Using TOF PET for Metal Artifact Reduction

Time-of-flight (TOF) PET imaging has been shown to provide gains in PET image quality. Specifically, it leads to a better trade-off in contrast versus noise, leading to improved image quality.1 Additional benefits of TOF include more uniform cold regions in images (darker blacks) and improved contrast recovery at the same noise level. Less obviously, TOF reconstruction is more immune to errors in attenuation maps, which is important for accurate attenuation correction.

At the University Hospital Zurich (USZ) in Switzerland, Edwin ter Voert, MSc, researcher, and his colleagues are among the first sites to install the new SIGNA™ PET/MR, the world’s first simultaneous TOF PET/MR system. From a research standpoint, a challenge USZ had was the assessment of the impact of TOF on PET/MR image quality. Initial observations of PET reconstruction performed with and without TOF demonstrated an interesting result: The TOF PET reconstruction reduced metal artifacts.

“We decided to look at this further, and initiated a study with GE on patients that compared reconstructions with and without TOF,” ter Voert explains. Two dual board-certified radiologists/nuclear medicine physicians were asked to review and score image quality based on the artifacts. The results were analyzed, and we found that TOF was better than non-TOF... it made the PET images clearly better,” ter Voert says. Implanted metal can cause large artifacts, or signal voids, that obscure anatomy in the MR images and therefore, when MR-based attenuation correction is used it will result in a poor attenuation map leading to decreased PET image quality. However, PET images reconstructed with the inclusion of TOF information are more reliable and ter Voert and his colleagues were able to identify PET activity present in the tissue near the metal implant, which would otherwise be obscured due to the artifacts in the MR-based attenuation map.

This article discusses ongoing research being conducted at University Hospital Zurich with support from GE Healthcare. The opinions expressed are those of the author and not necessarily those of GE Healthcare.
While MR metal artifact reduction techniques exist, such as MAVRIC SL, ter Voert says it requires a 5-10 minute scan, compared to the 2-3 minutes per bed position of a PET scan. The very fast PET detectors in the SIGNA PET/MR system are able to obtain TOF information without any additional scan time, he adds.

"Still, if GE’s MAVRIC SL could be used, for example, in a single bed station to reduce the metal artifacts in the PET attenuation map it would result in a better PET image, especially when combined with TOF,” ter Voert says. “Combining both techniques could, in my opinion, give us a near perfect image in the presence of metal.”

Results of this study on seven patients with simulated artifacts were published in the March, 2015 issue of Investigational Radiology. The authors reported promising results: the most significant artifact reductions were in the sternum, chest, and pelvic regions, where artifacts were reduced by at least 40% with the TOF reconstructions, with the largest percentage artifact reduction of 60% on a medium sized artifact in the sternum. The smallest reduction in artifacts was 21% on artifacts in the maxilla when using TOF reconstruction.

In their discussion, the authors noted that by including TOF information, the PET reconstructions are less sensitive to inconsistencies, such as inaccurate attenuation correction that could result from MR artifacts, than in PET reconstructions without TOF information.

While the study only focused on metal artifacts, ter Voert and co-authors suggest that the improved timing resolution of the new PET detector in the SIGNA PET/MR can also be beneficial for reducing other artifacts. To further investigate this, ter Voert and his colleagues are currently working on a larger sample size clinical study in conjunction with another institution and GE. Preliminary results of this prospective study, including 25 patients so far, again confirmed that TOF PET/MR significantly reduced artifacts, including those located near metal implants. These results were also presented and discussed in a scientific presentation at the Radiological Society of North America (RSNA) 2014 annual meeting.

He recalls one case where a patient had a thoracolumbar spinal fusion and bone metastases in the same location as the implanted hardware. “With TOF PET reconstruction, the artifacts were reduced so we could see the tumor; without TOF, we could barely see it.”

While MR metal artifact reduction techniques exist, such as MAVRIC SL, ter Voert says it requires a 5-10 minute scan, compared to the 2-3 minutes per bed position of a PET scan. The very fast PET detectors in the SIGNA PET/MR system are able to obtain TOF information without any additional scan time, he adds.

"Still, if GE’s MAVRIC SL could be used, for example, in a single bed station to reduce the metal artifacts in the PET attenuation map it would result in a better PET image, especially when combined with TOF,” ter Voert says. “Combining both techniques could, in my opinion, give us a near perfect image in the presence of metal.”

References
Figure 1. Coronal images obtained from a patient in their early 50s with lung cancer and thoracolumbar spinal fusion: previously obtained CT maximum intensity projection (MIP) image (A), T1-weighted MR image (B), MR-AC map (C), 18F-FDG non-TOF (D) and TOF PET (E) reconstructed images, both without attenuation correction (range: 0-1000 proportional counts per second [propcps]); 18F-FDG non-TOF (F) and TOF PET (G) reconstructed images both with attenuation correction (range: 0-3 g/ml); non-TOF (H) and TOF PET/MR (I) fused images.

The blue arrows indicate the location of the metal implants on the CT image and the resulting signal voids on the MR image and on the MR-AC map. The red and white arrows indicate the location of a spinal bone metastases.
**Edwin ter Voert, MSc**, is a researcher in the Department of Nuclear Medicine at the University Hospital Zurich in Zurich, Switzerland. Previously he received a Bachelor’s degree in Software Engineering from the Hogeschool Enschede and a Bachelor’s and Master’s degree in Biomedical Engineering from the Eindhoven University of Technology. As a doctoral researcher he performed (pre)clinical cancer research with MR and PET/CT at the Radboud University Medical Center in Nijmegen, the Netherlands.

**SIGNA PET/MR with TOF capabilities**

The implanted metal disturbs the homogeneous magnetic field of the MR and as a result there is no signal on the MR image in the area of the metal; the image has a signal void (see Figure 1). This artifact causes a similar signal void on the MR-AC map (see Figure 1, blue arrows).

The non-TOF PET reconstruction then uses the MR-AC map and, since it has no other information, assumes that there cannot be PET activity in the signal void locations.

The reconstruction tries to solve the puzzle and redistributes the measured PET activity (that actually also comes from the signal void, but the system doesn’t “register” this) to the other areas, resulting in these signal voids on the non-TOF PET image as well.

With TOF, timing information is added to the raw PET data which gives an estimate of where the signal originated. The TOF PET reconstruction also uses the MR-AC map with the signal voids. However, this time it also has the TOF information indicating that some activity originated in the signal voids and therefore there must be some tissue in these locations that generated the PET activity.

So now there is a conflicting situation: the MR-AC indicates there is no tissue/anatomy, yet the TOF information suggests there is tissue/anatomy that is of interest. The software again tries to solve the puzzle as good as it can, resulting in a solution that is closer to the real situation: The PET artifacts or signal voids are reduced and show more PET activity.

---

Figure 1 (cont). In the attenuation corrected non-TOF PET image (H) the metastases is obscured by the artifacts while the tissue is clearly visible on the TOF PET image (I). The yellow and white arrows indicate incorrectly enhanced activity on the attenuation corrected non-TOF PET (H) image due to air in the rectum, next to the urinary bladder.