

# Carestream's 2<sup>nd</sup> Generation Metal Artifact Reduction Software (CMAR 2)

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## Introduction

Cone beam computed tomography (CBCT), or cone beam CT technology, offers considerable promise as one type of diagnostic tool for providing 3D volume images. Cone beam CT systems capture volume data sets by using a high frame rate flat panel DR detector and an X-ray source. These are typically affixed to a gantry that revolves about the object to be imaged, directing, from various points along its orbit around the subject, a divergent cone beam of X-rays toward the subject. The CBCT system captures projection images throughout the source-detector orbit. The projections are then reconstructed into a 3D volume image using various reconstruction techniques.

Although 3D images of diagnostic quality can be generated using CBCT systems, a number of technical challenges remain. Highly-dense objects, such as metallic implants, can cause various image artifacts that can obscure useful information about the imaged tissue. These artifacts are not specific to CBCT, but affect MDCT as well. Dense objects, having a high atomic number, attenuate X-rays in the diagnostic energy range much more strongly than do soft tissue or bone features, so that far fewer photons reach the imaging detector through these objects. For 3D imaging, the image artifacts that can be generated by metallic and other highly-attenuating objects include dark and bright streaks that can spread across the entire reconstructed image. For example, see Figure 4. Such artifacts can be due to physical effects such as photon starvation, radiation scatter, and beam hardening. These artifacts can reduce image quality by masking soft tissue and bony structures, not only in the immediate vicinity of the dense object, but also throughout the entire image. At worst, this can falsify CT values and even make it difficult or impossible to use the reconstructed image effectively in assessing the patient's condition or determining suitable treatments.

The CARESTREAM OnSight 3D Extremity System provides a user-selectable option to apply a metal correction software

algorithm to the images for the situation where the patient has metal implants or other highly-attenuating objects that can cause severe artifacts in the reconstructed volume. The metal artifact reduction algorithm, described within the following pages, will be referred to as CARESTREAM Metal Artifact Reduction Software (CMAR 2). It should be understood that any attempt at metal correction can potentially change the diagnostic information contained in the reconstruction. It is recommended that this option is always used in conjunction with a non-metal corrected reconstruction to allow the viewer to fully understand the effect the metal correction algorithm has on the reconstructed volume.

## Description of CMAR 2 Functionality

The CMAR 2 algorithm can be separated into two steps. The first is the segmentation of the projection images into areas that contain "metal" and the remainder of the projection image that contains "normal" anatomy. Once the projection images have been segmented, the second step is to correct the data in the metal regions to reduce the impact of the highly-attenuating metal components on the final 3D reconstruction. The "corrected" projection images are then used to reconstruct the final 3D volume. The two steps (i.e., segmentation and correction) will be described in more detail below.

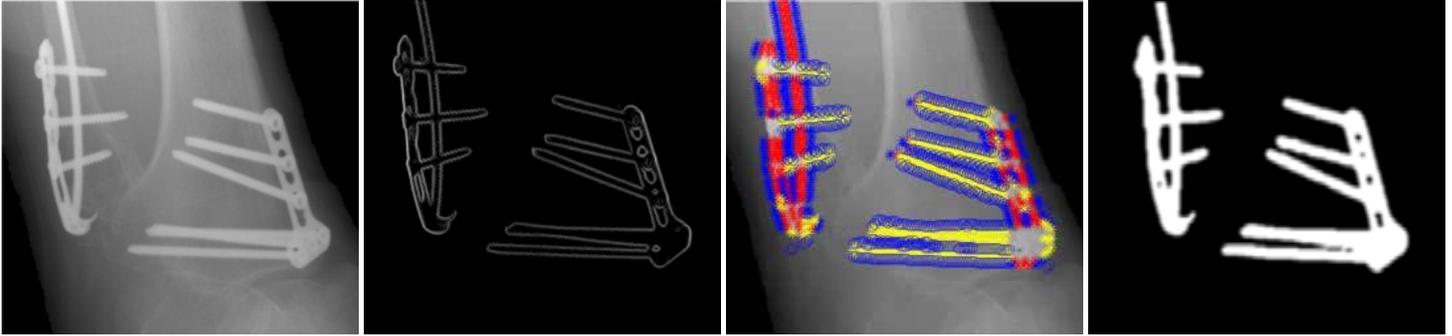
## Segmentation

The metal segmentation stage of the CMAR 2 algorithm can be separated into two steps. The first is the selection of "seed points" that define the interior and exterior of the metal components in the projection images. The second step is a "region-growing"-based segmentation of the image data to create a mask identifying where the metal content is in each projection image. This region-growing approach is widely understood as a traditional methodology for creating mask information in images containing multiple materials (Falcão et al., 2004).

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To improve the accuracy of the metal segmentation, the seed points are chosen in a manner that provides high confidence that they correctly identify the interior and exterior of the metal components. Once the seed points have been identified, the region-growing algorithm expands the metal mask to

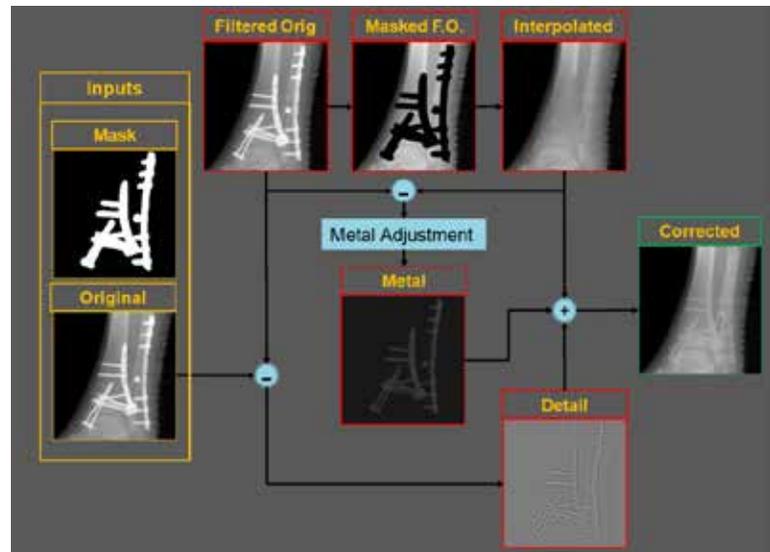
identify all pixels in a projection image that are located within the metal region. Figure 1 shows an example of the seed selection, as well as the final metal mask, for an ankle case with complex metal components.



**Figure 1.** This figure illustrates an automated detection metal ROI for an ankle image. The first image shows one of the projection images that has been identified as having high confidence of containing metal. The second image shows an enhanced metal edge. The third image shows the ROIs with selected seed points (red and yellow points correspond to metal seed points, blue points correspond to non-metal seed points). The fourth image is the final metal mask, generated using the seed points and segmentation algorithm.

### Metal Correction

Once the pixels in each projection image that belong to the metal mask have been identified, the next step in the CMAR 2 algorithm is to modify their pixel values to reduce the impact of the metal object on the reconstructed volume. This is referred to as the “correction”. The method used for metal correction falls under the general classification of projection completion methods (Lemmens et al., 2009). This metal “correction” is achieved by first removing the high-frequency information within the metal region. Next, background information from around the boundary of the metal is interpolated within the metal region. This results in a tissue signal within the metal region. The tissue signal is subtracted from the low-pass filtered original, producing a metal signal. The metal signal is then processed such that metal artifacts in the reconstructed volume are reduced. This metal signal, the tissue signal, and the high-frequency content are added together resulting in “corrected” projections, which are then passed through the reconstruction pipeline to generate the reconstruction volume. Figure 2 illustrates the metal correction algorithm.

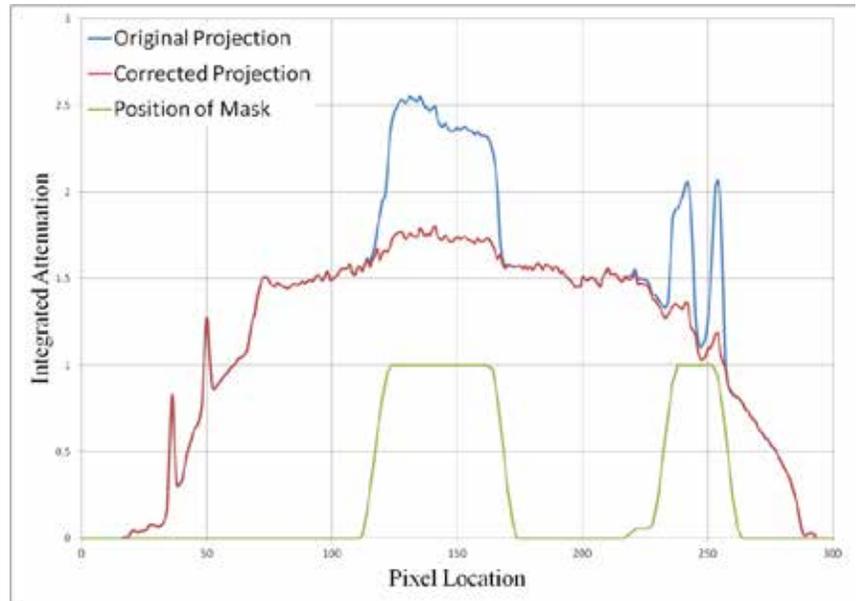
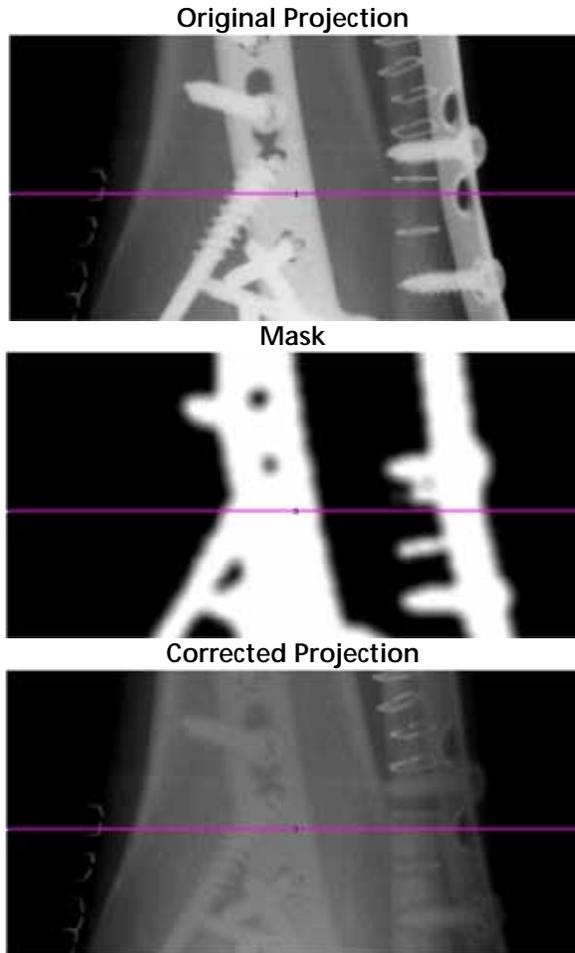


**Figure 2.** Correction steps of the CMAR 2 algorithm.

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Figure 3 below shows an example of this process for a section of a projection image of a patient with fixation hardware in their ankle. The top image shows the original projection data,

the middle image shows the metal mask segmented from the projection data, and the final image shows the corrected projection that will be used for reconstruction.

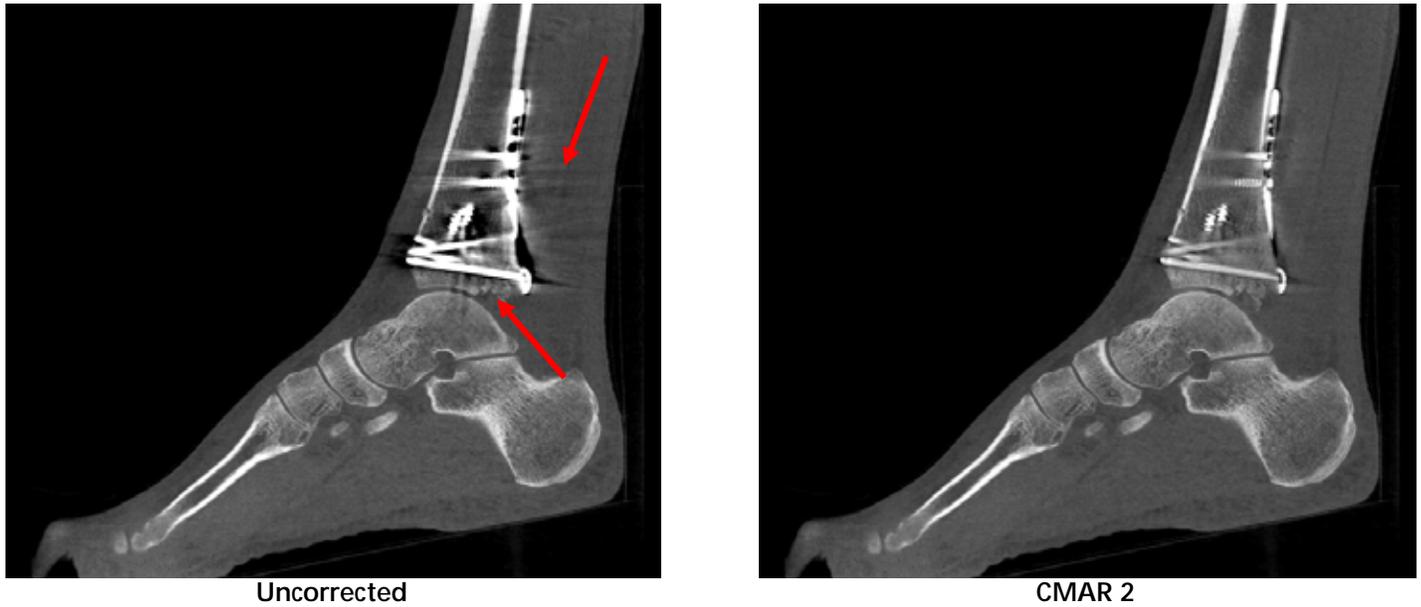


**Figure 3.** Example of the correction process. The top-left image is the original projection data, the middle-left image is the metal mask generated by the metal segmentation step, and the bottom-left image is the final corrected projection after the metal correction step. The horizontal lines indicate the location of the cross-section profiles. On the right is a plot of the line profiles through the images.

### Patient Images

In this section, combinations of anatomy with various amounts and types of metal will be examined to demonstrate the clinical utility of CMAR 2 using real patient data.

Figure 4 below shows a sagittal slice of the final reconstructed volume for the data in Figure 3, both with and without CMAR 2 applied. This fixation device contains multiple screws of different types of metal protruding in various directions. The dark and bright streaking, originating from the metal implant and passing through bone and soft tissue, has been reduced.



**Figure 4.** Sagittal plane through ankle. Reconstructions were generated from the data shown in Figure 3. Dark and bright streaking (red arrows) on left image has been greatly reduced.

Figure 5 below demonstrates the effectiveness of CMAR 2 when applied to a patient with internal fixation of the radius with a plate and screws. The blooming effect has been reduced, allowing better visualization of the fracture as well as the metal-bone interface along the radius.



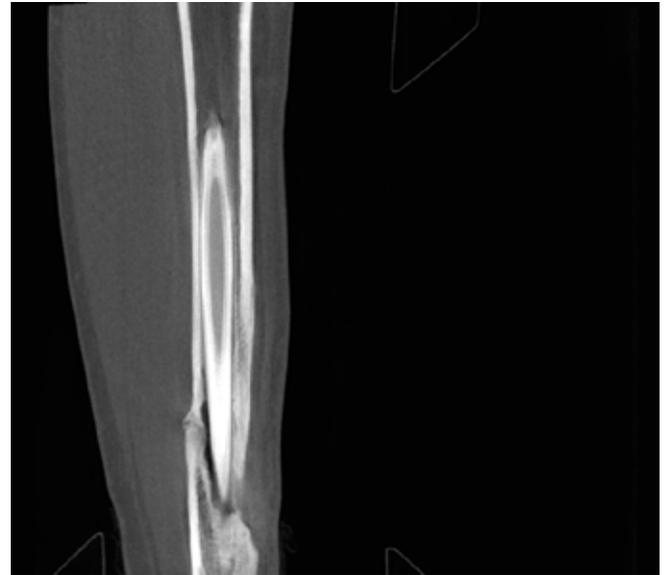
**Figure 5.** Sagittal plane through arm, showing internal fixation of the radius with plate and screws. Radius fracture (red arrow) is better visualized after CMAR 2 is applied due to the reduction in metal blooming.

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Figures 6 and 7 below show reconstructions of the lower leg with a tibial shaft fracture fixated with an intramedullary rod. Metal artifacts that propagated through the soft tissue have been reduced and the metal-bone interface is better visualized.

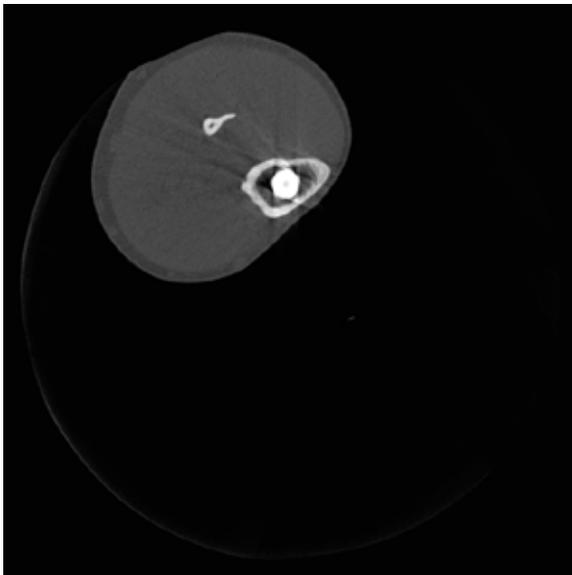


Uncorrected

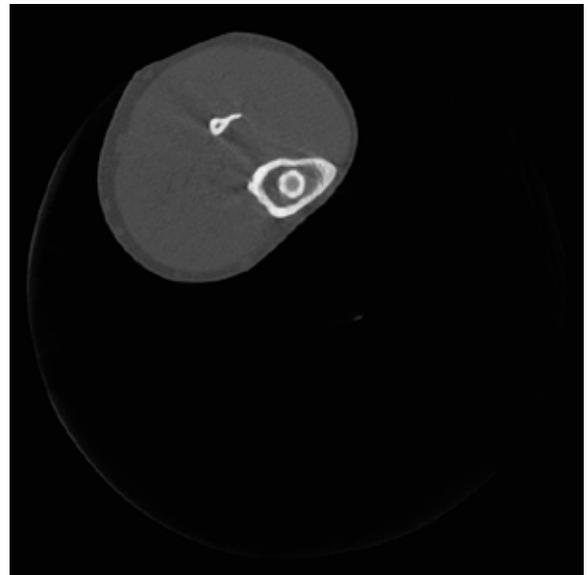


CMAR 2

**Figure 6.** Sagittal plane through lower leg, showing tibial shaft fracture fixated with an intramedullary rod. Metal artifacts and dark streaking (red arrows) have been greatly reduced. The metal-bone interface (green arrow) is better visualized.



Uncorrected



CMAR 2

**Figure 7.** Axial plane through lower leg, showing tibial shaft fracture fixated with an intramedullary rod.

An even more challenging problem is the correction of artifacts caused by large metal implants, such as total knee arthroplasty (TKA) shown in Figure 8. In this example, the application of CMAR 2 has allowed better visualization of the metal-tissue interface. This can aid in the evaluation of tissue healing in the vicinity of the implant.



**Figure 8.** Sagittal plane through knee, showing TKA hardware. Artifacts (red arrow) through the metal-bone interface have been reduced, improving visualization of tissue healing in the vicinity of metal implant.

## Conclusions

In this paper, we have shown how CMAR 2 can help reduce artifacts generated by highly-attenuating implants within patient anatomy. We have shown various configurations of metal along with various anatomy and the artifacts that can arise. With CMAR 2, these artifacts have been reduced, allowing better visualization of patient anatomy, as well as tissue healing in the vicinity of the metal-tissue interface.

## References

Falcão et al. (2004). The Image Foresting Transform: Theory, Algorithms, and Applications. *IEEE Trans. On Pattern Analysis and Machine Intelligence*, 26 (1), 19-29.

Lemmens et al. (2009). Suppression of metal artifacts in CT using a reconstruction procedure that combines MAP and projection completion. *IEEE Trans. Med. Imaging*, 28, 250-260.

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