Respiratory Motion Correction of PET using Simultaneously Acquired Tagged MRI

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We present our first results with incorporating clinically relevant motion information derived from MR into the PET reconstruction process in simultaneous MR-PET acquisitions. We describe our current methods for tracking non-rigid periodic motion over the entire FOV of the MR-PET scanner, during the PET acquisition. Our approach can be generalized to sequential PET-MR

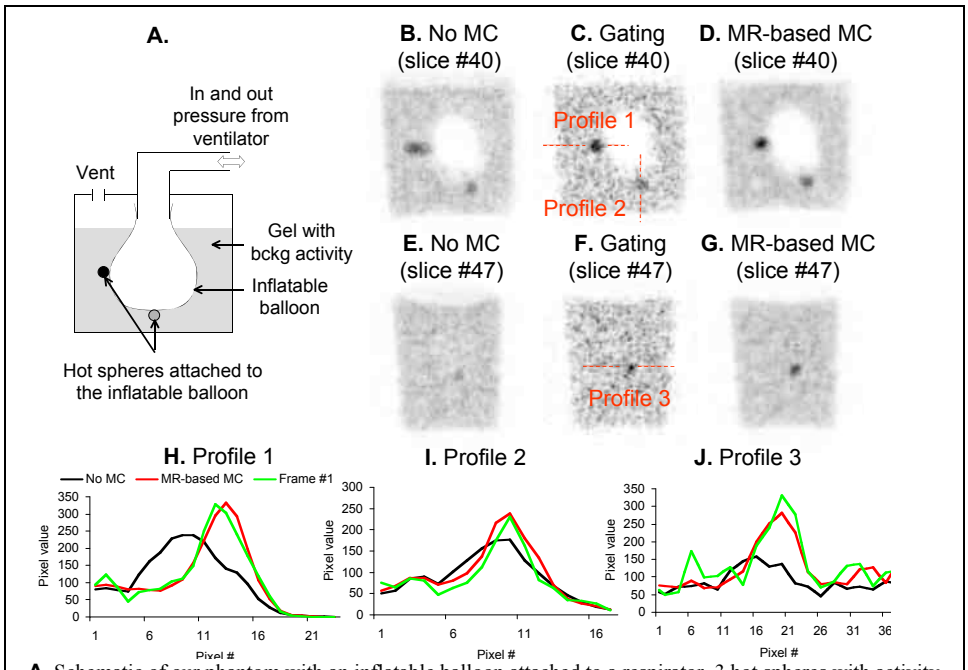
Methods: All studies were completed on the integrated MR-PET scanner located at our hospital. This dedicated brain scanner consists of an MR-compatible PET insert (called BrainPET) and the standard 3T TIM-Trio MR instrument (Siemens Medical, Germany). The BrainPET scanner has 32 detector modules consisting of six 12x12 LSO crystals arrays read out by a 3x3 array of APDs (Hamamatsu 8664-55, Japan).

Our phantom (see figure A) is a container full of methyl cellulose gel, of sufficient viscosity that flow is prevented while allowing realistic respiratory motion. Respiratory flow was provided by a Harvard ventilator (Harvard Apparatus, Holliston MA USA) connected to a latex balloon suspended in the gel, which mimics the periodic expansion and contraction due to respiration, is visible with MRI, and is filled with PET radioactivity (^{18}FDG, 0.5 mCi). Intramural pressure was monitored by an Edwards transducer connected to a Sonometrics amplifier (Sonometrics Corp., London, Ontario Canada). This signal was conditioned to serve as a trigger for the MR scanner and was also inserted in the PET listmode data, for subsequent temporal registration of the MR and PET data.

To track motion with MRI, a CSPAMM tagging sequence was written to acquire multislice-multiphase tagged data of the moving phantom [1]. The readout sequence was a GRE with TE of 2.41 ms, with an image matrix in 6 axes {±X, ±Y, ±Z} with matrix size 128x41x32, over a 128mm cube. 32 slices and 32 phases were acquired in each 1 sec ventilation cycle, with a TR of 1 sec. Hot spheres were attached to the balloon ("lesions"), with a foreground:background activity ratio of 6:1, 4:1 and 4:1. Scanning covered 800 ms of the 1 sec cycle, 25 ms per frame, spanning all inflation motion.

Motion was measured from the tagged images using HARP tracking [2]. To improve the data stability in the regions of low or no signal, the incremental motion was regularized using the following cost function: $C(\mathbf{d}) = \Sigma_i [\phi(\mathbf{r}_i+\mathbf{d}_i, t_{m+1}) - \phi(\mathbf{r}_i, t_m)]^2 + \beta U(\mathbf{d})$, for i ranging over all pixels. The penalty operator $U(\mathbf{d})$ is adjusted using the amplitude of β. Pixel phase $\phi(\mathbf{r}, t)$ in the HARP image is described by position $\mathbf{r}_i$ plus a displacement vector $\mathbf{d}_i$, at a time step t_m. The displacement field thus derived characterizes a single exemplary displacement cycle.

We have developed a novel listmode motion-corrected expectation-maximization (MC-EM) PET reconstruction algorithm that incorporates a motion field into the reconstruction of the data [3]. The timing of each PET event determines the amount of displacement from the baseline state associated with that event. Along with the listmode data, the displacement field is used as an input to our MC-EM PET reconstruction. The reconstruction strategy is fully 3D and incorporates the traditional physical effects of attenuation, sensitivity, randoms and scatters in the system matrix, in addition to motion.



A. Schematic of our phantom with an inflatable balloon attached to a respirator. 3 hot spheres with activity 6:1, 4:1 and 4: wrt background were attached to the balloon. **B-G:** PET images of the phantom, at reference frame #1. **B,E:** All counts reconstructed without motion correction. **C,F:** Gated with about one-eighth of all counts. **D,G:** All counts using our MC-EM reconstruction and MR-measured motion field. **H,I,J:** Profiles through the hot spheres, reconstructed with no motion correction, gated, and with motion correction, of the profiles marked in **C** and **F**.

Results: The respiration phantom shown in figure A was scanned with our CSPAMM sequence. The images were processed with regularized HARP, and a frame-by-frame displacement field created. A static 128x128x128 1 mm isotropic GRE image with no tags was acquired for creation of an attenuation map. The attenuation map, the fully 3D PET listmode data, and the displacement field were processed by our MC-EM PET reconstruction. Images with all coincidences summed and with coincidences divided into 8 gated frames were also calculated. Representative slices for no motion correction, gated, and motion corrected are shown in figures B-G. Figures H-J show representative profiles through features of interest in the slices. MR-based motion correction improved lesion contrast for all spheres compared to gating and no motion correction. Activity estimation accuracy in the sphere that moved the most was improved by 30% compared to gating and by 50% compared to no correction. SNR was also greatly improved when performing motion correction compared to gating (~80% improvement) and no motion correction (~66% improvement).

Discussion: As the spatial resolution of PET scanners improves, the deleterious effects of patient motion, both voluntary and involuntary, become an ever increasing limitation in PET studies. Gating does mitigate motion, but at the price of a significant reduction in signal-to-noise ratio (SNR) in the resulting gates and an increase in the volume of data. We have shown here that reconstructing all PET coincidences in a single frame while correcting the data for motion using MRI is feasible on an actual MR-PET system. Our approach significantly improves image quality, as measured by contrast and SNR, compared to both the gated and the non-gated strategies. Subsequent investigations will integrate navigator scans with the MR motion tracking, and then will proceed to *in vivo* testing in animal models.

References: [1] Osman NF et al. MRM 42:1048-60 (1999). [2] Fischer SE et al. MRM 30:191-200 (1993) [3] Guérin B et al. JNM 50 (supp. 2):591 (2009).