'Whole-Body PET/MR Imaging: Quantitative Evaluation of a Novel Model-based MR Attenuation Correction Method Including Bone

Daniel H Paulus[1], Harald H Quick[1,2], Matthias Fenchel[3], Christian Geppert[3], David Faul[4], Yiqiang Zhan[5], Fernando E Boada[6,7], Kent L Friedman[6], and Thomas Koesters[6,7]

[1]*Institute of Medical Physics, University of Erlangen-Nürnberg, Erlangen, Germany,* [2]*High Field and Hybrid MR Imaging, University Hospital Essen, Essen, Germany,* [3]*Siemens AG Healthcare, Erlangen, Germany,* [4]*Siemens AG Healthcare, New York, NY, United States,* [5]*Siemens AG Healthcare, Malvern, PN, United States,* [6]*NYU Langone Medical Center, Center for Biomedical Imaging, Department of Radiology, New York, NY, United States,* [7]*NYU Langone Medical Center, Center for Advanced Imaging Innovation and Research, CAI2R, New York, NY, United States*

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

Purpose: Attenuation correction (AC) in positron emission tomography (PET) is an essential step to provide accurate and quantitative PET images. In hybrid PET/MR imaging, this is a major technical challenge, since MR image information cannot directly be transformed to linear attenuation coefficients (LACs) at 511 keV, as it is done in PET/CT. Thus, in routine PET/MR AC, segmentation methods, based on a T1-weighted gradient echo (VIBE) Dixon sequence, are used providing four different tissue classes including air, lung, fat, and soft tissue [1] in AC maps (μmap). A limitation of this method is that due to lack of bone information in MR imaging, bone is currently disregarded in MR-based AC leading to a potential local underestimation of PET standard uptake values (SUVs) [2]. For head imaging different approaches have been proposed to consider bone in PET AC including atlas-based AC [3] or pseudo CTs using ultrashort echo time (UTE) sequences [4], but both are not yet assigned to whole-body PET/MR imaging. Thus, the aim of this study was to introduce and evaluate a novel model-based AC method for hybrid PET/MR imaging that considers bones in whole-body PET/MR additional to the head.

Methods: The proposed method (MODEL) generates a umap based on a regular 4-compartment segmentation from a Dixon VIBE contrast, while bone information is added by using a model-based prototype bone segmentation algorithm (Siemens AG Healthcare). The offline-constructed model includes a set of pre-aligned MR image and bone mask pairs for each major body bone. At run-time, the MR image of the template is registered with the subject MR image at each major body bone individually. The bone density information is added to the original μmap (DIXON) at all voxels of densities higher than soft tissue after the segmentation process. In order to minimize physiological and inter-scanner quantification biases, CT-based μmaps (CT) based on the PET/CT data set were generated for the PET/MR emission data by non-rigid registration for each patient individually and used as standard of reference. This allowed for an intraindividual comparison of three AC methods MODEL, DIXON, and CT in each patient data set. For PET evaluation, data of 19 oncology patients (mean age: 54.8±16.8 y, mean dose: 542±18 MBq, mean weight 65.5±15.4 kg) who underwent a clinically indicated PET/CT examination with a subsequent whole-body PET/MR acquisition (Biograph mCT and Biograph mMR, Siemens AG, Erlangen, Germany) were used. All patients provided informed consent and no additional radiotracer was injected. PET/MR data was reconstructed iteratively (3D OP-OSEM, 3 iterations and 21 subsets) with the basic whole-body protocol. PET images were evaluated with MIMfusion 6.3 (MIM Software Inc., Cleveland, OH). VOIs were drawn on normal tissue (aorta/blood, liver, spleen, psoas muscle L/R, femoral head L/R, iliac bones L/R, T3, and subcutaneous fat) using superimposed MR radial VIBE images and mean SUVs were calculated. Furthermore, VOIs of soft tissue and bone lesions were drawn using a 50% max contour of the PET SUV. All mean SUVs were compared to CT-based AC PET as a reference.

Results: All three different μmaps are shown in Fig. 1. Mean SUV deviations of normal tissue for DIXON (red) and MODEL (green) normalized to the corresponding CT mean SUV are plotted in Fig. 2 in absolute values. Thus, 1.0 means that the SUV is identical with the CT SUV and e.g. 1.1 means a 10% increase of the SUV compared to CT AC. The mean is calculated across all 19 subjects and the standard deviation is included. For cold background VOIs like aorta, liver, psoas muscles, and spleen, SUVs of DIXON and MODEL are almost equivalent (max. deviation 1.2%) and are close to the CT AC (less than 6% deviation). However, bony tissues like iliac bones and femoral heads were underestimated with DIXON by 42.8% (femoral) and 20.0% (iliac). With the new MODEL AC this underestimation is reduced to 4.7% (femoral) and 3.2% (iliac). Looking at active lesions, the results are similar to the normal tissue. For soft tissue lesions the deviation between DIXON and MODEL is negligible with a mean deviation of 0.4% (max 2.0%). However, deviations for bone lesions are mostly higher and SUVs with the MODEL method are closer to the CT SUVs than with the DIXON method, as seen in Fig. 3.

Discussion: The significant improvement regarding PET SUVs in bony regions with the new AC method that includes bone in whole-body PET/MR imaging can be seen in Fig. 2 and Fig. 3. It shows the benefit of adding bone to the MR-based μmap. The new AC method, however, seems to have only little impact on normal soft tissue and soft tissue lesions. This was expected, since former studies based on PET/CT data segmentation showed that adding bone to the μmap predominately affects areas with bone and regions close to bone [2]. In contrast to former PET/MR AC studies, PET data of each patient in this study is based on only one emission raw data set (PET/MR), which focuses the quantitative comparison to the differences of the attenuation maps.

Conclusion: The new MR-based AC method for whole-body PET/MR imaging, combining Dixon-based soft tissue segmentation and model-based bone estimation providing continuous LACs improves the PET quantification, especially in bony tissue, bone lesions, and tissue close to bone.

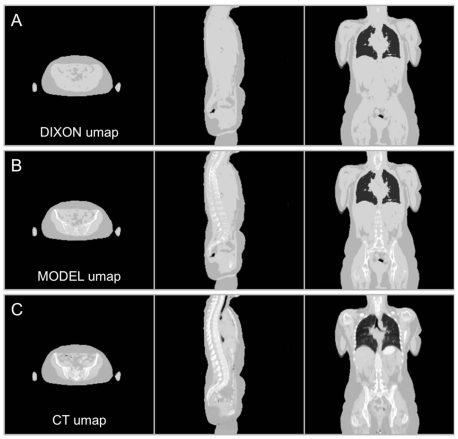

Fig. 1: *Dixon-based (A), model-based (B), and CT-based μmap (C) of one patient. Note that the model-based method (B) provides bone information with continuous LACs to the Dixon MR-based μmap.*

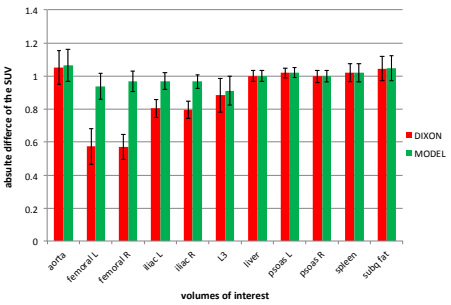

Fig. 2: *Percentage difference in absolute values of PET mean SUVs of normal tissue averaged across all subjects for DIXON (red) and MODEL (green) AC compared to the CT AC.*

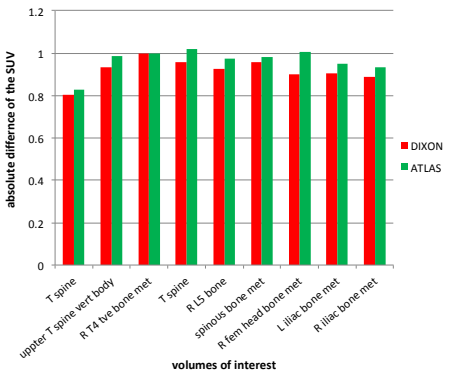

Fig. 3: *Percentage difference in absolute values of PET mean SUVs of indicated bone lesions in individual patients for DIXON (red) and MODEL (green) AC compared to the CT AC.*

References:

[1] Martinez-Moller et al. J. Nucl. Med. 2009;50(4):520-526
[2] Hofmann et al. J. Nucl. Med. 2011;52(9):1392-99
[3] Hofman et al. J. Nucl. Med. 2008;49(11):1875-1883
[4] Navalpakkam et al. Invest. Radiol 2013;48(5):323-332