Three approaches to Phantom Fluid Selection for Simultaneous PET/MR Hybrid Imaging

Susanne Ziegler[1], Harald Braun[1], Philipp Ritt[2,3], Carsten Hocke[2], Torsten Kuwert[2], and Harald H. Quick[1]

[1]*Institute of Medical Physics, University of Erlangen-Nuremberg, Erlangen, Germany,* [2]*Clinic for Nuclear Medicine, University Hospital Erlangen, Erlangen, Germany,* [3]*Pattern Recognition Lab, University of Erlangen-Nuremberg, Erlangen, Germany*

Target audience: Researchers and physicians working in the new field of PET/MR hybrid imaging.

Introduction: When combining PET and MR phantom measurements for simultaneous PET/MR hybrid imaging, phantom fluids may not be interchangeably applicable across these two modalities. Especially when imaging large-sized phantoms (Figure 1A) at high MR field strength (> 1.5 Tesla). Water reduces the RF excitation wavelength and thus can cause strong RF-excitation artifacts in MRI (Figure 1B). However water is used commonly in PET imaging, as it dissolves radiotracers like fluorodeoxyglucose (^{18}F-FDG) very well. In MRI the relative permittivity ε_r and conductivity σ of the phantom fluid are crucial[1,2]. Low ε_r, as in oil, is preferred in highfield MRI, but is not applicable for PET imaging, as it doesn't dissolve ^{18}F-FDG (Figure 1C). Alternatively to finding a fluid besides water and oil, an increase in the electrical conductivity of water causes the RF field to be attenuated towards the center of the sample and aforementioned RF artifacts (RF wave effects) in MRI are reduced. As another option the use of an alternative PET tracer that is soluble in pure oil can be analyzed. In this study 3 different approaches of fluid- and tracer-selection were considered and systematically evaluated with respect to their usability for simultaneous PET/MR phantom imaging.

Methods: All measurements were performed on a 3.0 Tesla integrated PET/MR whole-body system (Biograph mMR, Siemens AG, Erlangen, Germany) using a PET quality standard phantom (PTW, Freiburg, Germany, Figure 1A). The following 3 approaches for fluid-selection were investigated:

Approach 1: Finding an alternative fluid with lower ε_r than water and sufficient ^{18}F-FDG-dissolvability.

Approach 2: Supplementing water with substances for MR artifact-reduction

Approach 3: Finding an alternative PET tracer that is soluble in pure oil (very low ε_r)

Appr1 has been presented previously[3] where triethylene glycol was found to be the best compromise for both imaging modalities.

Appr2: 10 liters of demineralized water were supplemented with a) 37.5 g $NiSO_4$ to reduce the very long T1 relaxation time of pure water from around 2600 ms to 100 ms and b) 37.5 g $NiSO_4$ + 50 g NaCl to additionally increase the electrical conductivity (Table 1). The most commonly used PET tracer ^{18}F-FDG was used to test solubility.

Appr3: As an alternative tracer an intermediate stage in the synthesis process of ^{18}F-FDG was tested, here termed ^{18}F-fluoride Kryptofix 222 complex. It uses crown ethers, which could be utilized in this context to transfer negatively charged ions (e.g. tracer ^{18}F-fluoride ions) into organic solvents. The tracer solution consisted of 15 mg of Kryptofix 222 and 15 µl potassium carbonate, dissolved in 200 µl water and 800 µl acetonitrile.

Results: **Appr2:** When scanning pure water in phantom experiments, the automatic RF transmitter adjustment, optimized for patient imaging, generally adjusts to a high voltage value. This leads to the magnetization being flipped to such an extent, that signal voids can be seen in ring patterns (Figure 2, top left, adjusted at 279.5 V). Manually reducing the initial voltage of the adjustment algorithm leads to a lower adjusted RF transmitter voltage and results in the images shown in Figure 2, row 2 (adjusted at 74.6 V). The artifacts visible in the Dixon VIBE sequence used for PET attenuation correction (AC) in water at 279.5 V (Figure 2, row 1, col. 2 and 3) are an effect of both water's high permittivity and long T1 time. Therefore the addition of $NiSO_4$ for T1 relaxation time reduction should be preferred. When scanning pure water, however, the reduced transmitter voltage can also prevent these artifacts in phase encoding direction and results in an improved AC µ-map compared to water at 279.5 V (Figure 2, row 2, col. 3). Here, pre-scans, performed directly before the measurement can lead to the desired result. The central brightening in the selected T1 FLASH sequence in water can be reduced by the increased electrical conductivity of water+$NiSO_4$+NaCl but cannot be homogenized completely (Figure 2, row 4). This can also be observed in the B1-maps and flip angle profiles (Figure 2, last two columns) which show the resulting distribution of the RF-field after a predefined 90°-excitation and allow for evaluation of its resulting homogeneity.

Appr3: Through the use of crown ethers the alternative tracer ^{18}F-fluoride Kryptofix 222 complex dissolved in both oil as phantom background fluid and in water in the phantom inserts. However in oil the tracer accumulated at the bottom of the phantom during the time of measurement (Figure 3C).

Discussion: Compared to water, triethylene glycol improved MR homogeneity notably, but did not eliminate central brightening effects completely in this standard phantom[3]. ^{18}F-FDG distributed homogeneously (Figure 3B), however the tracer-fluid mixing effort is increased compared to dissolving ^{18}F-FDG in water (approach 1). Increased conductivity of water reduces central brightening, but does not homogenize the RF field completely (approach 2). In addition, SAR limits are reached earlier leading to reduced flexibility in the MR scan protocols. The use of crown ethers showed promising results with its ability to enable tracer-solubility in both oil and water (approach 3). However, the tested tracer-composition needs to be altered, for example by replacing acetonitrile with a more suitable organic solvent, in order to make the tracer usable for phantom scans with oil. Regarding attenuation correction of the PET images, this study only discusses the homogeneous display of the phantom content as an important prerequisite for successful AC.

Conclusion: This study systematically investigated different approaches towards phantom fluid and tracer selection for simultaneous PET/MR imaging of a given quality standard body phantom, and for phantoms of comparable size, at 3 Tesla. For simultaneous PET/MR scans which utilize the standard PET tracer ^{18}F-FDG, triethylene glycol as an alternative fluid to water and oil is proposed (approach 1) which is also superior to water with added substances (approach 2) in terms of flexibility of MR protocol-selection. Nevertheless, when water as background fluid is preferred, workarounds for generating an improved AC µ-map are presented. The use of an alternative PET tracer enables the utilization of pure oil in combined scans, but the tested tracer needs to be optimized for phantom measurement applications (approach 3).

[1] Sled et al. *IEEE Trans Med Imaging.* 1998; 17(4):653-662 [2] Vaidya et al. *Proc Intl Soc Mag Reson Med* 20. (2012) Abstract 2796 [3] Ziegler et al. *Proc. Intl. Soc. Mag. Reson. Med.* 20 (2012) Abstract 2722

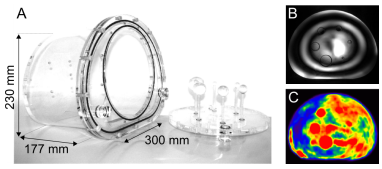

Figure 1: *The standard PET phantom used (A), examples of inhomogeneous MR excitation in water (B), and inhomogeneous PET tracer-distribution in oil-based substances (C)*

	Rel. Permittivity ε_r	Electr. Conductivity σ [S/m]
Water	75.68	0.003
Water + $NiSO_4$	77.57	0.192
Water+ $NiSO_4$ + NaCl	72.84	1.109
Triethylene glycol	21.66	0.020
Oil	2.68	0.001

Table 1: *Relative permittivity ε_r and electrical conductivity σ of chosen fluids, measured at the resonance frequency 125.5 MHz (~Larmor frequency at 3 Tesla).*

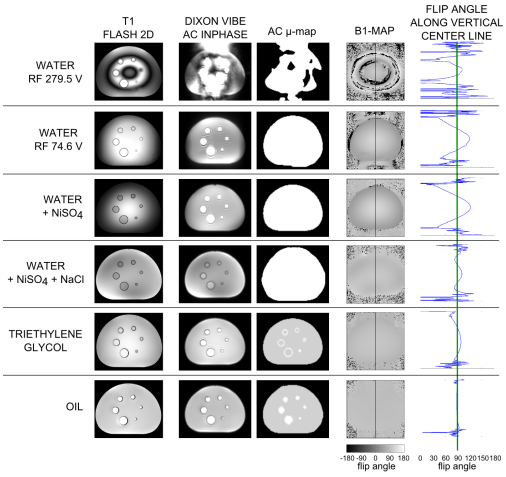

Figure 2: *MR images of fluids measured with a T1 FLASH sequence and a Dixon VIBE used for µ-map generation for PET attenuation correction. Measurement of B1-homogeneity (right two columns). B1-maps and flip angle profiles along the vertical center line in transversal orientation show deviation from excited 90° flip angle. Increasing B1-homogeneity when using phantom fluids with decreasing relative permittivity ε_r according to Table 1 can be observed.*

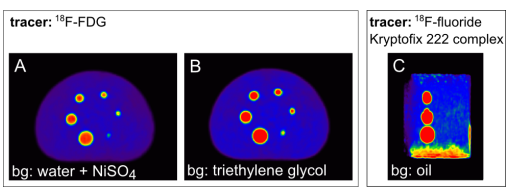

Figure 3: *^{18}F-FDG in water + $NiSO_4$ as reference and triethylene glycol as background fluid (A and B) show homogeneous PET images. ^{18}F-fluoride Kryptofix 222 complex dissolves in oil-background and water-inserts (C, sagittal view), but accumulates at the bottom of the phantom over time*