Hardware Attenuation Correction in PET/MR Hybrid Imaging: Evaluation of μ-maps for Local RF Coils

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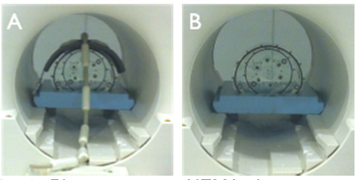

Fig. 1: *Phantom setup: NEMA phantom was placed in the PET FOV without the patient table and was scanned with (A) and without (B) the local RF coil.*

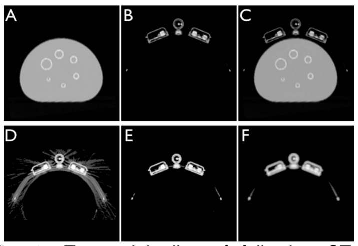

Fig. 2: *Transaxial slice of following CT-based μ-maps: (A) phantom (human μ-map), (B) RF coil (hardware μ-map), and (C) overall μ-map. CT-based μ-map without (D) and with post-processing (E) and with Gaussian filter and threshold (F). (Note: window width is changed to display the noise)*

Target Audience: Researchers and physicians who are working in the new field PET/MR hybrid imaging.

Purpose: Attenuation correction (AC) for simultaneously PET/MR imaging has become a spotlight of many research groups. Besides MR-based AC of the human body [1], another important topic is the AC of PET/MR hardware devices, such as local receiving radiofrequency (RF) coils that are positioned in the PET field-of-view (FOV) and attenuate the PET annihilation photons. Since RF coils are inherently not visible in MR images, CT-based attenuation maps (μ-map) are usually used to correct for attenuation if the position of the coil is known *a priori* [2]. The flexible RF surface coil can vary in position and geometry and is thus omitted in PET AC. First studies showed that markers can be used to determine the position of the RF coil to apply CT-based AC [3], but due to breathing of the patient or misregistration the position of the μ-map can slightly deviate from the real position. The aim of this study was to evaluate the effect of different parameters used to generate CT-based μ-maps of local receiving RF coils and to analyze misplacement between μ-map and the real RF coil position.

Materials and Methods: Measurements were performed with a PET body-mimicking emission phantom (L981602) according to CEC Project (PTW, Freiburg, Germany) with a diameter of 30 cm and a volume of 10 liters including six small glass spheres. The phantom was filled with water and ^{18}F (104.9 MBq; lesion to background ratio 9:1) and put on a styrofoam block. A flexible 6-channel RF receive body coil was used for this investigation. The setup was placed directly inside the FOV (without patient table) of a Biograph mMR (Siemens AG, Healthcare Sector, Erlangen, Germany), a 3.0 T whole-body hybrid PET/MR system and scanned with (Fig. 1A) and without (Fig. 1B) the RF coil fixed on the top of the phantom. Since MR-based AC just corrects water, the μ-map of the water filled phantom was replaced by a CT-based μ-map (Fig. 2A). To provide the right geometry of the RF coil, an additional CT scan of the phantom setup with RF coil was performed. After segmentation of the RF coil, it was used as PET/MR hardware μ-map (Fig. 2B). Since the scaling is not optimized for such hardware devices, several μ-maps were generated: 'no AC' (RF coil is omitted), 'standard' (conversion by [4]), 'extended scale' (extended CT scale was on), 'threshold' (post-processing of the μ-map, Fig. 2E), and Gaussian filter (FWHM = 5 mm, Fig. 2F). To simulate misregistration AC was also performed with following shifted μ-maps: z-direction (10, 20 mm), y-direction (10, 20 mm up and down), and rotation around the z-axis (3° and 6°). PET images were reconstructed using the standard PET 3D-OSEM reconstruction (3 iterations, 21 subsets, 4.0 mm Gaussian filter) and filtered backprojection (FBP) with a 4.0 mm Gaussian filter.

Results: None of the μ-maps (without misplacement) lead to image artifacts when using the OSEM reconstruction. Difference images of the PET OSEM reconstruction (scan without RF coil used as reference scan) are shown in Fig. 3(A-D). In the FBP images (Fig. 3(E-H)) small artifacts can be observed when using the 'standard' (F) or 'extended scale' μ-map (G), while with the 'threshold' μ-map the artifacts are clearly reduced. In Fig. 4 and Fig. 5 the effect of the μ-map shift is shown for the difference images (OSEM) and the FBP images. While in the PET OSEM images no artifacts are observed, but the deviation in some parts of the phantom increases/decreases obviously, artifacts in the PET FBP images are discernible in the region where the coil was positioned due to the misregistration. In both cases, the deviation and the artifacts can slightly be reduced by using a Gaussian filter of the μ-map.

Discussion: Omitting the RF coil in PET AC decreases the PET activity concentration especially in regions near electronic parts up to 17%. Since the μ-map generation is not optimized for hardware devices, the 'standard' conversion can lead to an overcorrection of about -7% in the regions near electronics. When using the extended CT scale the overcorrection even increases up to -12%. Post-processing of the μ-map (e.g. cutting off the noise or using a threshold) reduces CT artifacts and overestimation of electronic parts and thus leads to a better PET AC as seen in the difference image (Fig. 3D). In none of the PET difference images the lesions are visible, which means that the attenuation does not depend on the activity concentration. When using the OSEM reconstruction, small shifts or rotations do not lead to artifacts, but to a deviation of the activity concentration depending on the size of the shift, where the bigger the shift the higher the deviation in some regions. The high overcorrection in Fig. 4B is related to the effect, that parts of the RF coil μ-map were placed inside the phantom, which has a much higher influence on the PET AC than shifting the coil away from the phantom (Fig. C-D). A Gaussian filter reduces sharp edges of the μ-map so there is a lower sensitivity of misregitration, but the effect on the PET reconstruction is quite small. The FBP images show artifacts even if the μ-map is misplaced a bit, but only outside the phantom, where the coil was positioned.

Conclusion: Disregarding flexible RF coils in PET AC leads to a loss of the activity concentration. Using a modified CT-based μ-map of the RF coil, its attenuation can be compensated well. While for OSEM reconstructions a small shift or rotation between the u-map and the real RF coil position do not lead to artifacts but to deviations of the activity concentration, FBP is much more prone to artifacts when the μ-map is misplaced.

References: [1] Quick et al. MAGNETOM Flash 2011, 1, 80-100; [2] Paulus et al. Med. Phys. 2012, 39(7), 4306-4315; [3] Carney et al. Med. Phys. 2006, 33(4), 976-983

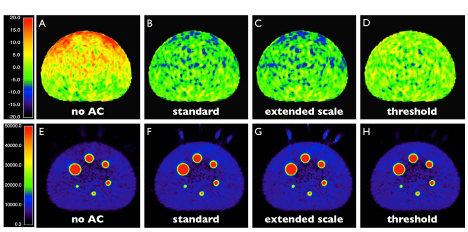

Fig. 3: *Upper row: Difference images of the PET OSEM reconstruction for different μ-maps (range: -20% to 20%). Lower row: PET FBP images in kBq/ml.*

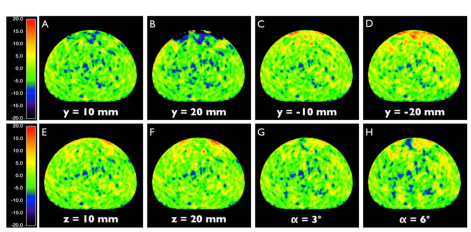

Fig. 4: *Difference images of the PET OSEM images for different shifts and rotations between μ-map and real position of the RF coil (range -20% to 20%).*

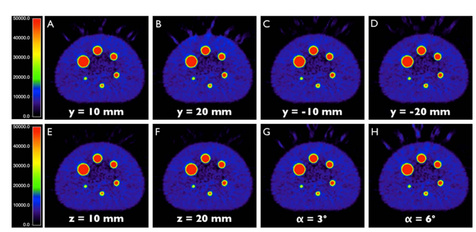

Fig. 5: *PET FBP images for different shifts and rotations between μ-map and real position of the RF coil showing the artifacts in the region of the RF coil.*