**UDC 616-073.756.8:004.052.44**

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# REVIEW OF MODERN COMPUTED TOMOGRAPHY METAL ARTIFACT REDUCTION TECHNIQUES

**Abstract.** Metal objects can cause severe artifacts on CT scans, and this complicates scan interpretation or may even hide or simulate pathology on the image. This article aims to present modern metal artifact reduction (MAR) methods that can be used in clinical practice. Described methods include scanning preferences adjustment and four popular commercially available MAR algorithms: O-MAR, SmartMAR, iMAR, and SEMAR.

**Keywords:** CT, computed tomography, metal artifact, MAR, O-MAR, SEMAR, SmartMAR, iMAR, MDT.

Metal objects, which are usually metal orthopedic prostheses, but may also be dental implants or surgical clips, are known to cause artifacts on CT images. There are several mechanisms of metal artifact emergence. A beam hardening effect around metal implants is caused by the disproportionate attenuation of lower-energy x-ray photons that pass through the object. This results in artifacts on a scan due to the *filtered back-projection* (FBP) – a common algorithm for reconstruction of CT images from a detector data – assuming equal attenuation of photons at all energies. A noise around metal objects may be caused by photon starvation, an effect of general x-ray attenuation by the metal, which results in too few photons reaching the detector. [1, p. 972]. Another type of artifact which is observed near the edges of metal objects is a nonlinear partial volume effect (NLPV). It occurs because, while the reconstruction algorithm assumes the linear attenuation coefficient of a material to be a linear combination of such coefficients of the material's parts, this dependency may be nonlinear for beams that pass through the border between the metal object and soft tissue [2, p. 5827][3, p. 27]. Metals with high atomic numbers are known to cause a higher amount of artifacts [2, p. 5827].

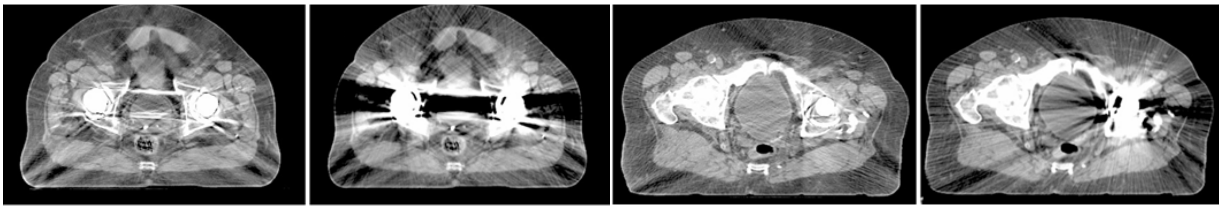
Some metal artifact reduction can be done simply by adjusting the scanning procedure. Without recourse to changing tomograph parameters, sometimes just changing the tilt angle of a metal object may have a positive impact [2, p. 5831]. For example, a "head tilt technique" has been successfully developed to lower metal artifacts from an aneurysm clip on CT angiogram [4, p. 694].

One of the widely used techniques that reduces beam hardening is increasing peak kilo-voltage (kVp). The effect is achieved through a reduction of the amount of lower energy photons. Moreover, noise that is caused by photon starvation can be significantly reduced by decreasing pitch or increasing tube current. However, it must be taken into account that all these methods result in a higher dose of radiation received by the patient. Also, in some cases, artifacts can be somewhat reduced by decreasing slice thickness. [2, p. 5831–5832][1, p. 972].

Modern Dual-Energy CT scanners produce less metal artifacts than conventional scanners. In Dual-Energy CT, a virtual monochromatic spectral (VMS) image is generated from two separate datasets that are acquired with different peak kilovoltage [5, p. 575]. However, high peak kilo-voltages (usually > 100 kVp) should be used to produce fewer artifacts, although some details may be lost due to higher voltage [1, p. 972][5, p. 576][6]. The optimal voltage for scanning often depends on a situation [2, p. 5832].

As it has already been revealed, special algorithms may be used to reduce metal artifacts, and the most popular commercially available algorithms are SmartMAR® by GE, iMAR® by Siemens, O-MAR® by Philips, and SEMAR® by Toshiba/Canon. Their viability has been proved by many studies. Generally speaking, these algorithms use raw scanner data to replace artifacts near metal objects with data, approximated or interpolated by the algorithm.

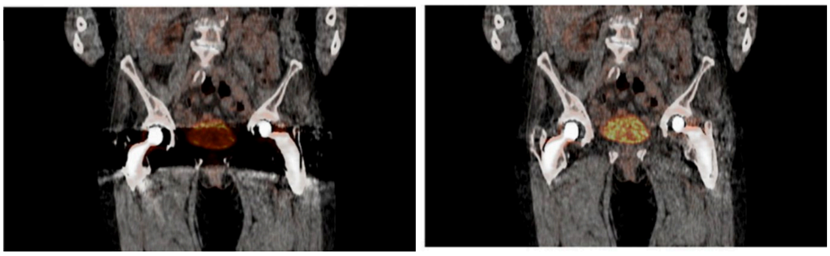
Firstly, we will review SmartMAR, a metal artifact reduction algorithm introduced in 2013 by GE Healthcare. It is a three-stage algorithm in which corrupted areas are replaced with corrected data, which is generated from forward projection [7, p. 2]. Figure 1 shows an example of an image produced by the algorithm. There is a series of studies that show a great quality improvement while using SmartMAR on patients with metal implants in different body regions; however, additional artifacts that were caused by the algorithm were observed too [8, p. 136]. Another study also shows a significant improvement in signal-to-noise and contrast-to-noise ratio, with 22% (8/36) of patients having a tumor which could be identified only with SmartMAR [9].



*a* *b* *c* *d*

**Fig. 1.** Images of a patient with hip prostheses, reconstructed with SmartMAR (*a*, *c*) and without SmartMAR (*b*, *d*) (Vicky W. Huang *et al.*, the image is licensed under CC BY 4.0)[8, p. 131]

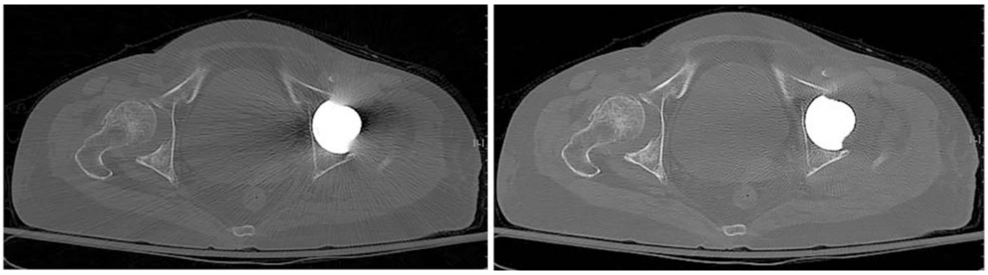
Another available MAR algorithm is iMAR, which is developed by Siemens Healthineers. The algorithm works by combining different MAR techniques, including projection completion and iterative filtering [10, p. 4][11, p. 1867]. Furthermore, iMAR has several protocols depending on the type of the metal object (dental fillings, hip implants, pacemakers, etc.) [10, p. 6]. An example of the iMAR effect is shown in Figure 2. The ability of iMAR to reduce metal artifact burden in CT images has been proved by studies [11, p. 1871–1872][12, p. 9][13, p. 4–7]; however, artifact reduction effectiveness on PET images is disputed [12, p. 7–9].



*a* *b*

**Fig. 2.** The region between both hip implants shows lower activity for standard PET/CT (*a*), whereas iMAR PET/CT (*b*) shows an image closer to the true distribution of a PET radiotracer (van der Vos *et al.*, J Nucl Med, non-commercial usage of the image is allowed by the journal)[11, p. 1870]

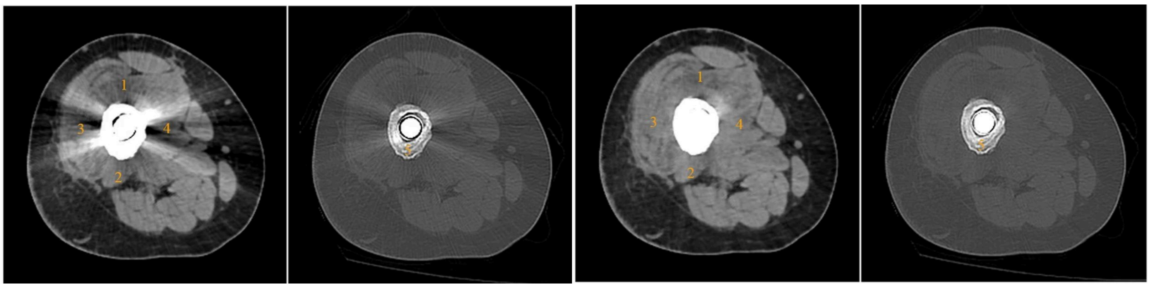
Philips has also developed its own MAR algorithm, which is called "Metal Artifact Reduction for Orthopedic Implants", or abbreviated as O-MAR. O-MAR has an iterative implementation. On each iteration, the image is divided into metal and tissue parts, and affected by metal artifact areas are replaced with extrapolated data, leaving tissue pixels unchanged [14, p. 2–3]. An example of a possible MAR effect by the O-MAR algorithm is presented in Figure 3. O-MAR was proved to be effective in cases with different types of metal implants, including dental fillings [15], shoulder arthroplasties [16, p. 863–865], hip implants, fracture fixation hardware, and spinal hardware [17, p. 25]. However, a study by Euddeum Shim *et al.* shows that O-MAR may introduce new artifacts around bones in patients with shoulder arthroplasty [16, p. 865]. The vendor stated that, mostly, new artifacts may occur when metal is located near air or low-density tissue; for example, in case of peacemakers (as they are located close to lungs), spine screws, and when a part of the metal object is located outside the skin [14, p. 10–12].



*a* *b*

**Fig. 3.** CT image reconstructed without (*a*) and with (*b*) the O-MAR technique (Jiwon Rim *et al.*, the image is licensed under CC BY-NC 4.0)[17, p. 23]

SEMAR, or “Single Energy Metal Artifact Reduction”, is a MAR tool developed by Toshiba and Canon. SEMAR uses forward projection and a special proprietary algorithm to generate a metal-affected sinogram, which is then subtracted from the original sinogram to form metal- and artifact-free sinogram, which undergoes FBP; at the end of the process, the previously extracted layer with an image of the metal object without surrounding artifacts is added to the reconstructed metal-free image [18, p. 3–4]. The effectiveness of the algorithm was proved with respect to knee prosthesis [19, p. 7–8], hip prostheses, metal embolization coils [20], intracranial clips and coils [21]. However, in one of the studies, SEMAR didn’t reduce artifacts significantly in the case of dental prostheses [20]. An example of the result of SEMAR image reconstruction is presented in Figure 4.



*a* *b* *c* *d*

**Fig. 4.** Effect of a SEMAR reconstruction (*c*-*d*) compared to unedited images (*a*-*b*) (Fang-ling Zhang *et al.*, the image is licensed under CC BY 4.0)[19, p. 4]

There are also some other available MAR algorithms, but they aren’t so widespread. For example, MDT (“Metal Deletion Technique”) by F. Edward Boas and Dominik Fleischmann can be used with scanners from any manufacturer and, in one of the studies, showed itself better in metal artifact reduction than O-MAR, SmartMAR, and iMAR [22, p. 7–8].

As shown above, all currently commercially-available MAR algorithms are effective in comparison to the standard reconstruction algorithm – FBP. Generally, enabling MAR for CT scan doesn’t require changing the scanning procedure. Also, MAR doesn’t significantly affect scanning time or radiation dose received by the patient, so it is recommended to use, if possible, any available algorithm for all patients with metal implants. However, all MAR algorithms have been reported to produce new artifacts in some cases, so it is important to analyze corrected images along with unedited FBP images.

Although many studies on each of the four most popular MAR algorithms have been published, only a few articles try to compare them with each other. In a 2015 phantom study by Dirk Wagenaar *et al.*, three MAR algorithms – O-MAR, SmartMAR, and iMAR – were compared. O-MAR showed slightly better results than SmartMAR, with both performing better than iMAR [22, p. 7]. Another study by Kirsten Bolstad *et al.* has claimed SEMAR, followed by SmartMAR, to be the best in comparison with iMAR and O-MAR [23, p. 1115]. However, further clinical studies are required to give clear conclusions.

**Conclusion**. A series of different MAR methods was described in this article. Changing scanning preferences, namely increasing peak kilovoltage and tube current, decreasing pitch, is a simple and generally available metal artifact reduction method; however, these changes will result in a higher dose of radiation received by the patient. Also, modern Dual-Energy CT scanners have less artifacts than conventional ones. On some CT scanners, commercial MAR algorithms are present, and they can be used to improve image quality in addition to changing scanning options or when it is important that the patient shouldn't receive a higher dose of radiation. These MAR algorithms may sometimes produce new artifacts, so original unedited images should be examined along with reconstructed ones.

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