Towards Simultaneous PET/MR Breast Imaging: Systematic Evaluation and Integration of an RF Breast Coil

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Purpose: Simultaneous PET/MR breast imaging is a potentially attractive new clinical application of PET/MR hybrid technology [1, 2]. The introduction of this method into clinical routine, however, requires examination and implementation of several physical and technical pre-conditions. In combined PET/MR breast imaging, the RF breast coil used for MR signal detection is located in the field-of-view (FoV) of the simultaneously acquiring PET detectors. This leads to photon attenuation and thus to a reduction of PET statistics and an increase in scatter events that may reduce the PET quantification accuracy [3]. In this study, the influence of a commercially available 4-channel RF breast coil on the measured PET signal has been systematically evaluated and quantified in phantom experiments. CT-based attenuation maps (μ-maps) of the RF coil are generated and successfully used for hardware attenuation correction (AC). For the first time, our PET/MR studies in breast cancer patients demonstrate the successful integration of the RF breast coil into the new application of PET/MR breast imaging.

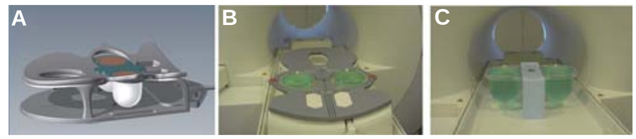

Figure 1: (A) Breast phantom positioned in the 4-Channel RF breast coil. (B) PET scan setup with RF breast coil and breast phantom. (C) PET scan setup with only the breast phantom as a reference scan.

Materials & Methods*: 1) Phantom measurements:* All phantom experiments were performed on a commercially available 3.0 T whole-body PET/MR hybrid system (Biograph mMR, Siemens Healthcare, Erlangen, Germany) using a 4-channel RF breast coil (Noras MRI Products GmbH, Würzburg) (Fig. 1A). Reproducible positioning of the RF breast coil on the system's patient table was achieved with a custom-built spacer. For evaluation of the influence of the RF breast coil on the PET signal, two different PET scans were performed using a homogeneous breast phantom filled with fluid (distilled water, NaCl, $NiSO_4$) and ^{18}F as radio tracer (50 MBq): 1) PET scan with the RF breast coil and phantom placed in PET FoV (Fig. 1B), and 2) PET scan with the breast phantom only (no RF coil) serving as a reference scan at identical phantom position as scan 1 (Fig. 1C). The phantom holder used for the 2nd PET scan has negligible photon attenuation. For AC of PET emission data, a CT scan of the RF breast coil and the breast phantom are necessary as the attenuating coil is not visible in MR images and also the attenuating Plexiglas phantom housing cannot be visualized with the MR system itself. For generation of such CT-based μ-maps, the acquired 3D CT data sets were converted from Hounsfield units to attenuation factors at 511 keV using a bilinear scaling [4] followed by Gaussian filtering. The resulting PET images were evaluated quantitatively with and without application of CT-based AC. ***2) Patient studies:*** As a proof of concept of the simultaneous PET/MR breast imaging, two breast cancer patients (62 years, 92 kg and 41 years, 73 kg) were scanned in the Biograph msMR system in the Bernard and Irene Schwartz Center for Biomedical Imaging, New York, NY, USA. Both patients were injected with ^{18}F-FDG radiotracer and gadolinium-based MR contrast agent (Magnevist, Bayer Healthcare). For generation of human μ-maps used for the AC of the patient, a 3D Dixon VIBE sequence was used. The hardware AC of the system's patient table and of the RF breast coil was performed using the pre-acquired CT-based 3D μ-maps. Dynamic MR imaging was performed post-contrast with fat suppressed T1-weighted radial VIBE sequence in axial orientation and simultaneous to PET data acquisition.

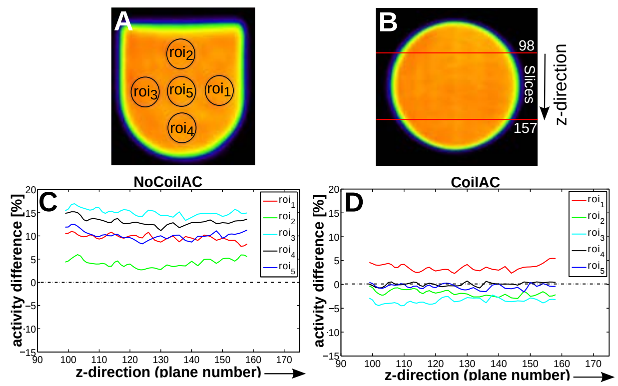

Figure 2: (A) Axial PET image shows the 5 circular ROIs used for quantitative evaluation of the local attenuation due to the RF coil. (B) Coronal PET image illustrates the range of reconstructed axial planes plotted in graphs (C) and (D). (C) PET data sets with no AC of the coil. (D) PET data sets with CT-based AC of the RF coil.

Results: The local attenuation of the RF breast coil varies between 4%-16% depending on the ROI position (Fig. 2C) in the phantom experiments. The upper part of the phantom (roi_2) shows less attenuation (4%) than lower parts (roi_4) (16%) due to higher attenuation of photons caused by the coil frame and RF coil elements in the lower regions. By application of the CT-based AC, the coil attenuation can be reduced to 5%, however, with a slight over-correction in some areas up to an average of -4% (roi_3) (Fig. 2D). In both breast cancer patient examinations (Fig. 3), two μ-maps were used for AC: 1) MR-based human μ-map of the patient (Fig. 3A) and 2) 3D CT-based hardware templates of patient table and RF breast coil (Fig. 3B). The first patient shows a bright lesion in MR images (arrow in Fig. 3C) that corresponds well with an FDG active lymph node metastasis in the left axilla (arrow in 3D). The second patient shows bilateral contrast enhancement in MR (Fig. 3F) also corresponding with bilateral FDG activity in PET images (Fig. 3G). PET/MR images (Fig. 3E, H) demonstrate very good spatial and geometric overlap of the simultaneously acquired and attenuation corrected data sets.

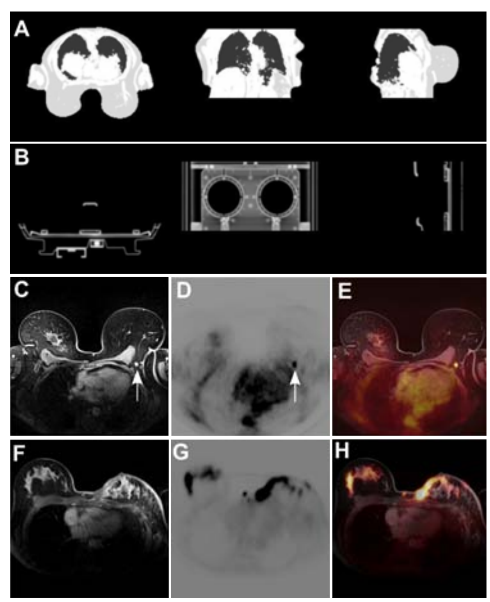

Figure 3: (A) MR-based human μ-map (shown only for the 1st breast patient) used for the AC of the patient. (B) 3D CT-based templates of the patient table and the RF breast coil used for the hardware AC. (C-E) Breast cancer patient with active lymph node metastasis in the left axilla (arrow). (F-H) breast cancer patient with invasive breast cancer and DCIS in the right breast and post-radiation cellulitis, inflammation and residual tumor on the left breast. (C, F) Contrast-enhanced fat-suppressed T1w MR. (D, G) ^{18}F-FDG PET images. (E, H) PET/MR images show very good spatial and geometric overlap of activity provided by PET and morphology provided by MR.

Discussion: The influence of a commercially available 4-channel RF breast coil for MR mammography on simultaneously acquired PET data has been evaluated and quantified. Pre-acquired CT-based μ-maps of the coil could successfully be used in PET data reconstruction for hardware AC of the RF coil components. Phantom data and first measurements on breast cancer patients demonstrate the successful technical integration of the RF breast coil into the application of simultaneous PET/MR breast imaging.

References: [1] Heusner et al., Br. J. Radiol. 2011 84: 126-135; **[2]** Moy et al., J. Nucl. Med. 2007 48: 528-537; **[3]** Paulus et al., Med Phys 2012 39: 4306-4315. **[4]** Burger et al., Eur J. Nucl. Med. Mol. Imaging 2002 29: 922-927.