MR-based PET Attenuation Correction for Neurological Studies Using Dual-Echo UTE Sequences

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INTRODUCTION

Due to the limited space available inside an MR scanner, most of the MR compatible PET inserts are not equipped with a transmission source, which makes the implementation and validation of an MR-based attenuation correction (AC) method necessary. The obvious challenge is that MR images are not typically directly related to tissue linear attenuation coefficients (LACs). Furthermore, although MR provides excellent soft tissue contrast, the challenging task consists of differentiating bone tissue from air-filled spaces, since they both appear dark on the MR images obtained using conventional sequences. Bone is especially relevant as a photon attenuating medium, being the tissue with the highest LAC. Fortunately, special MR sequences – ultra-short echo time (UTE) sequences – have been recently proposed for bone imaging [1, 2] and we report here our experience using these sequences for bone/air segmentation.

MATERIALS AND METHODS

Integrated MR-PET scanner: An MR-compatible brain PET scanner prototype (called BrainPET), installed at our site was used for these experiments. This system operates while inserted into the bore of the Siemens 3T TIM Trio MR scanner [3].

Bone tissue imaging using UTE sequences: We have previously reported on our initial experience using single-echo UTE sequences for bone/air segmentation [4]. As a next step, dual-echo UTE (DUTE) sequences were implemented for collecting the signal from both echoes during the same acquisition. Human volunteers were scanned inside the BrainPET. The following parameters were chosen for these studies: TE 0.07/2.24 ms, TR 200 ms, FA 10°, radial projections 32,000, bandwidth 1532 Hz/Px, FOV 320 mm, base resolution 192, acquisition time 3:20 min:sec.

Simultaneous MR-PET studies: The method currently used for obtaining the AC factors consists of the following steps:

- Acquire PET and DUTE-MR data simultaneously;
- Generate head attenuation sinogram: align/reslice DUTE volumes to the PET volume using a predetermined transformation matrix; normalize DUTE data using a 3D Gaussian low-pass filter; generate soft tissue mask based on the $DUTE_2$ data; combine $DUTE_1$ and $DUTE_2$ to segment bone tissue and air cavities; assign 0.096 cm^{-1} and 0.151 cm^{-1} LACs to soft and bone tissue, respectively; forward project the μ-map to generate the AC in sinogram space.
- Include the RF coil attenuation derived from a CT of the coil;
- Reconstruct normalization and attenuation corrected volume;
- Generate the 3D scatter correction sinogram;
- Reconstruct fully corrected volume using OP-OSEM (16 subsets, 6 iterations).

Simultaneous MR-PET data were acquired in brain tumor patients at multiple time points during the course of their treatment. CT data were also available for some of these subjects and were used to generate the CT-derived μ-maps. The CT and MR-PET studies were performed less than one month apart and no surgical procedures that would alter the skull/brain morphology were performed between the scans. The DUTE-derived μ-maps generated at each time point were also compared to test the reproducibility of the method.

RESULTS AND DISCUSSIONS

Bone tissue imaging using UTE sequences: Ideally, the time spent on acquiring the data used for deriving the μ-map should be minimal so that other MR sequences can be run simultaneously with the PET data acquisition. A solution to this problem is the DUTE-based method proposed. This would also have the advantage of reducing the motion artifacts that could occur when the signal from the two echoes are acquired separately which is particularly relevant as the segmentation accuracy depends on the relationship between the two signals for each voxel. Representative slices from the data acquired using the DUTE sequences are shown in Fig.1. The μ-maps generated from the corresponding segmented CT and DUTE data are shown in Fig.2 (top and bottom, respectively). Very encouraging, these images demonstrated a good overall agreement: most of the soft and bone tissue, air cavities being correctly segmented. A more precise selection of the thresholds and/or adding the information derived from another sequence (e.g. T2 SPACE, MPRAGE) could improve the segmentation, but they would increase the complexity of the method. Instead, we will focus on improving the DUTE sequence (e.g. higher spatial resolution, bandwidth, number of radial projections, etc), the goal being to develop a method that requires minimal user intervention.

Simultaneous MR-PET studies: The PET images corrected using the two methods (Fig. 4) suggest that a DUTE-based AC method would suffice if a qualitative analysis of the PET data were the goal of the study. In longitudinal studies, the μ-maps showed good reproducibility. Furthermore, our results suggest that an MR-DUTE-AC method based on an accurate three component segmentation could in principle provide accurate (i.e. within 5-10%) estimation of the radiotracer concentration in a particular voxel.

REFERENCES: [1] Reichert ILH et al, MRI, 2005; 23(5): 611-618; [2] Robson MD et al, NMR in Biomed, 2006;19(7):765-780; [3] Schlemmer HP et al, Radiology, 2008; 248(3):1028-35; [4] Catana C et al, ISMRM 2009.

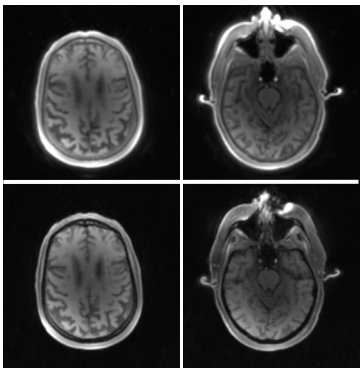

Fig. 1: MR-DUTE IMAGES $DUTE_1$ (top) and $DUTE_2$ (bottom)

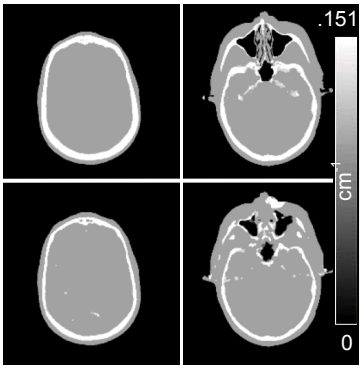

Fig. 2: ATTENUATION MAPS CT_{segm} (top) and $DUTE_{segm}$ (bottom)

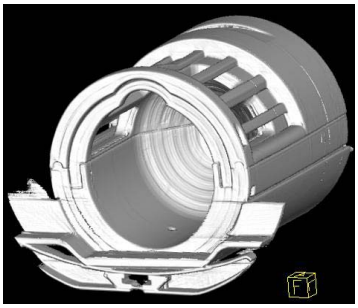

Fig. 3: CT of the RF coils

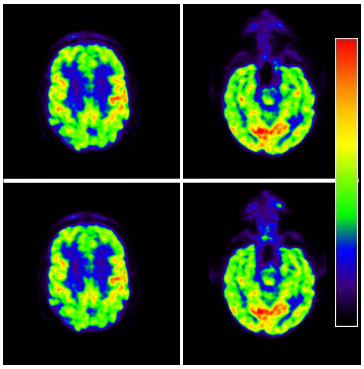

Fig. 4: RECONSTRUCTED PET IMAGES - CT_{segm} (top) and $DUTE_{segm}$ (bottom)