Attenuation Correction for Flexible MRI Coils Using the Ultra-short Echo Time Sequence in MR/PET Imaging

Mootaz Eldib[1], Jason Bini[1,2], Philip M Robson[1], David Faul[3], and Zahi A Fayad[1]

[1]Translational and Molecular Imaging Institute, Ichan School of Medicine at Mount Sinai, New York, NY, United States, [2]Biomedical Engineering, The City College of New York, NY, United States, [3]Siemens Healthcare, New York, New York, United States

Introduction: For combined MR/PET imaging to reach its full potential as a quantitative imaging tool, accurate attenuation correction must be included in the PET reconstruction for all objects in the field of view (FOV) including the patient as well as any MR coils used in the exam. Attenuation correction for MR coils is a new challenge the came about with the advent of combined MR/PET scanners. For rigid coils such as the head and neck coil, that have fixed position in the FOV, a pre-computed attenuation map of the coil is stored and incorporated in the PET reconstruction when the coil is present during the PET acquisition. On the other hand, flexible surface coils (e.g. cardiac or carotid) change position and shape from one scan to another and thus the use of pre-computed, static attenuation map of the coil in the PET reconstruction is not feasible. In this study, we utilize an ultrashort echo time (UTE) MR sequence to image and localize a flexible carotid coil to allow for accurate registration of a pre-computed attenuation map of the coil to account for attenuation that occurs during PET acquisition. The use of the UTE sequence for this purpose is novel.

Methods: In order to validate our method, a uniform cylindrical germanium-68 phantom with 61 MBq of activity was scanned on the Siemens Biograph mMR with and without the Machnet carotid coil for 10 minutes. Then the phantom with the coil was imaged using a UTE MR sequence (TE=0.07 msec, TR= 11.94 msec, flip angle= 10^{o}, FOV=192 voxels isotropic of 1.56 mm). The phantom was segmented from the resultant UTE image using the corresponding non-attenuation corrected PET image as a mask. The UTE image was then split for subsequent registration of the right and left side of the coil separately. A pre-computed CT based attenuation map attenuation map of the coil was generated as discussed previously (1). Registration of the coil attenuation map to the UTE image of the coil was initialized by rigid registration maximizing the normalized mutual information between both images. Then, the diffeomorphic demons algorithm was used to warp the attenuation map non-rigidly (2). The accuracy of the registration was assessed by measuring the mean distance between fiducial markers that are visible in the UTE image and the post-registration coil attenuation map. The attenuation map was then added to that of the phantom and used in the reconstruction of the acquisition done with the coil present. Finally, to verify our method in a clinical scan, a patient with family history of cardiovascular disease was injected with 376 MBq of 18F-fluorodeoxyglucose and scanned for 8 minutes with and without the coil. PET emission data of the subject collected with the coil present was reconstructed either without including the coil or with the coil present in the overall attenuation map using our proposed registration method.

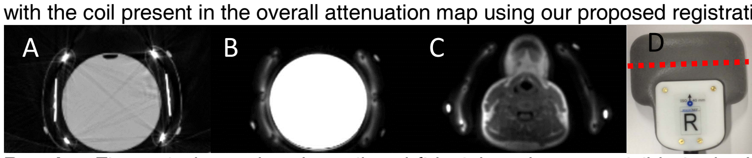
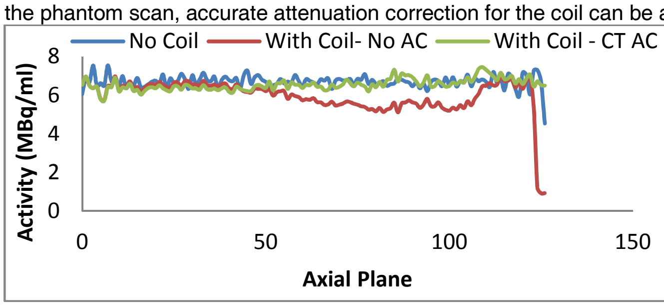


Figure 1: Axial CT image of the coil showing the coil and the markers (A). Axial UTE image from a phantom (B) and patient (C) scan showing both the coil and markers using for registration accuracy calculation. Image of the right side of the coil. Red line showing

Results: Figure 1 shows that the coil and fiducial markers are visible in the UTE (B,C) and CT (A) image in both phantom and clinical scans. In the phantom study, the coil attenuated 4.3% of PET events as compared to the phantom only acquisition serving as ground truth. Local bias reached 25% in regions on interest 3 cm from the coil (With Coil-No AC) as shown in figure 2. Using our registration method to correct for the coil's attenuation in the acquisition conducted with the coil present using a CT based attenuation map (With Coil - CT AC) resulted in accurate quantification compared to the phantom only scan) No Coil. The accuracy of the registration by localizing the markers was 1.4 mm, which is less that the spatial resolution of the PET scanner suggesting sufficient accuracy of our registration algorithm. In a patient study the overall loss due to the coil was 2.8%. Similar to our findings in the phantom scan, accurate attenuation correction for the coil can be achieved using our proposed method in the clinical study as shown in figure 3.



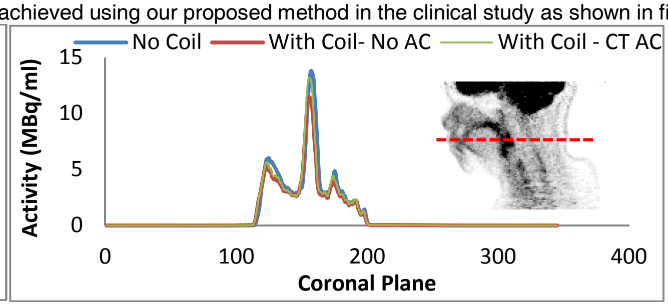


Figure 2: Plot over all axial slices of the mean activity within a 2.5 cm circular ROI. Large error is visible when the attenuation of the coil is not accounted for (With Coil-No AC). Our registration method for attenuation correction results in accurate quantification (With Coil - CT AC) compared to the ground truth (No Coil).

Figure 3: Plot over all coronal slices of the mean activity within a 2.5 cm circular ROI). Similar error in the patient study was observed as in the phantom study. Quantitative error is remedied with attenuation correction using our method (With Coil - CT AC).

Conclusions: We measured the attenuation of a flexible carotid coil that is used routinely in high resolution MR carotid imaging. Given the high and non-uniform nature of the attenuation profile of the coil, ignoring the attenuation of the coil will result in large errors and artifacts. Taken together, high resolution MR imaging combined with accurate PET scans are not feasible on combined MR/PET scanners without accounting for the attenuation of coils used in the exam. We present a method to accurately correct for the attenuation of a flexible coil. In contrast to recently proposed methods, our method mitigates the use of external markers placed on the coil for localization during MR acquisition (2). Our method outlined here may be easily translated into routine clinical scans on the MR/PET to produce quantitatively accurate PET images.

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