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CT Metal Artifact Reduction Algorithm for Rib Cage Bone Evaluation in Polytrauma Patients: A Preliminary Study

Francesco Contiello[1], Vincenzo Alfano[2], Ludovico Sicignano[3], Luca Basso[1]

1. Radiology Department, "P.O. San Paolo" ASL Napoli 1 Centro;
2. Radiology Department, "P.O. San Leonardo" ASL Napoli 3 Sud;
3. Radiology Department, "P.T.S. Annunziata DS 31" ASL Napoli 1 Centro;

**Corresponding Author*: francescocontiello@alice.it

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Abstract

Chest injuries account for 25% of trauma-related deaths, with survivors often facing long-term consequences. Recent emphasis on early detection and management of chest injuries highlights the need for effective diagnostic tools. The Smart Metal Artifact Reduction (MAR) algorithm is designed to reduce artifacts caused by metallic materials in CT images, such as prostheses and screws, enhancing visualization of bone structures near implants. This improvement aids in the assessment of rib fractures and other pathologies, crucial for patients with thoracic injuries who require swift and accurate diagnoses. This study aimed to evaluate the impact of the MAR algorithm on the image quality, particularly of rib cage bones in chest CT scans in polytrauma patients with thoracic metallic devices such as medical monitoring equipment. The study found that while the MAR algorithm generally enhances diagnostic accuracy and aids in treatment planning, it can also introduce increased noise and artifacts, potentially leading to false positives. Therefore, radiologists are advised to compare CT images with and without MAR to ensure an accurate diagnosis. This approach ensures a more reliable interpretation of thoracic injuries in patients with metallic implants.

Introduction

Polytrauma patients, often victims of severe accidents, present with multiple, complex, and life-threatening injuries that necessitate a multidisciplinary approach involving specialties such as emergency medicine, surgery, orthopedics, radiology, neurology, and intensive care [1]. These patients may experience systemic complications like shock and multiple organ dysfunction syndrome [2]. Chest injuries, which are common in polytrauma, range from rib fractures and pneumothorax to hemothorax, pulmonary contusion, flail chest, cardiac contusion, and aortic injury [3]. If not promptly addressed, chest injuries can lead to severe pain, respiratory distress, impaired gas exchange, arrhythmias, and potentially fatal outcomes [3]. Rib fractures are particularly prevalent and impactful, leading to severe pain, impaired ventilation, and complications such as pneumonia or atelectasis due to reduced respiratory effort [4]. Management of rib fractures in polytrauma patients follows the ABCDE (Airway, Breathing, Circulation, Disability, Exposure) protocol, along with imaging techniques like chest X-rays and computed tomography (CT) scans essential for accurate diagnosis. While radiography is a primary technique, it fails to detect up to 50% of rib fractures, making CT advantageous for diagnosing bone fractures and associated injuries such as pulmonary lacerations [5]. This is especially crucial for elderly patients, who often have metallic objects in or on their chest, such as pacemakers, prostheses, screws, and plates, but also non-removable external metal objects or material useful for monitoring the vital parameters. In CT imaging, metal artifacts from implants like dental fillings, orthopedic hardware, and surgical clips pose significant challenges by degrading image quality and impeding accurate diagnosis. The high density of metals causes beam hardening, photon starvation, and scattering effects, manifesting as streaks and dark bands that compromise diagnostic utility. These metal artifacts significantly degrade the image quality, complicating diagnostic interpretation and therapeutic planning [6]. The physical cause of these artifacts arises primarily from the high attenuation coefficient of metals, leading to beam hardening, scatter, photon starvation, and nonlinear partial volume effects [7,8]. To mitigate the impact of metal artifacts, several reduction techniques have been developed over the years. These approaches generally fall into three categories: hardware-based, projection-based, and image-based techniques. Hardware modifications, such as using dual-energy CT, attempt to minimize beam hardening by capturing images at different energy levels [9]. Projection-based methods, including sinogram interpolation, aim to correct raw data before image reconstruction [10]. Image-based post-processing algorithms, such as iterative reconstruction methods and machine learning techniques, directly reduce artifacts in the reconstructed images [11,12]. In recent years, machine learning and deep learning approaches have shown great promise in further improving metal artifact reduction. These techniques leverage large datasets to learn the complex patterns of artifacts, leading to more accurate correction and better image quality [13]. Despite the advancements, there remain significant challenges in ensuring robust, generalizable solutions across various patient anatomies

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and different types of metal implants. While these technological advancements hold great potential for addressing this issue, their adoption is still uneven within the Italian healthcare system. Currently, such advanced techniques are primarily available in large hospitals or private clinics, leaving many smaller healthcare facilities without access to these innovations.

Various metal artifact reduction (MAR) algorithms have been developed by the CT scan manufacturers. The development of specific MAR tools has significantly advanced the ability to handle artifacts caused by metallic implants in CT imaging. MAR tools are designed to identify and reduce the impact of streaks and distortions by improving the accuracy of image reconstruction. These tools often integrate with conventional CT workflows and operate using either projection-based or image-based techniques. One widely used MAR algorithm is the normalized metal artifact reduction, which compensates for metal-induced inconsistencies by segmenting the metal regions and applying interpolation in the projection domain [9]. This process helps to correct the data before it undergoes image reconstruction, resulting in clearer images with fewer distortions.

In clinical practice, commercial MAR tools have been embedded in CT scanners from leading manufacturers, providing real-time metal artifact correction during the scanning process. Techniques such as iterative reconstruction combined with MAR have been shown to significantly improve image quality by reducing noise and streak artifacts without compromising diagnostic accuracy [14]. The integration of machine learning models into MAR tools further enhances their ability to recognize complex artifact patterns and perform more sophisticated corrections [11]. While these tools represent a major improvement, ongoing challenges such as the variability in artifact severity across different types of metals and patient anatomies continue to be areas of active research [15].

Our study investigates the potential of the GE HeathCare Metal Artifact Reduction (MAR) algorithm, which stands out for its efficacy and clinical application. The GE MAR algorithm uses advanced image reconstruction techniques to identify and correct metal-induced artifacts, enhancing image clarity and improving the visibility of surrounding tissues and structures. This process involves metal detection, sinogram inpainting, and iterative reconstruction, each meticulously designed to reduce metal influence on CT images. By effectively reducing metal artifacts, the algorithm allows better visualization of critical areas, such as bone structures, soft tissues, and adjacent organs. The aim of this preliminary study is to elucidate the algorithm's capabilities and limitations for evaluating rib cage bones in polytrauma patients, offering insights into its role in advancing medical imaging and patient care. By comparing CT images with and without MAR, this study investigates the algorithm's efficacy and identifies potential risks, contributing to improved diagnostic accuracy and treatment planning for patients with thoracic injuries and metallic implants or objects on the chest, ensuring better clinical outcomes.

Materials and Methods

Sixteen patients (7 males and 9 females, with an average age of 73.1 years and an age range from 52 to 93 years) were admitted to the emergency department of San Paolo Hospital in Naples, ASL Napoli 1 Centro, and underwent chest CT scans from April 2024 to May 2024. Informed written consent was obtained from all patients. Patients were transported on spinal boards and immobilized. Due to their critical health conditions, continuous monitoring of vital parameters, including ECG tracing, blood oxygenation levels, and oxygen administration via mask, was performed. The patients had various metallic devices both on and inside their chests, such as pacemakers, extracorporeal monitoring devices, intubation equipment, and sternal cerclages.

CT scans were performed using a GE Revolution EVO CT scanner (64 slices) (GE Healthcare, Chicago, Illinois, USA) with automatic tube current modulation (min 130 mA – max 350 mA) and 120 kV, a rotation time of 0.5 sec. (helical scan mode), a noise index of 21.1, and pitch of 0.984:1. All scans were conducted on critically ill, uncooperative, or minimally cooperative patients in the supine position, and only non-contrast chest CT scans were included.

Images were retrospectively reconstructed on a workstation using REVO_EVO1.1 software, employing the MAR algorithm on axial images with a slice thickness of 1.5 mm and a bone kernel (Window: L=600, W=1900).

Statistical Analysis

In this study, all imaging datasets were reviewed by two independent radiologists, each with over ten years of experience in reporting CT examinations in polytrauma patients. They evaluated both reconstructed and unreconstructed images. The radiologists independently assessed the diagnostic quality of the images obtained with and without the application of the MAR algorithm. The evaluation was conducted using a 5-point Likert scale, ensuring a standardized and reproducible assessment of image quality. This approach allowed for an objective comparison of the effectiveness of MAR in reducing artifacts and preserving diagnostic accuracy.

Likert scale values ranged from 0 to 4 with the following definitions:

0. excellent anatomic delineation with sharp depiction of the bone structure and boundaries;
1. good anatomic delineation with minimal distortion of the bone structure and boundaries;
2. acceptable anatomic delineation with slightly compromised visualization of the bone structure and boundaries;

3. markedly reduced anatomic delineation that impairs diagnostic interpretability;
4. severely reduced anatomic delineation that prevents diagnostic interpretation.

A paired t-test was performed to compare the diagnostic quality before and after the application of the MAR algorithm.

Results

The statistical analysis of the dataset revealed that the mean diagnostic quality before the application of the MAR algorithm (Pre-MAR) was 1.93, whereas after its application (Post-MAR), it significantly improved to 0.31. The standard deviation for the Pre-MAR dataset was 1.34, indicating a high variability before the application of MAR. In contrast, the standard deviation for the Post-MAR dataset was substantially lower at 0.87, reflecting a more consistent reduction in values and higher diagnostic quality across the samples. Furthermore, the mean difference in diagnostic quality count before and after MAR was 1.62, highlighting the effectiveness of the MAR algorithm in reducing metal-induced artifacts in CT images.

Following the application of the MAR algorithm, diagnostic quality significantly improved from a statistical perspective, with a p-value of 0.0026 from paired t-test analysis of the imaging datasets with and without the MAR algorithm.

Specifically, in 11 patients who had metal components on their chest from monitoring and restraining devices, the application of the MAR algorithm significantly reduced beam hardening artifacts. This reduction in artifacts led to a decrease in false positives, which could otherwise result in diagnostic errors and inappropriate patient management (Figure 1).

Conversely, in 1 patient, the application of the MAR algorithm introduced dark banding artifacts. These erroneously simulated the presence of thoracic rib fractures, leading to potential misdiagnoses (Figure 2).

The most significant finding from the evaluations by the two radiologists was the mixed outcome observed in 4 patients. Specifically, there was an improvement in image quality, with a reduction in beam hardening artifacts, particularly in areas with large metallic objects. However, concurrently, deteriorating elements were identified that could lead to misdiagnosis (Figure 3).

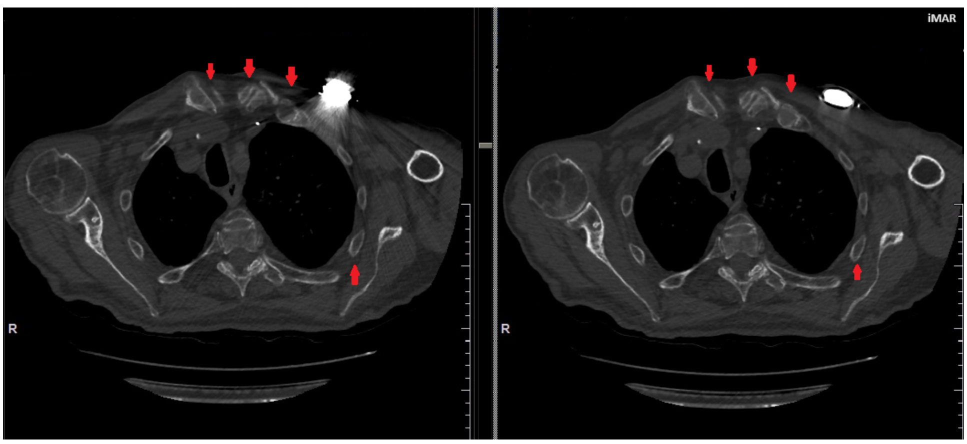

Figure 1. *Thoracic CT scan. Left: unreconstructed image. There are many artifacts on the rib cage caused by a metallic device. Right: reconstructed MAR image. The application of the MAR algorithm showed a reduction in metal artifacts caused by the metallic device.*

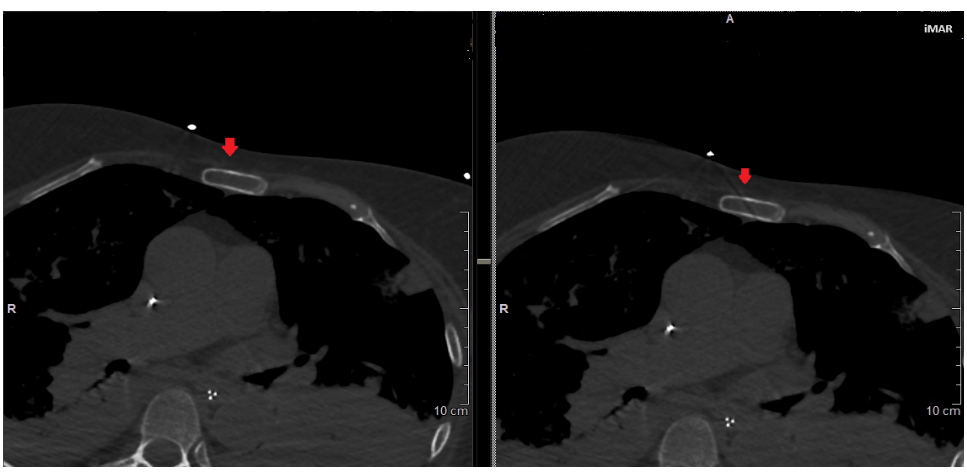

Figure 2. *Thoracic CT scan. Left: unreconstructed image. There are no artifacts despite the presence of an external metal cable laterally to the patient's sternum. Right: reconstructed MAR image. There is a primary artifact represented by a hypodense band that interrupts the cortical bone.*

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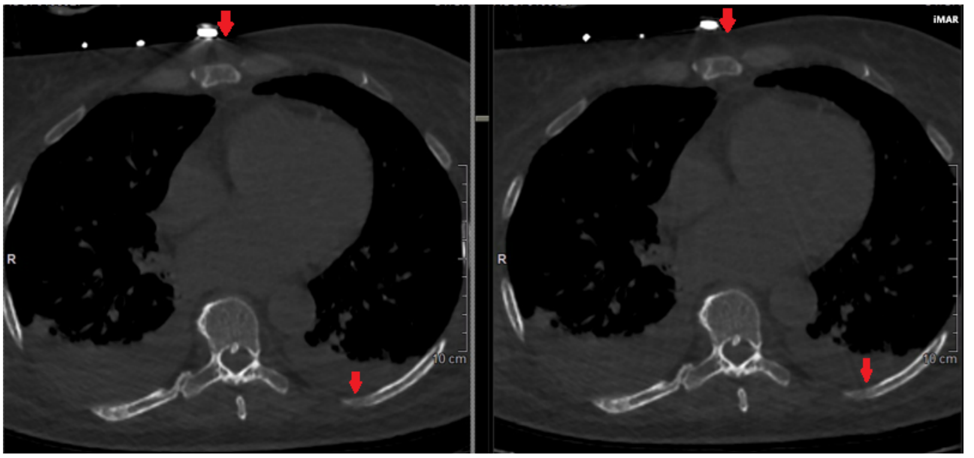

Figure 3. *Thoracic CT scan. Left: unreconstructed image. Artifacts are present on the sternum, but none on the ribs. Right: reconstructed MAR image. The artifacts on the sternum disappear, but a new artifact appears on a rib.*

Discussion

This study investigated the impact of a novel iterative metal artifact reduction (MAR) algorithm on the quality and degree of artifacts in thoracic CT scans of critically ill patients with thoracic metallic implants. Thoracic CT scans were compared with their counterparts reprocessed using the MAR algorithm. The significant reduction in beam-hardening artifacts, particularly in patients with metal components from monitoring and restraining devices, highlights the potential of the MAR algorithm to enhance image clarity and improve clinical decision-making. This is especially relevant in emergency and intensive care settings, where prompt and accurate interpretation of imaging is crucial for patient management. The reduction of beam-hardening artifacts has direct clinical implications. In patients with complex trauma or post-surgical interventions, metallic implants can obscure critical anatomical structures, leading to diagnostic uncertainties or false positives [16,17]. Our results demonstrate that the MAR algorithm mitigates these issues by improving the visualization of soft tissues and bones, ultimately aiding in more precise diagnoses and reducing the likelihood of unnecessary interventions. This aligns with previous studies that have reported similar improvements in metal artifact reduction using iterative reconstruction techniques in various anatomical regions.

However, our findings also reveal an important limitation of the MAR algorithm: its tendency to introduce dark banding artifacts that may mimic rib fractures in patients without metallic implants for monitoring or restraint. These artifacts could mislead radiologists into diagnosing fractures that do not actually exist, leading to unwarranted clinical decisions, such as unnecessary orthopedic consultations or additional imaging studies. This unintended consequence highlights the need for careful image interpretation and the potential role of training radiologists to recognize and distinguish algorithm-induced artifacts from true pathological findings [18]. These results suggest that while MAR algorithms significantly enhance image quality in certain clinical scenarios, they may not be universally beneficial across all patient groups. The introduction of dark banding artifacts necessitates further optimization of the algorithm to ensure consistent performance across different patient profiles. Hybrid approaches that combine multiple artifact reduction techniques, such as deep learning-based reconstruction methods or dual-energy CT imaging or photon counting detectors [16], could provide more robust solutions to address the drawbacks observed with the MAR algorithm.

Future studies should focus on refining the algorithm to minimize undesirable artifacts while preserving its artifact-reducing benefits. Investigating different MAR techniques and their impact on various types of metallic implants could provide further insights into optimizing image processing strategies. Additionally, evaluating the clinical outcomes associated with MAR-processed images—such as changes in diagnostic accuracy, patient management decisions, and follow-up imaging rates—could help clarify the true clinical value of these advanced reconstruction methods.

In conclusion, while the iterative MAR algorithm represents a promising advancement in metal artifact reduction, its application must be carefully considered to balance its benefits against potential limitations. Radiologists must remain vigilant in identifying algorithm-induced artifacts, and ongoing research should aim to develop improved reconstruction methodologies that maximize image quality without introducing new diagnostic pitfalls.

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