Optimized CT metal artifact reduction using the Metal Deletion Technique (MDT)

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Purpose

CT metal streak artifacts are extremely common: 21% of scans in one series (1). They are caused by multiple mechanisms, including beam hardening, scatter, Poisson noise, motion, and edge effects. We developed an iterative method called the Metal Deletion Technique (MDT) (1, 2), which is based on the principle that projection data involving or near metal is less accurate. MDT starts with either raw projection data from the scanner, or simulated projection data from a DICOM image. It then only uses high quality non-metal data to reconstruct the non-metal portions of the image. Metal pixels are erased from the reconstructed image, and on each iteration, the inaccurate metal data are replaced with forward projected values from the previous iteration. This means that, instead of trying to look *through* the metal to see soft tissue, we look *around* the metal.

An initial evaluation of MDT showed that it had the best image quality when compared against FBP and two metal artifact reduction methods (1). In 2 of 11 scans, the improved image quality revealed important new findings. This included a case of rectal cancer (in a patient with bilateral hip replacements) that was originally missed when reviewing only the images produced by the scanner. A follow-up study of 80 patients showed that MDT improved image quality 73% of the time for small metal implants, and 75% of the time for large metal implants (3). In that study, MDT had better image quality than all three other metal artifact reduction techniques tested.

MDT reduces metal artifacts due to beam hardening, motion, edge effects, and Poisson noise (1, 4). We have found it to be particularly useful for radiation oncology, interventional radiology, orthopedics, and neurosurgery applications (4).

The main limitations of MDT are the long processing time, decreased resolution for large or long implants, and new artifacts introduced in certain cases. In this paper, we develop a variation on the MDT algorithm that addresses some of these limitations.

Methods

The institutional review board approved this HIPAA-compliant study; informed patient consent was waived.

We optimized the speed and image quality of the Metal Deletion Technique (MDT) for metal artifact reduction, by testing 84 variations of the MDT algorithm on a diverse test set of 22 DICOM images reconstructed by the scanner. Raw projection data was estimated by forward projecting the DICOM images.

The optimized metal artifact reduction algorithm was then set up as a scalable (tested up to 40 CPU cores in parallel) cloud application, which was integrated with our clinical PACS. The “DICOM send” function is used to send scans to a server that automatically reduces artifacts and sends the processed images back to PACS as a new series under the same accession. This procedure works with images from any scanner, and it does not require any manual drawing of regions of interest, or tuning of parameters. Radiologists and clinicians can submit studies for metal artifact reduction.

90 full scans referred for metal artifact reduction at a single institution were then evaluated for image quality, and whether the metal artifact reduction images affected diagnosis, visualization of key findings, or diagnostic confidence.

Results

The optimized MDT algorithm includes changes to virtually all steps of the algorithm, resulting in an improvement in both speed and image quality (shown below). Improvements in processing speed were primarily due to optimized automatic determination of the sampling resolution. Improvements in image quality were primarily due to the following changes: simulated raw data is iteratively corrected to optimize fidelity, the level of streak suppression tapers off with distance from metal, and the algorithm detects cases where it performs poorly, and automatically switches to a different algorithm.

The optimized MDT algorithm can process a single image in 15 minutes on a single CPU core, compared to 97 minutes previously (Intel Xeon Nehalem X5575 2.93 GHz), a speed-up of more than 6-fold. With a 40 CPU-core server, 40 slices containing metal artifact can be processed in a total of 15 minutes. (Note that our previously reported processing time of 28 minutes per slice (1) used raw projection data from the scanner. In this paper, we use projection data that is simulated from the DICOM image generated by the scanner. Simulated projection data requires more processing time due to both the time required to forward project the DICOM image, and the higher sampling resolution required to prevent blurring and artifacts introduced by the forward projection step. The advantage of simulated projection data is that it does not require access to proprietary raw data, and thus works with any manufacturer’s scanner.)

In 18 of 22 DICOM images, the optimized MDT algorithm had better subjective image quality. In particular, image quality was substantially improved compared to the original algorithm for aneurysm coils in the same slice as the mastoids (Figure 1). This is a particularly difficult case for metal artifact reduction algorithms, due to the motion of the coil and the fine bony details in the mastoids.

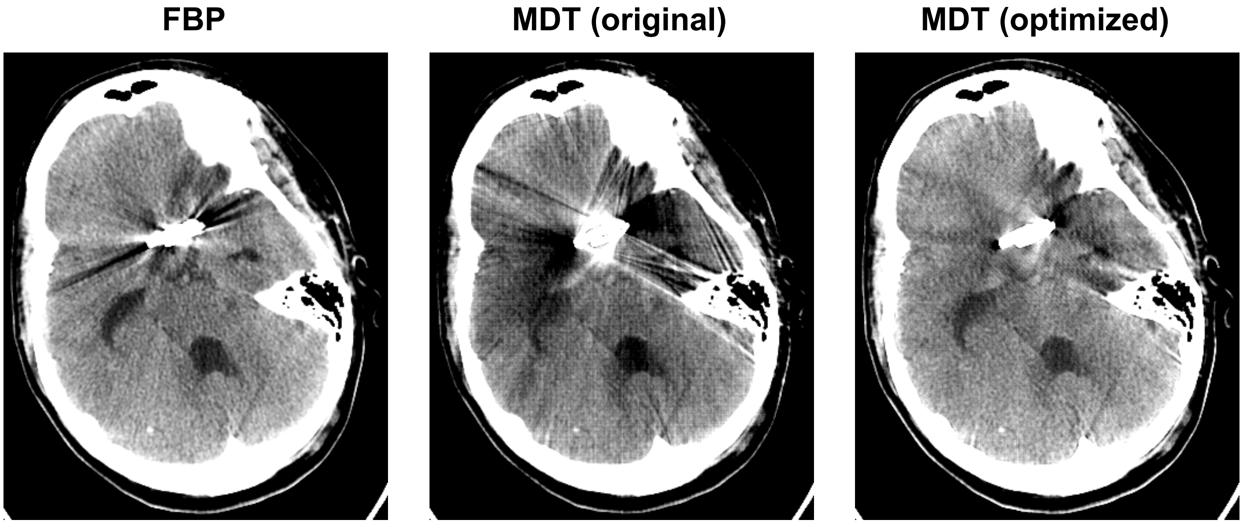

Figure 1. Filtered backprojection (FBP) images generated by the scanner, compared to the original and optimized Metal Deletion Technique (MDT) algorithms.

Of the 90 scans referred for metal artifact reduction by radiologists or clinicians, image quality was improved compared to the image generated by the scanner in 86% (77 scans). The most common cause of worsened image quality was resolution loss around implants measuring > 5 cm in the axial plane, such as pedicle screws. In 13 scans (14%), MDT changed the diagnosis, improved visualization of key findings, or improved diagnostic confidence (Table 1 and Figure 2).

Result	Finding	Metal implant	Number of cases
Changed diagnosis	Obstructing ureteral stone	Bilateral hip replacements	1
Improved visuaization	Hemorrhage or infarct	Intracranial aneurysm coil or clip	6
Improved visualization	Pelvic mass	Bilateral hip replacements	1
Improved visualization	Periprosthetic fluid collection	Hip replacment	1
Improved visualization	Traumatic urethral injury	Bilateral hip hardware	1
Improved confidence	No parotid duct stone	Dental fillings	1
Improved confidence	No ureteral stone	Hip replacement	1
Improved confidence	No PE or mesenteric ischemia	Biventricular assist device	1

Table 1. Cases where MDT changed the diagnosis, improved visualization of key findings, or improved diagnostic confidence.

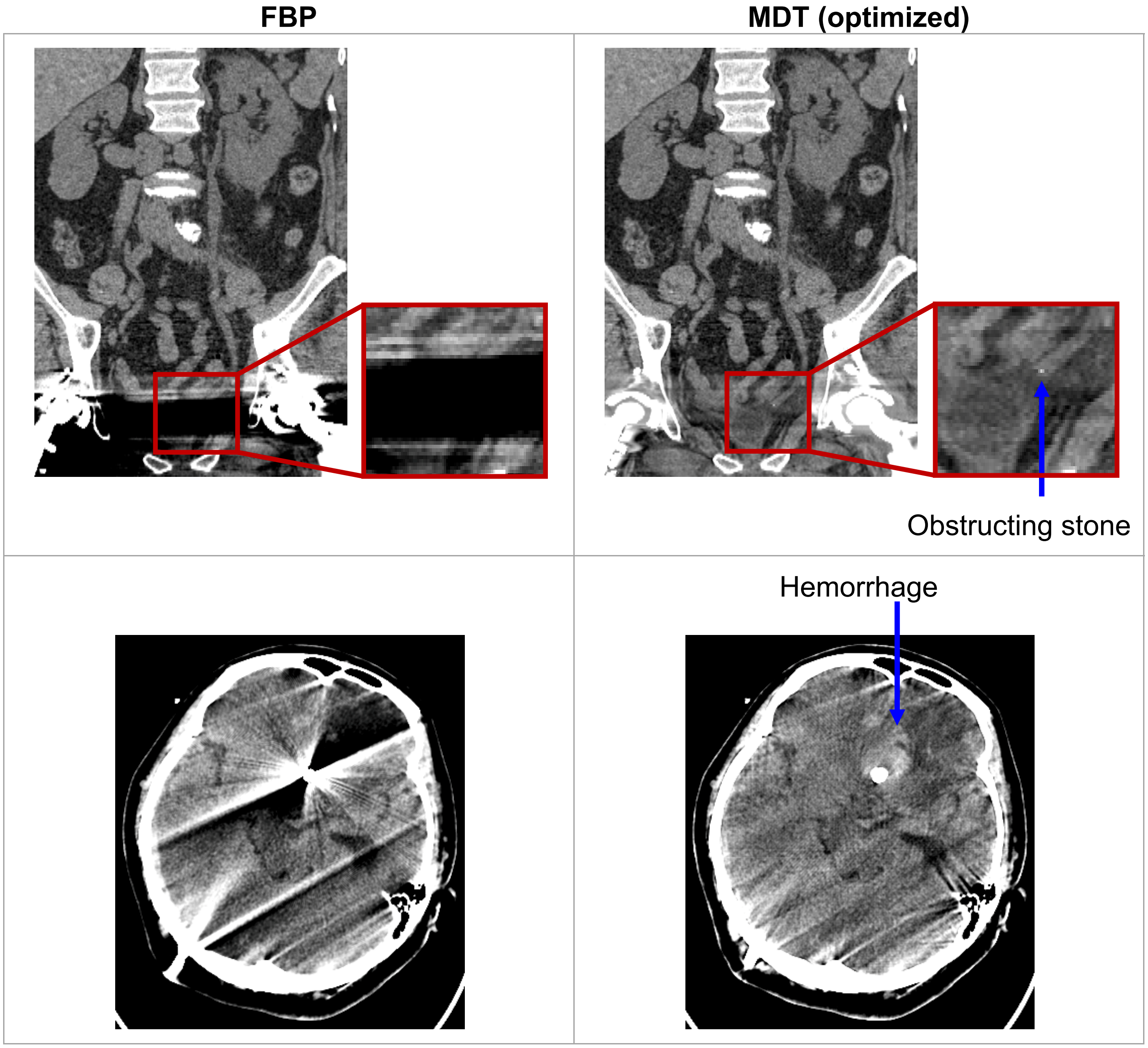

Figure 2. Filtered backprojection (FBP) images generated by the scanner, compared to Metal Deletion Technique (MDT) post-processed images. **First row**: FBP image (curved planar reformat) shows left hydroureteronephrosis. MDT image reveals an obstructing ureteral stone, which was originally obscured by streaks from bilateral hip replacements. **Second row**: FBP image shows motion artifact around a metal aneurysm coil. MDT image reduces the artifact, and more clearly shows the hemorrhage.

Conclusion

MDT can be helpful in the clinical evaluation of patients with metal implants. The optimized version of MDT is 6x faster, and has further improved image quality. In 14% of cases, it changed the diagnosis, improved visualization of key findings, or improved diagnostic confidence.

Integration with PACS allows any clinician or radiologist to easily perform metal artifact reduction. MDT works with scanners from all major CT manufacturers, and is now used in 55 hospitals around the world.

The speed of MDT could be further improved by implementing the algorithm on a graphics processing unit (GPU) or field-programmable gate array (FPGA), rather than running on the CPU.

MDT completely discards metal data. The advantage of this approach is that motion, edge, and scatter artifacts are reduced, not just beam hardening artifacts. The disadvantage is loss of resolution around large or long implants. Thus, MDT images are not a replacement for FBP, but must be viewed in conjuction with the FBP images generated by the scanner.

References

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