Is Accurate Bone Segmentation Required for MR-based PET Attenuation Correction?

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INTRODUCTION

There has been recently great interest in combining PET and MRI, and a number of integrated scanners capable of simultaneous acquisition have been developed and successfully tested for small animal [1,2] and human [3] imaging. Correcting for photon attenuation in PET is an important and required step not only for quantitative studies, but also for performing meaningful qualitative PET image analysis [4]. However, this correction is quite challenging in a combined MR-PET scanner. Due to the limited space available inside an MR scanner, the MR compatible BrainPET prototype from Siemens is not equipped with a transmission source, which makes the implementation and validation of an MR-based attenuation correction (AC) method necessary. Such a method has the advantage of reducing the subject's radiation exposure and the total examination time and of eliminating the co-registration errors between the emission data and attenuation map. The challenge is that MR images are not typically directly related to tissue linear attenuation. Furthermore, although MRI provides excellent soft tissue contrast, tissues with very different linear attenuation coefficients (i.e., air and bone) cannot be easily distinguished using conventional MR sequences. In this work, we studied the effects of misclassifying the bone on the PET data quantification in structures of interest using segmented MR images.

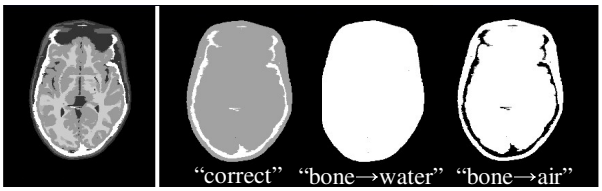

Fig. 1: Segmented MR data and the attenuation maps obtained using the three methods described in the text.

MATERIALS AND METHODS

"Approximate" MR-based AC: The MR-based method currently used for obtaining the AC consists of the following steps: acquire PET and MR data simultaneously; co-register the PET and MR volumes to account for differences in slice positioning; reslice the MR volume in the PET space; binary segment the MR images; assign the water attenuation coefficient to all the voxels above the threshold to obtain the μ-map; forward project the μ-map to generate the AC in sinogram space. PET data were reconstructed first without AC and then with AC factors obtained from a μ-map derived from the simultaneously acquired MR data.

Simulations of the Impact Bone Misclassification on PET Quantification. The importance of using an accurate AC in the brain was studied by performing simulations starting from the MR data acquired in a real human subject. A high-resolution dataset was acquired using an MP-RAGE sequence and structures of interest have been segmented and identified on these images [5]. The emission data were simulated by assuming uniform uptake in the brain and then forward projecting the volume to obtain the "ideal" emission sinograms. For creating the μ-maps, all tissues were classified into three classes: soft tissue, bone and air cavities. It is reasonable to assume that the attenuation properties of soft tissues are uniform, so that a constant linear attenuation coefficient of 0.096 cm^{-1} can be assigned. The more challenging task consists of differentiating the bone tissue from the air-filled spaces, since they both appear dark on the MR images. Bone is especially relevant as a photon-attenuating medium, being the tissue with the highest attenuation coefficient (~0.151 cm^{-1} at 511 keV). In our simulations, we considered three cases (Fig. 1): bone is correctly identified ("correct", μ=0.151 cm^{-1}), bone is misclassified as water ("bone→water", μ=0.096 cm^{-1}) or bone is not identified ("bone→air", μ=0 cm^{-1}). The maps obtained in each case were forwarded projected to obtain the AC. The "ideal" emission sinogram was "attenuated" using the correct attenuation (i.e. the one in which bone is correctly identified) to obtain the "ideal attenuated" sinogram. Finally, these data were reconstructed using the three different AC to estimate the regional bias.

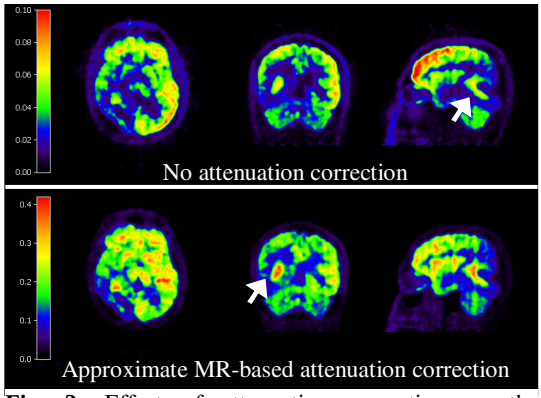

Fig. 2: Effect of attenuation correction on the interpretation of the PET study in a GBM subject.

RESULTS AND DISCUSSIONS

"Approximate" MR-based AC: The importance of performing AC is illustrated in the example shown in Fig.2. The overall depression of the activity at the center of the volume is evident (see axial sections). Furthermore, without any correction, the FDG uptake in the tumor is lower than in the GM (arrow on sagittal section). After AC, the FDG uptake in the tumor is comparable or even higher than in the GM uptake (arrow on coronal section). This is clinically relevant as it might suggest malignant transformation. This example illustrates the need of performing AC even in the cases where a visual assessment of the images is performed.

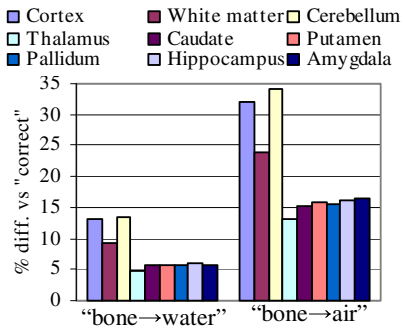

Fig. 3: Effects of bone misclassification on PET data quantification.

Impact on PET Quantification: Since the location of different structures (e.g. cortex, cerebellum, thalamus, etc) was accurately known from the MR images, we were able to estimate the effect of AC approximations on the activity measured in these structures (Fig. 3). Early methods for estimating AC consisted of determining the contour of the head from the emission data, which is similar to the "bone→water" method. Although the overall magnitude of the error when using this method could be considered clinically acceptable, more relevant is the variation of the effect across different structures (i.e. ~5% error for deep GM structures and close to 15% for cortex and cerebellum) due to their proximity to the bone. Furthermore, these methods are prone to fail in more challenging regions close to the, skull base or the mastoids where a mixture of tissue types is present in a less predictable manner. This has real impact: for example, the cerebellum is often used as reference region in receptor studies, so a very accurate determination of the activity in this region is desirable. The errors were definitely clinically significant when the "bone→air" method was used, with over 30% errors in the cortex and cerebellum and ~15% in the other structures. These data demonstrate that an accurate identification of the bone is necessary even for brain studies using combined MR-PET scanners and a method to precisely identify the bone is essential.

REFERENCES: [1] Catana C et al, PNAS, 2008; 105(10): 3705-10; [2] Judenhofer MS et al, Nature Medicine, 2008; 14(4):459-465; [3] Schlemmer HP et al, Radiology, 2008; 248(3):1028-35; [4] Zaidi H et al, E JNM&MI, 2004; 31(1): 52-63; [5] Fischl B et al, Neuron, 2002; 33: 341-355.