Wavelet-based Partial Volume Effect Correction for Simultaneous MR/PET of the Carotid Arteries.

Jason Bini[1,2], Mootaz Eldib[1], Philip M Robson[1], and Zahi A Fayad[1]

[1]Translational and Molecular Imaging Institute, Icahn School of Medicine at Mount Sinai, New York, New York, United States, [2]Department of Biomedical Engineering, The City College of New York, New York, New York, United States

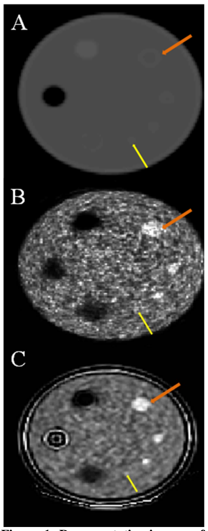

Figure 1. Representative images of A) High resolution image of ACR phantom B) ACR phantom PET image with no partial volume effect correction C) ACR phantom PET image with partial volume effect correction.

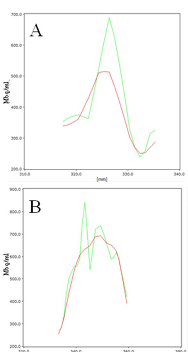

Figure 2. Line profiles through A) 8mm cylinder before (green line) and after (red line) wavelet-based PVE correction B) 25mm cylinder before (green line) and after (red line) wavelet-based PVE correction

Introduction The superior soft tissue characterization of magnetic resonance (MR) imaging and the ability to detect inflammation in positron emission tomography (PET) makes the combination of both modalities an attractive candidate for detection of atherosclerotic plaques in the carotid arteries. In simultaneous MR/PET, the high spatial resolution anatomical MR images are simultaneously acquired and inherently coregistered to the lower resolution PET images. Although coregistration of MR and PET allows more accurate co-localization of the radiotracer, the limited resolution of conventional PET scanners has an impact on the accuracy of quantitative measurements in 18F-Fluordeoxyglucose (FDG)-PET due to partial volume effects (PVE). Partial volume effects consist of blurring from both the point spread function of the PET system and the tissue fraction effect.[1] The tissue fraction effect occurs when the tissue boundaries of two tissues of interest are split into pixel sub-regions, a direct effect of the PET image voxel size. PVE correction methods, to date, have been hindered by the challenge of accurately registering MR and PET images acquired on different scanners. Simultaneous MR/PET scanners allow for the exploration and development of novel PVE correction techniques without this concern. The development of a wavelet-based PVE correction method, to improve PET quantification, has proven successful in brain PET.[2] However, we report here the first attempt to apply these methods to simultaneous MR/PET imaging of the carotid arteries.

Methods The American College of Radiology (ACR) phantom was injected with 18F-FDG for a lesion to background ratio of 2.5. As per ACR protocol, hot cylinders ("lesions") were injected with 30.71MBq and the phantom background was injected with 12.95MBq. The ACR phantom was then scanned on the Siemens mCT (PET/CT) and Siemens Biograph mMR (MR/PET). The CT from the PET/CT acquisition and PET image from the MR/PET acquisition were then coregistered using first coarse manual registration then normalized mutual information rigid registration (SPM8). The Biograph mMR system standard PET reconstruction was used for the phantom with the CT image converted to 511keV attenuation values as the attenuation map inserted into the Biograph mMR reconstruction algorithm. One patient with family history of cardiovascular disease was injected with 446.6MBq of 18F-FDG and scanned after a circulation time of 90 minutes on the Siemens Biograph mMR. The MR/PET acquisition consisted of the system standard Dixon attenuation correction sequence, which separates air ($0 cm^{-1}$), lung ($0.022 cm^{-1}$), fat ($0.086 cm^{-1}$) and soft tissue ($0.100 cm^{-1}$) into distinct compartments. The patient PET reconstruction was performed using the system standard Biograph mMR attenuation map (air/lung/fat/soft tissue) and reconstruction algorithm. Wavelet-based PVE correction was performed using wavelet decomposition software from New York University Polytechnic (http://eeweb.poly.edu/iselesni/WaveletSoftware/) that was adapted in-house in MATLAB to incorporate high frequency wavelet information from MR images into PET images to improve resolution. Line profiles through, and circular regions-of-interest (ROIs) around, the 8mm and 25mm cylinders were drawn to measure the effect of PVE correction on measured activity in the largest and smallest cylinders in the ACR phantom. To measure effect of PVE correction in the patient, ROIs were drawn on 15 consecutive axial slices of the left and right carotid arteries, centered around the carotid bifurcation, on the Dixon water MR sequence. These ROIs were transferred to the non-PVE corrected PET and the PVE corrected PET to measure standardized uptake value (SUV) of the radiotracer in the carotid arteries.

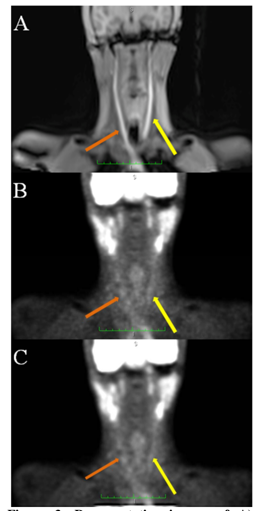

Figure 3. Representative images of A) Dixon water image (High frequency information) B) PET image with no partial volume effect correction C) PET image

SUV	*Mean*	*p*	*Std Dev*	*Max*	*p*
L Carotid No PVC	0.639	0.141	0.063	0.747	0.005
L Carotid with PVC	0.638		0.060	0.739	
R Carotid No PVC	0.661	0.451	0.095	0.841	<0.001
R Carotid with PVC	0.661		0.093	0.826	

Table 1. Standardized Uptake Values (SUV) in the left and right carotid arteries with and without wavelet-based partial volume effect correction (PVC).

Results Figure 1 shows a qualitative comparison of an axial slice of the ACR phantom in the high resolution CT attenuation map used in the PET reconstruction and wavelet-based PVE correction (Fig 1A), the PET image with no PVE correction (Fig 1B) and the PET image with wavelet-based PVE correction (Fig 1C). The line profiles drawn through the 8mm cylinder (Fig 2A, yellow arrows Fig 1) and 25mm cylinder (Fig 2B, orange arrows Fig 1) demonstrated an improvement of quantification in the non-PVE corrected PET image (green lines, Fig 2) compared to the wavelet-based PVE corrected PET image (red lines, Fig 2). The mean quantification of ROIs in the non-PVE corrected PET in the 25mm cylinder was 630.6 ± 132.5 Bq/ml as compared to 593.9 ± 88.6 Bq/ml in the PVE corrected PET. In the 8mm cylinder, mean quantification of ROIs in the non-PVE corrected PET was 484.9 ± 101.2 Mq/ml as compared to 493.0 ± 55.0 Mq/ml in the PVE corrected PET. Figure 3 shows a qualitative comparison of the Dixon acquisition (water image) (Fig 3A), the PET image with no PVE correction (Fig 2B) and the PET image with wavelet-based PVE correction (Fig 2C). Table 1 shows mean SUV and max SUV with standard deviation before and after PVE correction in the left and right carotid arteries.

Discussion The current study shows a comparison of the effects on quantitative PET of a wavelet-based partial volume effect correction technique for use in carotid MR/PET protocols. The wavelet-based partial volume technique is designed to compensate for partial volume artifacts such as tissue fraction effects. The technique applied here demonstrated an improvement in both resolution and quantification in the phantom and the patient. In the ACR phantom, after PVE correction, we were able to resolve the 8mm cylinder that was not visible prior to wavelet-based correction (Fig 1, yellow arrow). The line profiles and ROIs of the 8mm (Fig 2A) and 25mm (Fig 2B) both showed improvement with more accurate mean quantification and lower standard deviations suggesting that PVE were minimized. In the patient the carotid arteries seem to appear sharper in qualitative assessment (Fig 3, yellow and orange arrows) and even though the mean standardized uptake value (SUV) uptake remain unchanged the max SUV and standard deviation were both significantly minimized in the left ($p=0.005$) and right ($p<0.001$) carotid arteries. We chose to use the water acquisition of the Dixon attenuation correction sequence in this instance because it is a required attenuation correction MR sequence run simultaneously during MR/PET acquisition. Currently, we are testing additional MR sequences and optimizing parameters of the wavelet-based PVE correction algorithm. However, these positive results demonstrate the feasibility of wavelet-based PVE correction to provide improved quantification for MR/PET in the carotid arteries.

Acknowledgement This work was supported in part by NIH/NHLBI ROI HL071021 and an AHA Student Scholarship in Cardiovascular Disease **References**1. Soret, et al. Partial Volume Effect in PET tumor imaging. *JNM* 48, 9832-54 (2007). 2. Boussion, et al. A multiresolution image based approach for resolution recovery and partial volume effect correction in brain PET. *Phys Med Biol* 51, 1857-75 (2006).