

# Quantitative Carotid MR/PET Imaging: Comparisons to PET/CT and clinical evaluation of MR-Attenuation Correction versus CT-Attenuation Correction in MR/PET Emission Data

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**Introduction** 18F-Fluorodeoxyglucose (FDG) positron emission tomography (PET) has shown promise in characterizing and quantifying metabolic activity of inflammation in atherosclerotic plaques in patients.<sup>1</sup> In order to co-localize PET radiotracers, patient scans are routinely performed on combined PET/computed tomography (CT) scanners to provide anatomical co-registration to complement functional PET images. In combined MR/PET systems, the substitution of CT with MR still allows for high spatial resolution anatomical images but provides superior soft tissue contrast for radiotracer co-localization. However, there are still challenges to provide accurate quantitative PET images in a clinical setting. MR measures proton density and magnetic relaxation times and thus provides no direct relationship to photon attenuation. Current MR/PET systems employ segmentation of MR images and subsequent assignment of empirical attenuation map values for quantitative PET reconstruction. Several groups have previously studied the relationship between PET/CT and MR/PET systems for a variety of imaging protocols.<sup>2-6</sup> These studies have shown that MR/PET generally underestimates quantitative measures of inflammation (i.e., FDG uptake) compared to PET/CT. This is believed to be due to misrepresentative MR-based attenuation correction (MRAC) maps, differences in circulation time (clinical PET/CT performed first and experimental MR/PET second with a single radiotracer injection), differences in PET detector sensitivity and efficiency and differences in PET reconstruction algorithms. In this current study we examine the quantitative differences between our carotid artery imaging protocol on both a PET/CT and an MR/PET scanner controlling for acquisition parameters, such as circulation time, not previously been accounted for in such comparisons.

**Methods** Seven patients, mean weight of  $76.6 \pm 17.6$  kg, were injected with 18F-FDG ( $507.8 \pm 84.8$  Mbq) and imaged on both a PET/CT (GE Discovery STE, Waukesha, WI, USA) and an MR/PET (Philips Ingenuity TF, Cleveland, OH, USA) scanner. Acquisition time consisted of 2 bed positions, for 8 minutes each, centered on the carotid bifurcation. PET/CT and MR/PET acquisitions were performed one week apart to control for equal circulation time in both acquisitions. All acquisitions were co-registered to the MR/PET acquisition space using SPM8 (SPM, University College London, London, England). PET images from the PET/CT acquisition were reconstructed using the both system standard CT-based attenuation correction (CTAC) map and reconstruction. PET images from the MR/PET acquisition were reconstructed using both the system standard 3-segment attenuation map (air  $0.00\text{cm}^{-1}$ , lung  $0.022\text{cm}^{-1}$  and soft tissue  $0.096\text{cm}^{-1}$ ) with the system standard reconstruction. To control for differences due to PET detectors and reconstruction algorithms between system standard PET/CT and MR/PET quantitative PET images, the PET acquisition from the MR/PET scanner was reconstructed also with the CTAC map. Mis-segmentation MRAC maps were manually segmented (lungs and trachea) and the PET emission data were re-reconstructed using the system standard MR/PET reconstruction to provide a more accurate comparison to PET/CT. Linear correlation and Bland-Altman plots were calculated in MATLAB (MATLAB, Natick, MA, USA) to quantitatively compare PET images. Five comparisons were performed (PET/CT v MR/PET with MRAC map errors; PET/CT v MR/PET with MRAC map corrected; MR/PET CTAC v MR/PET MRAC map errors; MR/PET CTAC v MR/PET MRAC map corrected; MR/PET MRAC map corrected v MR/PET MRAC map error) to provide a comprehensive comparison of quantitative PET/CT and MR/PET imaging.

**Results** Figure 1 presents a qualitative comparison of the same coronal slice through each CTAC and MRAC map and the resulting respective PET reconstruction of one representative patient. Comparisons include the system standard PET/CT CTAC map (Fig 1A), the system standard MR/PET MRAC map with segmentation errors (Fig 1B), the MR/PET MRAC map corrected (Fig 1C), CTAC map used in the MR/PET reconstruction (Fig 1D) and their corresponding PET reconstructions including the system standard PET/CT image (Fig 1E), system standard MR/PET image with errors in MRAC map (Fig 1F), system standard MR/PET image with corrected MRAC map (Fig 1G) and the MR/PET reconstructed with the CTAC map (Fig 1H). Figure 2 shows linear correlations of PET quantification for all seven patients for PET/CT versus MR/PET with MRAC map errors ( $R^2=0.794$ ) (Fig 2A), PET/CT versus MR/PET with MRAC map corrected ( $R^2=0.788$ ) (Fig 2B), MR/PET reconstructed with CTAC map versus MR/PET with MRAC map errors ( $R^2=0.980$ ) (Fig 2C), MR/PET reconstructed with CTAC map versus MR/PET with MRAC map corrected ( $R^2=0.984$ ) (Fig 2D), and MR/PET with MRAC map corrected versus MR/PET with MRAC map with errors ( $R^2=0.994$ ) (Fig 2E). Figure 2 also shows the Bland-Altman plots of PET quantification for all seven patients for PET/CT versus MR/PET with MRAC map errors (mean difference  $0.040 \pm 0.213$  standardized uptake value (SUV)) (Fig 2F), PET/CT versus MR/PET with MRAC map corrected (mean difference  $0.048 \pm 0.230$  SUV) (Fig 2G), MR/PET reconstructed with CTAC map versus MR/PET with MRAC map errors (mean difference  $-0.029 \pm 0.135$  SUV) (Fig 2H), MR/PET reconstructed with CTAC map versus MR/PET with MRAC map corrected (mean difference  $-0.002 \pm 0.111$  SUV) (Fig 2I), and MR/PET with MRAC map corrected versus MR/PET with MRAC map with errors (mean difference  $-0.027 \pm 0.077$  SUV) (Fig 2J).

**Discussion** The current study shows a comparison of quantitative PET for use in carotid MR/PET protocols on both PET/CT and MR/PET scanners. Qualitatively, MR/PET images reconstructed with both MRAC and CTAC maps showed strong tracer uptake in carotid arteries due to the time-of-flight PET detectors in the Philips system (Fig 1F-H). PET images acquired on the MR/PET (Fig 1G) with accurate system standard MRAC maps Fig 1(C) generally overestimate SUV (Fig 2B/2G) compared to PET/CT PET images (Fig 1E). Despite the equivalent circulation time, large differences between PET/CT and MR/PET were observed which highlight the time-of-flight reconstruction, in addition to, newer generation PET detectors (higher sensitivity and efficiency) that allow for a higher count rate and more accurately placed coincidences in the same acquisition duration. However, when reconstructing and comparing the same PET data with MRAC and CTAC maps in the system standard Philips MR/PET reconstruction algorithm we see a high correlation between reconstructed PET images (mean difference  $-0.002 \pm 0.111$  SUV) ( $R^2=0.984$ ) (Fig 2G/2H). Currently, we are further exploring region-of-interest based analysis to determine whether the lack of bone segmentation in the neck has an influence on quantitative measures in the carotid arteries. The results of this study support the use of MR/PET for quantitative measure of metabolic activity (e.g., inflammation) in the carotid arteries.

**Acknowledgement** This work was supported in part by NIH/NHLBI RO1 HL071021 **References** 1. Rudd, et al *JNM* 49:871-8 (2008) 2. Drzezga, et al. *JNM* 53:1-11 (2012) 3. Quick, et al. *Invest Radiol* 48(5):280-9 (2013) 4. Heusch, et al. *Eur J Rad* 82(11): 2055-60 (2013). 5. Schwenzer, et al. *Radiology* 264(2):551-8. 6. Wiesmuller, et al. *Eur J Nucl Med Mol Img* 40:12-21 (2013).

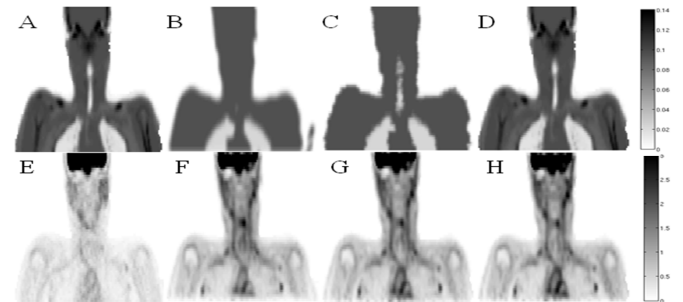


Figure 1. Representative images of A) system standard PET/CT CTAC map B) system standard MR/PET MRAC map with errors C) MR/PET MRAC map corrected D) CTAC map used in MR/PET reconstruction E) system standard PET/CT PET image F) system standard MR/PET PET image with errors in MRAC map G) MR/PET PET image with corrected MRAC map H) MR/PET PET image reconstructed with CTAC map

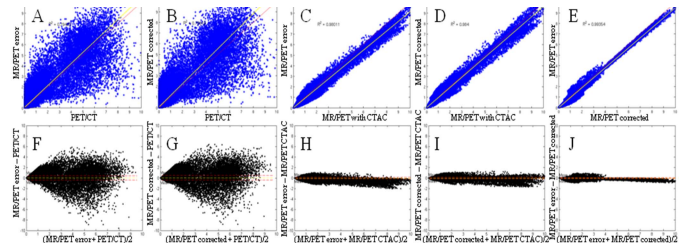


Figure 2. Correlation Plots of A) PET/CT versus MR/PET with MRAC map errors B) PET/CT versus MR/PET with MRAC map corrected C) MR/PET reconstructed with CTAC map versus MR/PET with MRAC map errors D) MR/PET reconstructed with CTAC map versus MR/PET with MRAC map corrected E) MR/PET with MRAC map corrected versus MR/PET with MRAC map with errors. Bland-Altman plots of F) PET/CT versus MR/PET with MRAC map errors G) PET/CT versus MR/PET with MRAC map corrected H) MR/PET reconstructed with CTAC map versus MR/PET with MRAC map errors I) MR/PET reconstructed with CTAC map versus MR/PET with MRAC map corrected J) MR/PET with MRAC map corrected versus MR/PET with MRAC map with errors.