Analysis of Tissue Properties and MRI Signals in the Head for PET/MRI Attenuation Correction

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Introduction: Positron emission tomography (PET) requires photon attenuation correction to accurately reconstruct the PET images. PET-MR systems use MRI to image and differentiate tissue and generate attenuation or μ (mu-) maps. Tissues are typically delineated into four categories (air, bone, fat, and water) using Dixon fat/water or ultra-short TE (UTE) pulse sequences. Unfortunately, these sequences have limitations in differentiating tissue types and foreign objects. Mu values can be accurately predicted from acquired and published tissue properties with the exception of solid bone which cannot be directly imaged with MRI due to its short T_2 (< 20 μs). The study's goal was to identify the relationship between tissue properties and mu to optimize the accuracy of the mu-map.

Methods: T_1-weighted MPRAGE (TI: 0.9 s, TE:3 ms, TR:2.3 s), spin echo (TE:8.4 ms, TR:0.7 s), and UTE (TE:0.07/2.5 ms, TR:11.9 ms) MRIs; and proton density/T_2 (TEs:7.6/91 ms, TR:16 s) weighted MRI signals were acquired in human subjects (N=5, <age>= 80 years) on a Siemens 3T mMR (PET/MR) scanner after informed consent. Relaxation times, fat/water compositions, proton and mass densities, and magnetic susceptibilities of tissues were obtained from the literature (Table 1). Mass attenuation coefficients were calculated from http://www.nist.gov/pml/data/xraycoef/index.cfm/. Tissue regions of interest (ROIs) were analyzed for signal intensity and normalized to the maxima. T_2 was calculated from fits to the PD/T_2 signals. Linear regression and forward variable selection was used with Mathematica v8.0 to correlate tissue parameters and mu.

Table 1: MRI Head Tissue Parameters at 3 T

Tissue Class	μ (cm^{-1})	Norm. T_1-wtd Signal Mean	Norm. T_2-wtd Signal Mean	Norm. MPRAGE Signal Mean	T_1 (s)	T_2 (s) Msd/Lit.	% Water	% Fat	Mass Density (g/cm^3)	Norm. Proton Density Msd/Lit.	Mag. Susc. χ ($x10^{-6}$)
Air	0.000105	0.01	0.01	0.02	0	NA/0	0	0	0.00121	0.01/0.00	0.36
CSF	0.097	0.17	1.00	0.11	4.20	NA/1.99	97.5	0.001	1.00	1.00/1.00	-9.05
Diploë	0.125	0.22	0.16	0.27	0.71	0.14/0.06	35.0	50.0	1.37	0.30/0.57	-10.52
Fat	0.092	1.00	0.46	1.00	0.38	0.12/0.08	10.0	82.0	0.92	0.90/0.95	-8.44
Gray Matter	0.100	0.30	0.32	0.33	1.30	0.15/0.10	82.0	7.0	1.04	0.57/0.86	-8.97
Muscle	0.100	0.26	0.10	0.47	1.16	0.06/0.04	79.2	2.0	1.06	0.39/0.83	-8.85
Sinuses	0.000105	0.02	0.02	0.04	0	NA/0	0	0	0.00121	0.03/0.00	0.36
Skin	0.092	0.35	0.14	0.32	0.90	0.08/0.08	80.0	12.2	0.95	0.41/NA	-8.44
Compact Bone	0.172	0.04	0.04	0.09	0.20	NA/ <0.005	12.2	1.7	1.90	0.05/0.14	-11.31
White Matter	0.100	0.37	0.20	0.59	0.89	0.11/0.08	75.0	16.0	1.04	0.44/0.77	-8.80

NA: Not available (or measurable). Msd: Measured. Lit: Literature value. Relative UTE signals are not shown due to space limitations. Note: the diploë MR signal originates from red marrow.

Results and Discussion: Based on the regression, mu can be calculated for the ten tissue types based on mass density (R^2=0.996) which cannot be directly measured using MRI. Mu can be calculated based on magnetic susceptibility alone (R^2=0.927) or combined with proton density (R^2=0.967). Adding T_1- or T_2-weighted data did not affect the outcome although combining 11 tissue parameters resulted in accurate calculation of mu for all ten tissue types (R^2=1.000). Obviously, many of the tissue parameters are correlated (e.g, fat/water fraction, mass and proton densities; T_1 or T_2 weighted signal intensity and relaxation times). Most of the measured proton densities were significantly lower than the literature. Diploë (marrow), bone, skin, and sinus measurements were vulnerable to partial volume effects during the ROI analysis.

Bone can be differentiated from air through their magnetic susceptibilities since air/tissue boundaries will have significant magnetic inhomogeneities while bone/tissue interface will not. Phase or susceptibility maps can be combined with image segmentation to accurately identify bone and foreign bodies (e.g., implants) from air for improved mu-maps.[1,2]

References: 1. B Dogdas et al., Human Brain Mapping 26:273-285 (2005). 2. K Shmueli et al., MRM 62:1510-1522 (2009).