A Low PET Attenuation Transmit-Receive Head Coil for Simultaneous PET and MR Spectroscopy

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Purpose: The advent of commercially available integrated PET and MR imaging systems allows for simultaneous acquisition of MR and PET data, minimizing registration errors and scan time [1,2,3]. However, RF coils create an attenuating barrier to PET photons, potentially diminishing quality and increasing artifacts in PET images [4,5]. MR-PET systems can also combine PET with MR Spectroscopic Imaging (MRSI) to obtain complementary quantitative metabolic information. However, this adds to design requirements, as the RF pulses used in brain MRSI require an efficient transmit-receive coil. Therefore RF coils for MR-PET must be evaluated both for their innate efficiency and SNR, and for 511keV photon attenuation. Here we present a transmit-receive birdcage head coil design at 3T that maximizes sparsity of coil materials in the field of view of the PET camera while providing substantially improved transmit efficiency compared to the scanner body coil. The MRI performance of the coil was compared with the TEM 3000S head coil (MR Instruments, Minneapolis, MN), a coil designed for only MR imaging, and the PET transparency was compared to a coil-free acquisition.

Methods: The MR-PET Birdcage head coil was tested on a 3T MR-PET Biograph mMR Scanner (Siemens Medical Solutions, Erlangen Germany) with transmit-receive coil capability. The 8 rung high-pass birdcage design was mounted on a 27.9cm diameter, 3.5mm thick, cylindrical acrylic former (**Figure 1**). The rungs and endrings were created with 12mm copper tape, and rung length was defined such that the endrings, capacitors and all additional coil components remained outside the PET photon path, assuming a male head norm in the 99th percentile (**Figure2**) [6]. Tuning matching and decoupling were optimized for a human head load inside the bore using a network analyzer (Agilent Technologies, E5061A), and a transmit/receive interface system was optimized and installed at the service end of the coil. A plastic stand was designed to stand out of the PET field of view and fit the table and the gantry opening securely. A 3D-printed component was designed to fit directly into registration tabs in the patient table to ensure repeatable positioning for attenuation-map registration (**Figure 1c**). A 5mm thick foam lining was designed to ensure that the patient remained a safe distance from the coil during the scan. In place of a plastic covering for the coil, which would add photon attenuation, a plastic barrier at the front of the coil was built to fill the gantry opening in the bore in order to prevent patient contact with the exposed components (**Figure 1b**). After calibrating flip angle in the thalamus, SNR was measured by acquiring two gradient echo scans in 3 slice directions (TR/TE/TA/Flip/Slice/BW = 200ms/4.07ms/53sec/20°/3mm/300, FoV 220x220, matrix 256x256), one with RF excitation and a noise scan with no RF excitation. SNR maps were calculated according to the Kellman method [7]. A multi-slab 4-slice MRSI acquisition was performed to test the MRSI capability of the coil (TR/TE/TA/BW/ = 1080ms/36ms/18.35min, FoV 40x160x160, matrix (16x16x4) x 256). All volunteer measurements were made in accordance with our institution's IRB. A PET attenuation map was converted from a CT scan of the completed coil in extended Houndsfield units to linear attenuation coefficients at 511keV (140kVp, 450mAs, FoV 768x768x400mm, matrix 512x512x667, B40s, pitch 140x0.6cm) [8,9] (**Figure 3**). PET transparency was calculated by acquiring two PET datasets, with and without the coil, using a water phantom (1900mL, 8624186-K2285, Siemens Medical Solutions, Erlangen,Germany) filled with 20mCi FDG-18. PET transparency was additionally tested using uniformity phantom (2.44mCi Ge, CS-mMR-8264, calibrated 6/6/2013, Siemens Medical Solutions, Erlangen,Germany) to quantify the photon counts lost to coil attenuation, by performing a 30 minute acquisition both with and without the coil present.

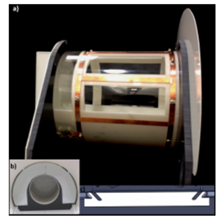

Fig 1: a)Coil b) Barrier in scanner bore. c) Registration component in patient table

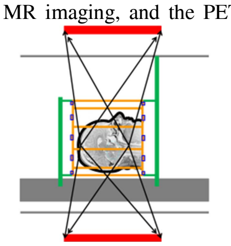

Fig 2: Coil geometry: PET array (red), former (green), coil with components (bronze/blue), and bore and table (grey).

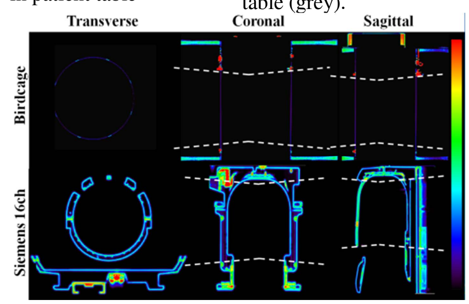

Fig 3: Attenuation maps of central slices with PET FoV (dashed lines): color range 0-0.1

Results: The S12 coupling of the two ports was < -26dB with a human head load, and the S11 was <-27dB for each port. The unloaded to loaded Q ratio was 5. The birdcage coil showed improved SNR over the TEM in the base of the brain and brainstem (**Figure 4**), though it showed loss at the top of the head where the TEM's endcap provides additional SNR. We plan to mitigate this difference by installing an end cap into the birdcage coil, the work for which is in progress. The RF voltage required to create a 90° flip angle with a 500µs hard pulse was 160V for the birdcage, and 136V for the TEM coil, as compared to the 327V required for excitation by the body coil. The birdcage coil was found to attenuate only 2.3% of the net true photon counts. This low attenuation can be seen in comparison to the Siemens 16ch receive head coil designed for low PET attenuation (**Figure 3**), where the additional mechanical stability guidelines required of the Siemens coil increase the attenuation to 16% of the net true counts. **Figure 5** shows the attenuation corrected images with and without the coil present, as well as the effect of not utilizing the attenuation map of the coil in the reconstruction. The artifacts in all cases are due to the attenuation and scatter of the patient table. The MRSI data obtained with the coil demonstrate good spatial resolution and localization, apparent in the reproduction of gross anatomy in the metabolite maps, and the clean spectra of the acquired MRSI data (**Figure 6**).

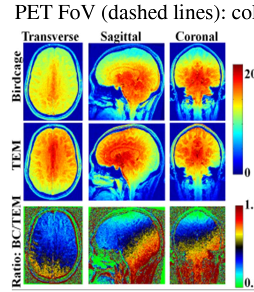

Fig 4: SNR maps (top) and SNR ratios

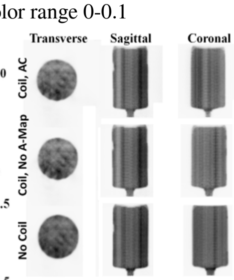

Fig 5: PET images of phantom

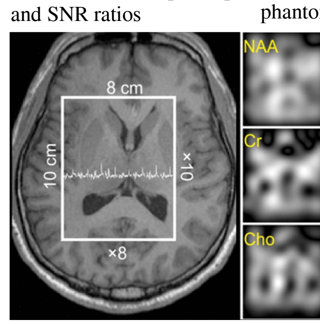

Fig 6: (left) T1-weighted image with VOI; one line of spectra from the VOI. (right) metabolic maps of N-acetyl-aspartate, creatine, and choline from the VOI

Discussion: The transmit efficiency and receive sensitivity of this MR-PET birdcage coil design allows for MRSI data acquisition, while providing minimal photon attenuation from the ROI. However, in order to minimize the photon attenuation, the length of the birdcage was increased significantly from the standard, which has decreased the coil's innate transmit efficiency. The sparse design of the birdcage coil has also limited the ability to map the coil's attenuation, as the small values succumb to some loss below the noise threshold, and additional investigation into correcting the loss in the attenuation map is planned. Further investigation is also planned to improve transmit efficiency and receive sensitivity at the top of the head.

References: [1] Catana,et al.,J Nucl Med,2006;**47**:1968.[2] Schlemmer,et al.,Radiology,2008;**248**:1028. [3] Shao,et al.,IEEE Trans Nuc Sci,1997;**44**:1167. [4] Bindseil,et al., Proc ISMRM 2012;146. [5] Herrick,et al., Proc ISMRM 2011;3801. [6] Tille. *The measure of man and woman*. New York;1993. [7] Kellman,et al.,MRM,2005; **54**: 1439. [8] Carney,et al.,Med Phys, 2006; **33**:976. [9] Paulus,et al.,Phys Med Biol, 2013;**58**:8021.