopedic implants (orthopedic metal artifact reduction [O-MAR], Philips Healthcare). It is based on an iterative loop, in which the metal sonogram is identified, extracted, and applied as a mask in the generation of the metal artifact-corrected images.[12] This O-MAR algorithm was developed in the year 2012, after which few studies detailed its exceptional results in reducing metallic artifacts for optimal visualization of various target lesions. Boomsma et al., in their phantom study, concluded that an increasing Cisco Network Registrar on a 64 slice CT system in light and medium disturbance image and using O-MAR in the presence of metal artifacts increased image quality.[13] In another study by Li et al.,[14] where the clinical evaluation of a commercial O-MAR tool for CT simulations in radiation therapy was used, the noise levels of the selected region of interest were reduced from 93.7 to 38.2 HU.

However, the literature is scarce on the effect of O-MAR on patients undergoing CT scans, especially in India. Hence, the present study was aimed to evaluate the effectiveness of O-MAR among patients undergoing CT in a tertiary setting.

Aims and objectives

The aims of this study was to evaluate the effectiveness of orthopedic metal artifact reduction (O-MAR) among patients undergoing CT at a tertiary setting.

MATERIALS AND METHODS

A cross-sectional study was conducted in the radiology department of a tertiary care setting for a period of 1 year, from December 2018 to 2019. By universal sampling method, 30 subjects with metallic objects/implants/dental fillings who underwent various CT scans were selected. Prior permission was obtained from ethical members of the tertiary care setting (Reference number: 236/IHEC/1-19), and a written informed center was taken from all the subjects before the study started. Confidentiality was maintained all along.

Inclusion criteria

The following criteria were included in the study:

- Thirty subjects, both male and females aged 18–60 years, were selected
- Patients with metallic objects/implants who underwent CT scans were included in the study.

Exclusion criteria

The following criteria were excluded from the study:

- Females of reproductive age group and pregnant women.

Data collection

The CT scan was performed in a 64-detector row (PHILIPS INGENUITY CORE 128 slice) scanner. The patient was asked for the presence of metallic objects/history of implants, and the topo gram confirms it. Corrections for the metallic objects, if removable, were made, and a helical scan was performed with O-MAR software which reconstructs both uncorrected and corrected images as default. Original data were extracted from the CT console to Philips EBW. In the Philips EBW workstation, a slice with the maximum artifact in the plain image was noted, the same slice was compared in the O-MAR image, and their standard deviation (SD) of HU values was compared.

O-MAR algorithm

The commercial O-MAR algorithm evaluated in this study is an iterative projection modification solution. The original CT image, which is not corrected, is reconstructed without MAR. This input image is then divided into tissue and non-tissue pixels and used during the first iteration. Then, tissue-classified input images are all forward projected to generate sinogram data which are subtracted from the original image sinogram to produce an error sinogram. The metal sinogram data are then utilized as the mask to remove the non-metal data points from the error sinogram. This error sinogram data are back-projected to generate a correction image and combined with the current input image to generate the updated image for the next iteration. This process is iteratively performed until reaching optimization. In this algorithm, the metal-only image consists of all pixels set to zero except for those pixels categorized as metal, which will be used to identify the projections within the sinogram data that have contributions from metal. If no large clusters of metal pixels are present in the image, no further processing is performed. Therefore, this algorithm has no impact on non-metal regions in the images and can be used for processing large orthopedic metal implants. During the first iteration process of this O-MAR algorithm, the severe metal artifacts and hypodense areas in the original uncorrected image may have an impact on generating a robust tissue-classified image. As such, the tissue-classified image is not produced from the original uncorrected sinogram but from the sinogram with the metal region identified, removed, and interpolated with simulated tissue values. This modified sinogram is back-projected, and the resultant image is used to create the tissue-classified image. This step was performed only in the first iteration. As a significant portion of the metal artifacts was corrected, the tissue classified image is generated from the current input image during the start of the second iteration. The spatial resolution of the original image is maintained as the corrections only affect the metal artifact regions of the original image. This procedure is different from some other algorithms, where an entirely new image is produced to correct metal artifacts, which can deteriorate the overall spatial resolution of the corrected image.[12]

Examination technique

Patients were undergone routine protocols. In the case of metal/implants found in the topo gram scan, an additional O-MAR series is made.

Table 1 illustrates O-MAR applied abdomen protocol.

Statistical analysis

The coGuide software was BDSS Corp[15], used for data analysis. Basic statistics, that is, the mean and the SD, were calculated for quantitative data.

Image noise was considered the primary outcome variable. The type of image was considered the primary outcome variable. Data were represented as the mean and SD for noise level. Data were also represented using appropriate diagrams like a bar diagram.

RESULTS

All 30 participants were finally analyzed.

Image noise in plain image type was 79.5 SD of Hounsfield units, and in O-MAR image type, it was 44.01 SD of Hounsfield units which denotes a higher percentage of SD in plain than O-MAR images (Table 2).

Table 1: O-MAR applied abdomen protocol

Protocol	Abdomen – helical		
Patient position	Supine - feet first		
Scan	PA-180		
Area coverage	Domes of diaphragm – Symphysis pubis		
Scan direction	Craniocaudal		
Gantry angle	0		
Slice thickness	5 mm		
Increment	5 mm		
Kv, mAs/slice	120, 250		
Resolution	Standard	Filter	Standard (C)
Collimation	64*0.625	Pitch	0.984
Rotation time	0.75 s		
FOV	350 mm	Matrix	512*512
Enhancement	0.0		
Recon (IRS)	Plain phase 2 mm/1 mm		
Reconstruction	Axial, coronal, and sagittal		
O-MAR	Selected – 5 mm thickness		

O-MAR: Orthopedic metal artifact reduction

Table 2: Summary of image noise in a different type of images (N=30)

Type of Image	Average SD values
Plain	79.5
O-MAR	44.01

O-MAR: Orthopedic metal artifact reduction

Table 3 shows the comparison of mean of HU with plain and O-MAR images and no statistically significant difference between HU and type of image (P=0.170).

Figure 1 explains the stages of planning O-MAR image.

Figure 2 shows a patient with the implant in the left femur showing artifact in the plain image and the artifact reduction in the O-MAR image.

Figure 3 shows a patient with the implant in the right shoulder showing artifact in the plain image and the artifact reduction in the O-MAR image.

Figure 4 shows axial reformatted CT images (Soft-tissue window) of a patient with metallic implant in distal humerus showing dark streak artifact obscuring depiction of adjacent soft tissue and degrading image quality (on left). The O-MAR axial image (on right) showing general noise artifact reduction helps in visualizing the bony cortex and adjacent soft tissue.

Table 3: Comparison of mean of HU between group (N=30)

Parameter	Type of image (Mean±SD)		P value
	Plain (N=30)	O-MAR (N=30)	
HU	59.37±71.26	37.54±48.27	0.170

O-MAR: Orthopedic metal artifact reduction

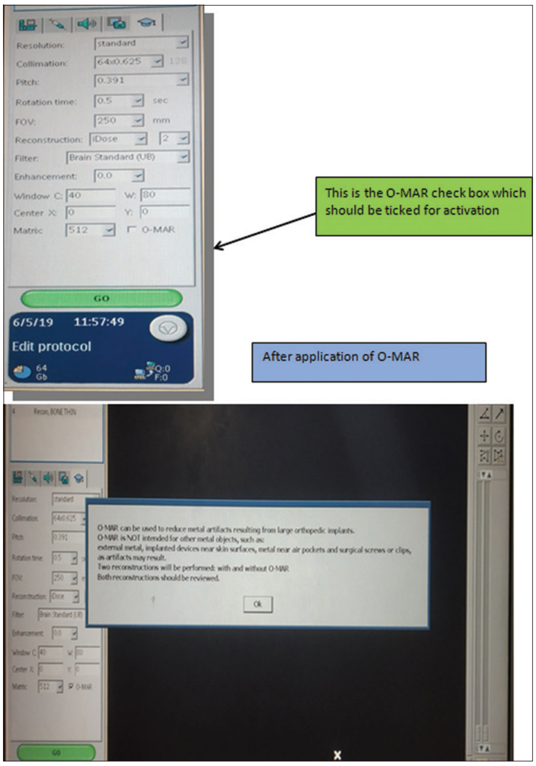

Figure 1: Stages of planning

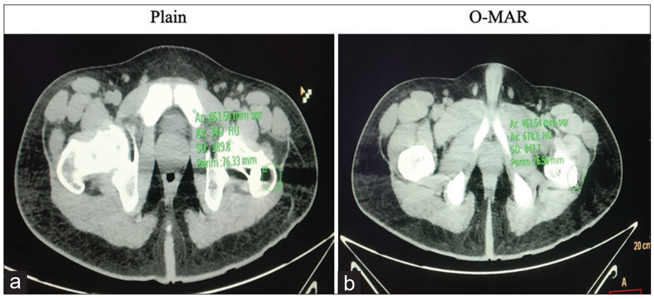

Figure 2: Axial reformatted CT images (Soft-tissue window) of a patient with metallic implant in the left femur showing dark streak artifact obscuring depiction of adjacent soft tissue and degrading image quality (a). The O-MAR axial image (b) showing general noise artifact reduction helps in visualizing the bony cortex and adjacent soft tissue

DISCUSSION

This study is the first to be conducted in our knowledge, in India, that aims to evaluate the effectiveness of O-MAR among patients undergoing CT in a tertiary setting. A total of 30 subjects were included in the study. Image noise in plain image type was 79.5, and in O-MAR image type, it was 44.01. Average noise expressed as SD of HU values in 30 patients with and without O-MAR denotes a higher percentage of SD in plain than O-MAR images.

The findings of the present study showed that, regardless of FBP and iterative reconstructions, image noise induced by metallic orthopedic prostheses in phantom and clinical studies can be reduced conceptually by applying the O-MAR algorithm and represented as a quantitative measure in terms of SD. This finding is similar to Jeong et al.,[16] who found that by applying the O-MAR algorithm, image noise was reduced significantly in all clinical cases except one. The mean score O-MAR algorithm was 1.04, better than 2.6 for CT images without O-MAR. Although there was image noise reduction in their study, the quality of the image did not improve much as image quality is influenced by image noise and several other factors, such as image texture, contrast and spatial resolution, and CT number accuracy. The findings are in contrast to a study by Toso et al.,[17] where they used iMAR algorithms in low-dose pediatric CT, and preliminary results demonstrate improved Hounsfield units near the implant and decreased image noise in bone without changing baseline tissue density or noise far from the implant.

The efficacy of O-MAR was previously confirmed by Kidoh et al.,[18] in their study on dental implants. The importance of the technique followed in O-MAR to improve the image quality was reported by Jeong et al.,[16]

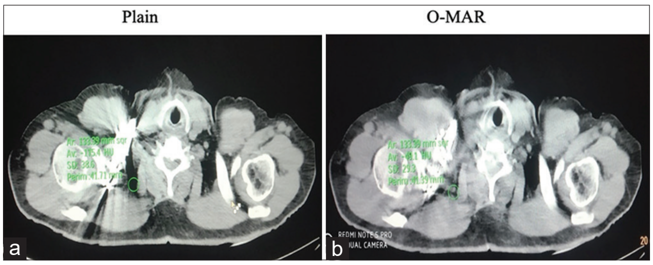

Figure 3: Axial reformatted CT images (Soft-tissue window) of a patient with metallic implant in the right shoulder showing artifact obscuring depiction of adjacent soft tissue and degrading image quality (a). The O-MAR axial image (b) showing general noise artifact reduction helps in visualizing the bony cortex and adjacent soft tissue

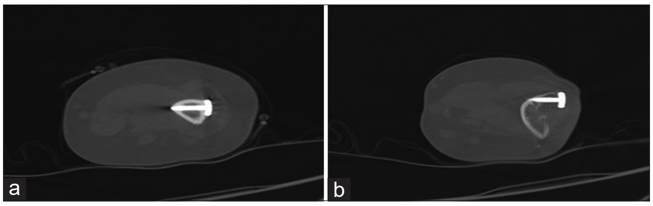

Figure 4: Axial reformatted CT images (Soft-tissue window) of a patient with metallic implant in distal humerus showing dark streak artifact obscuring depiction of adjacent soft tissue and degrading image quality (a). The O-MAR axial image (b) showing general noise artifact reduction helps in visualizing the bony cortex and adjacent soft tissue

who used abdominal CT studies with metal artifacts. Li et al.,[14] concluded that the algorithm could improve the quality of CT images taken for radiation therapy planning. Hu et al.,[19] in their animal study on rabbits, reported that comparing muscular CT attenuation in the animal experiments indicated the accuracy and reliability of O-MAR, with no significant difference between pre-operative and post-operative O-MAR images. The study concluded the efficacy of O-MAR in lowering orthopedic metal artifacts, using various tube voltages, and CT for patients with orthopedic metal implants could be improved using low-tube-voltage. Ali[20] concluded that O-MAR could effectively reduce metallic artifacts in patients with spinal instrumentation with highly diagnostic 3DCT reconstruction images.

Image noise is represented as SD in this study, which was significantly reduced on O-MAR compared to the non-O-MAR image. Image noise in plain image type was 79.5, and in O-MAR image type, it was 44.01. This finding is in comparison to a study by Sunwoo et al.,[21] who reported that image noise was significantly reduced in the immediate vicinity of the metallic object. A study by Boomsma et al.,[13] concluded that metal artifacts reduction by O-MAR depends on interference caused by metal artifacts, and the relative improvement in HU deviation varies between 32% and 68% on a 64-slice CT system. Huang et al.,[22] their study, reported that MAR methods were unsuccessful in reducing artifacts caused by dental fillings and in small metallic implants located in a heterogeneous environment such as teeth and air cavities, where they evaluated three commercially available MAR methods, including the O-MAR.

In the present study, we used O-MAR alone. This is in contrast to a study by Park et al.,[23] where the study results demonstrated that image noise was able to be significantly reduced by applying VMI with high keV (140 keV) or O-MAR compared to that using FBP alone. When both VMI and O-MAR were applied in conjunction, image noise was further able to be decreased as compared to when VMI or O-MAR has applied alone. Thus, when possible, the use of both VMI and O-MAR is recommended for maximum MAR, particularly in patients whose metal artifacts significantly deteriorate image quality, leading to a diagnostic challenge.

Imaging of stents, external fixation metal implanted devices near the skin surface, air pockets, surgical screws or clips, etc., is not satisfactory as recommended by the commercial company Philips. It should also be avoided in reproductive-age females and pregnant women, as mentioned in the exclusion criteria.[24] The metal artifact occurs when it is in close proximity to air or lung tissue or a small metal object (e.g., stents) within iodinated contrast. Whenever there are unsatisfactory construction images, the corresponding radiologist should address the uncorrected images by cross-referencing with the O-MAR dataset. Both sets of images are reconstructed by the system, and whenever O-MAR is selected, the uncorrected images are available promptly.[17]

Radiologists must acquaint themselves with the clinical and technical characteristics of various methods available for artifact reduction and should be able to choose the optimal method according to the clinical situation. The exact mechanism of the artifact is not known. However, the results of the present study, along with those of previous studies, show that new artifacts may be created by the O-MAR process itself, and O-MAR images should be viewed along with the FBP images to avoid erroneous interpretation of the images.

Limitations of the study

The main limitation is a small sample size and single hospital-based study, which can question the generalizability of the findings. Second, we did not compare pre- and post-operative CT results that showed improved image quality by MAR. There are also limitations concerned within areas near low-density tissue, beyond skin, and pacemakers, that can influence the effect of O-MAR processing. The evaluators could not be blinded to the image processing technique, because the effect of O-MAR was evident in the images. Future studies are recommended with a large sample covering a large geographical area to determine the diagnostic value and quality assessment of O-MAR by 2 or 3 radiologists who can evaluate how the underlying bone mineral density can influence the effect of O-MAR processing.

CONCLUSION

The use of the O-MAR algorithm significantly reduces metal artifacts in CT. It can also improve diagnostic quality in the evaluation of patients with severe metallic artifacts by decreasing the negative impacts of orthopedic metals; as the system always reconstructs both sets of images, uncorrected plain images are also accessible whenever O-MAR is chosen and can be compared for references. Finally, more clinical case studies which will contain a wide selection of different implanted metals and different amounts of metal artifacts, as well as comparison studies with other existing methods in terms of restoration quality and time performance, are required.

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Authors Contribution:
GI- Has conceptualized the study and played primary role in compiling, analysis and interpretation of the data; All the drafts were prepared and reviewed, and final draft was approved by **RP, EAP, AR, GI, NAK-** Have contributed in fine tuning of the proposal, contributed in data collection and entry; **RP, EAP, AR, GI, NAK-** Reviewed the results and contributed to preparation and review of drafts. All the authors have read and approved final version of the manuscript. All the authors take complete responsibility for the content of the manuscript.

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