Radial k-space Acquisition Improves Robustness of MR-based Attenuation Maps for MR/PET Quantification in an Animal Imaging Study of the Abdomen

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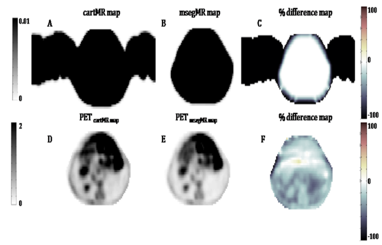

Figure 2. Representative images of A) cartMR map B) msegMR map C) percent difference between MR maps. D) cartMR map attenuation corrected PET E) msegMR map attenuation corrected PET F) percent difference between attenuation corrected PET.

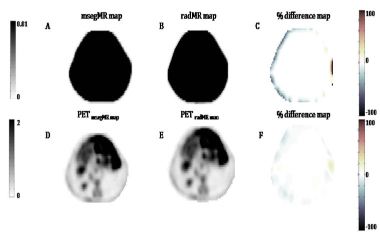

Figure 3. Representative images of A) msegMR map B) radMR map C) percent difference between MR maps. D) msegMR map attenuation corrected PET E) radMR map attenuation corrected PET F) percent difference between attenuation corrected PET.

Introduction Attenuation correction in quantitative PET is important to accurately establish the location of positron annihilations. FDA approved clinical MR/PET systems employ segmentation of low resolution, gradient echo (GRE) based, T1-weighted MR images to generate attenuation maps for attenuation correction[1]. Acquisitions are optimized for human subjects and therefore may exhibit artifacts when used in preclinical MR/PET studies. Pronounced breathing artifacts in animal models used for preclinical imaging, can impede accurate segmentation for generation of attenuation maps, impacting quantitative measurements of PET images. User input is often necessary to correct erroneous segmentation of these maps. PET images must then be re-reconstructed using the system standard algorithm to obtain more accurate quantitative PET images, an inefficient and time consuming process. In this study, we propose a radial k-space MR acquisition sequence designed to redistribute coherent breathing artifacts that result from Cartesian k-space trajectories into incoherent pseudo-noise spread across the image domain. It is proposed that the use of a radial sequence with automatic segmentation, replacing subjective user interaction in image processing, will facilitate more robust segmentation of MR images to generate attenuation maps. The objective of the current study was to then qualitatively and quantitatively evaluate the respective MR-based attenuation maps generated, in addition to their resultant quantitative PET images, to evaluate alternative preclinical MR/PET protocols.

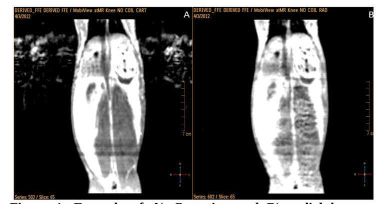

Figure 1. Example of A) Cartesian and B) radial k-space acquisitions. Coherent breathing artifacts, which cause segmentation errors, are visible in the Cartesian acquisition (A) while noise is spread into incoherent pseudo-noise across the image domain of the radial acquisition(B).

Methods Five rabbits were analyzed for this study. MR/PET acquisition was performed on the Philips Ingenuity TF whole-body sequential MR/PET system. PET data was reconstructed using the system standard MR-derived attenuation map with segmentation errors, acquired using the Cartesian acquisition (cartMR map), the manually segmented MR-derived attenuation map (msegMR map) and the radially acquired MR, segmented by the system standard algorithm (radMR map). The resulting attenuation corrected PET from each respective MR map ($PET_{cartMRmap}$, $PET_{msegMRmap}$ and $PET_{radMRmap}$) was then qualitatively and quantitatively evaluated. A correlation plot for voxel-by-voxel comparisons for all three methods and Bland-Altman plots were used to compare quantitative differences in PET reconstructed images. Region-based analysis was performed in six regions of interest (ROI): aorta, liver, kidneys (left and right), spine and soft tissue (back muscle) to determine differences in standardized uptake values (SUV) within specific tissue regions. SUV mean and SUV maximum were calculated for each ROI in the $PET_{cartMRmap}$, $PET_{msegMRmap}$ and $PET_{radMRmap}$ images. Pearson's correlation, Bland-Altman and paired t-test were evaluated using SPSS software to identify correlation and significant differences between each method, respectively.

Results Figure 1 shows an example of the system standard Cartesian k-space acquisition (1A) and the proposed radial k-space acquisition (1B). Figures 2 and 3 display axial plane comparisons of MRmaps and attenuation corrected PET images and comparisons of their percent differences in attenuation coefficient values and SUV. Voxel-by-voxel comparison of PET values for all five rabbits showed excellent correlation between $PET_{msegMRmap}$ and $PET_{radMRmap}$ SUV values (R=0.999, p<0.0001) (Fig 4A). Voxel-by-voxel correlations of PET values for all five rabbits between $PET_{msegMRmap}$ and $PET_{cartMRmap}$ SUV values and between $PET_{radMRmap}$ and $PET_{cartMRmap}$ showed lower correlation with similar correlation coefficients (R=0.971, p<0.0001 and R=0.971, p<0.0001, respectively). Bland-Altman plots showed that the mean of the difference of SUVs between $PET_{msegMRmap}$ and $PET_{radMRmap}$ voxels for all five rabbits was 0.53% (0.004±0.014SD) (Fig 4B). In addition, Bland-Altman plots showed that the mean of the difference of SUVs between $PET_{msegMRmap}$ and $PET_{cartMRmap}$ voxels for all five rabbits was 16.28% (0.121±0.209SD) and between $PET_{radMRmap}$ and $PET_{cartMRmap}$ voxels for all five rabbits was 15.67% (0.117±0.207SD). ROI-based comparison showed that $PET_{radMRmap}$ and $PET_{msegMRmap}$ methods differ in quantification of SUVmean by -0.7% to 0.9% and SUVmax by -1.2% to 2.7%, which is in concordance with respective correlation (Fig 4A) and Bland-Altman (Fig 4D) plots. Comparatively, $PET_{radMRmap}$ and $PET_{msegMRmap}$ methods, when compared to $PET_{cartMRmap}$ in ROI analysis, show that the system standard cartMR map without corrected segmentation demonstrates a large overestimation in SUVmean (6.4% to 26.1%) and SUVmax (8.6% to 27.8%).

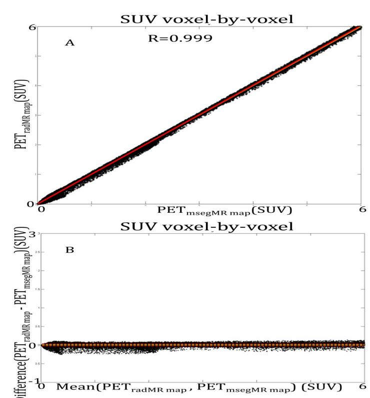

Figure 4. Voxel-by-voxel comparison of radMR map and msegMR map methods. Correlation plot for all rabbits showing A) radMR map attenuation corrected PET versus msegMR map attenuation corrected PET. Bland-Altman plot of SUV measurements for B) radMR map attenuation corrected PET versus msegMR map attenuation corrected PET.

Discussion The current study shows a comparison of the effects on quantitative PET of a radial k-space MR acquisition sequence, designed to redistribute coherent breathing artifacts associated with preclinical animal imaging, with that of the system standard Cartesian k-space acquisition sequence. It is clear that the radial k-space acquisition redistributes coherent breathing artifacts (Fig 1B). These breathing artifacts produce errors in the attenuation maps produced from the Cartesian acquisition and cause over estimation of SUV. Direct comparison of the proposed radMR map and msegMR map demonstrated that segmentation is nearly identical with minimal errors in the percent difference map (Fig 3). To our knowledge at this time, there have been no reports of preclinical MR-derived attenuation map errors. It is almost certain that there will be an increasing number of preclinical studies performed on clinical MR/PET scanners as they become more readily available and users must be aware of possible MR map errors when performing such preclinical studies, as these errors will have significant impact on SUV values. While the Cartesian k-space MR acquisition is well suited for many clinical MR/PET protocols, it is not suited for certain preclinical MR/PET protocols where breathing artifacts can impede accurate segmentation. For these cases, we have shown that employing a simple radial k-space MR acquisition during preclinical abdominal MR/PET protocols facilitates highly accurate segmentation and PET quantification, without the need for subjective user input and is therefore, better suited for use in preclinical MR/PET protocols than the existing MR Cartesian acquisition.

Acknowledgement

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References

1. Z. Hu, et al., NSS/MIC record, 2009; 3508-3512