Continuous Bone Density Measurement for Simultaneous MR-PET Attenuation Correction using Water- and Fat-Suppressed Projection Imaging (WASPI)

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Target Audience: Scientists and clinicians interested in accurate bone attenuation correction for simultaneous MR-PET.

Purpose: Simultaneous MR-PET is an emerging hybrid modality that is attracting substantial interest. Currently, one of the hurdles for MR-PET is its quantitative accuracy due to challenges in obtaining accurate attenuation correction (AC). In PET-CT, the AC maps are measured with X-ray and remapped to estimate the AC coefficients for 511 keV photons. For MR-PET, the PET AC map typically needs to be derived from the MR images. The standard approach is to segment an MR image volume into different tissue classes and then assign the corresponding attenuation coefficients to them.

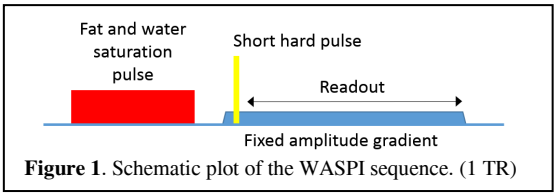

Figure 1. Schematic plot of the WASPI sequence. (1 TR)

Although the segmentation approach works relatively well for air and soft tissues, accurate AC in regions within or near bone is still an open problem [1] due to lack of signal from solid bone (due to its short T2) in most MR sequences. Investigators have proposed to use atlas-based maps [2] and the ultrashort echo time (UTE) pulse sequence [3] to identify bones. However, these approaches do not take into account the intra- and inter-patient bone density variations, which are much larger than in soft tissue, and may lead to bias in the quantitation. In this work, we investigated the possibility of using the *Water- And fat-Suppressed Proton projection Imaging* (WASPI) sequence to measure bone density.

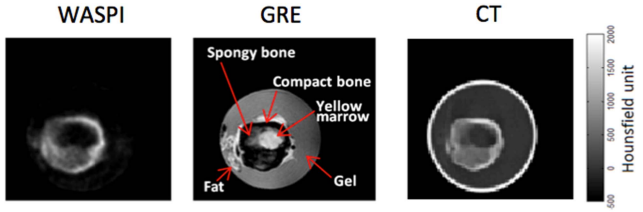

Figure 2. A transverse slice of the WASPI MR volume compared with the corresponding image slice acquired using a conventional GRE pulse sequence and CT. It can be seen that the WASPI signal intensity is approximately proportional to the corresponding CT Hounsfield unit.

Methods: WASPI [4] is a 3D radial zero-TE sequence with fat and water suppression leaving signal only from very short T2 protons, primarily the immobile proteins in the bone matrix. Previous work [5] has shown that the signal intensity is proportional to bone matrix density, which for normally mineralized bone is in turn proportional to bone mineral density. The schematic plot of the sequence for 1 TR is shown in **Figure 1**. The WASPI sequence first saturates the fluid (molecularly mobile) tissue constituents with chemical shift selective RF pulses at the water and fat frequencies; each RF pulse is followed by a crusher gradient pulse to dephase the fluid signals. Then a fixed-amplitude gradient is first turned on, and a very brief (10 μs in this work) rectangular hard RF pulse is applied, eliciting a free induction decay (FID) which is sampled to yield a single radial line of k-space. The direction of the fixed amplitude gradient is advanced to successive orientations to cover a spherical volume of k-space. The data can be reconstructed using regridding.

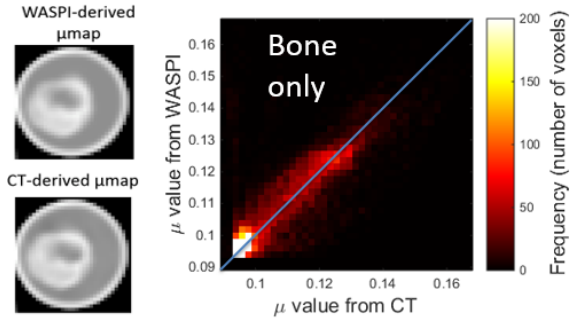

Figure 3. (left) The attenuation map (μmap) obtained using the proposed WASPI compared with the CT derived μmap. (right) The joint histogram of the bone μ values obtained from WASPI and CT.

In this work, the gradient strength was fixed at 18.35 mT/m, 15972 radii were acquired with 128 points sampling each radius, the bandwidth was 781 Hz/pixel, and TR was 28 ms. For WASPI, the effective TE is 0. The field of view was 128×128×128 mm^3 with 1 mm isotropic spatial resolution. The acquisition time of the non-optimized WASPI acquisition was 7.5 minutes.

In order to obtain realistic bone images, a cow tibia along with some fatty tissue was placed inside a cylindrical glass container 8.5 cm in diameter. The container was then filled with 5% gelatin gel with radioactivity mimicking soft tissue. The phantom was first scanned on a Siemens Biograph 64 PET-CT scanner (120 kVp, 66 mAs). Afterwards, the phantom was imaged in a Siemens Trio 3T MR using WASPI and conventional GRE. To achieve a fast switch from transmitting to receiving, a home-made cylindrical transmit-receive quadrature RF coil was used (inner diameter = 8.8 cm). MR images were reconstructed using a dedicated in-house code.

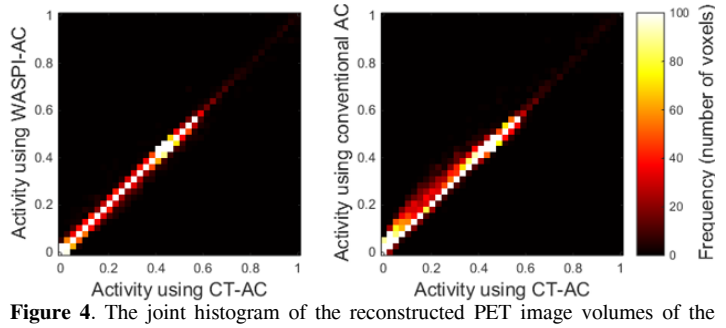

Figure 4. The joint histogram of the reconstructed PET image volumes of the phantom using CT based AC v.s. WASPI based AC or conventional MR AC.

Results and Discussion: **Figure 2** shows a slice of the WASPI MR volume compared with the corresponding slice acquired using conventional GRE and CT. In contrast to the GRE sequence which provides good detail for soft tissue and bone marrow but no signal from bone, the WASPI MR exhibits signal from bone but not soft tissue. Furthermore, it can be seen that the WASPI signal intensity is higher for the region of the bone with higher CT Hounsfield units (HU), hence higher bone density. The left panel of **Figure 3** shows the attenuation map obtained using WASPI compared with CT derived attenuation map. Their joint histogram of the bone is also shown on the right. The WASPI derived attenuation agrees well with that generated from CT. **Figure 4** shows the joint histogram of the reconstructed PET activities of each voxel in the image volumes using CT based attenuation correction (AC) and WASPI based AC or conventional MR AC, the current AC used in the commercial MR-PET scanner. It can be seen that the WASPI-AC agrees better with CT-AC.

Conclusion: This work provides preliminary evidence for the use of WASPI MR imaging to supply continuous bone density information for MR-PET attenuation correction. Additional studies are required to quantitatively assess the performance of WASPI vs. CT in this application.

References: [1] J Ouyang, et. al, IEEE TNS, 2013, 60(5) [2] CB Poynton, et. al, Am J Nucl Med Mol Imaging 2014, 4(2) [3] BK Navalpakkam, et. al, Invest Radiol 2013, 48 (5) [4] Y Wu, et al, JMRI 2010; 31 [5] H Cao,et. al, MRM 2008; 60