Simultaneous Whole-Body PET/MRI with Continuous Table Motion

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Introduction: Simultaneous Positron Emission Tomography/Magnetic Resonance Imaging (PET/MRI) as a new hybrid imaging modality has become clinical reality [1, 2]. In both PET and MRI, data is usually acquired in a multi-station (MS) approach where the patient bed is held at a constant position during data acquisition. Multi-station data acquisition, however, inherently might suffer from several shortcomings when performing whole-body examinations. Examples of such shortcomings are varying sensitivity (PET) or distortion (MRI) in z-direction, combination artifacts between individual stations/bed positions in whole-body examinations, etc. Furthermore MR data acquisition is constrained to the table positions dictated by PET when performing the PET scan in MS mode. Therefore an acquisition scheme with continuous table motion (CTM) seems attractive, most notably in the context of a simplified workflow and higher patient throughput.
In this work, a rebinning approach to enable reconstruction of PET data that was acquired with CTM was developed and evaluated. In combination with existing CTM MRI protocols (e.g. [3]), this approach for the first time enables simultaneous whole-body PET/MR hybrid imaging during continuous table movement.

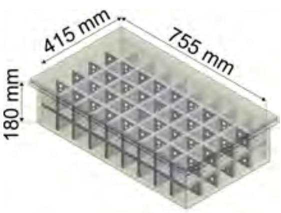

Figure 1: *CAD drawing of the custom built phantom*

Materials and Methods: All measurements were performed on a Biograph mMR (Siemens AG, Healthcare Sector, Erlangen, Germany), a hybrid whole-body PET/MRI system consisting of a 3T MRI scanner and a fully integrated PET unit that allow for simultaneous PET and MRI data acquisition. An axial field-of-view (in z-direction) of around 258 mm for PET and around 450 mm for MRI are provided. The bore opening is 60 cm in diameter.
Simultaneous and independent acquisition of PET and MRI data is possible on the scanner, however only MS acquisition mode is supported by the user interface for the PET unit. The MRI unit supports several CTM protocols (syngo TimCT, Siemens AG) that are to be evaluated: 2D FLASH (fast low angle shot), 3D FLASH, TSE (turbo spin echo) and HASTE (half fourier acquisition single shot turbo spin echo).
For the PET unit, CTM data acquisition has to be started manually on the scanner via command line in list-mode format. Several corrections like decay correction, normalization, randoms correction and attenuation correction are then performed offline as well as rebinning considering the moving table geometry with software that was developed in the context of this work. PET data reconstruction is then performed using the STIR toolkit [4].
Image quality of MR data (artifacts, SNR, geometric distortion, sharpness) as well as of PET data (spatial resolution, mean activity, noise) were evaluated and compared between MS and CTM mode (also subject to table motion speed) with the help of a custom built phantom. The phantom is brick-shaped with an inner size of 755 x 415 x 180 mm^3 and can be filled with approx. 34 l of water, providing visibility in MRI (Fig. 1). Adding radioactive tracers like ^{18}F-FDG yields simultaneous visibility in PET. A polypropylene grid can be inserted that separates the inner compartment into cubes of 70 x 70 x 70 mm^3 with 15 mm wall thickness. Additionally the grid contains drillings of 4, 6 to 10 and 15 mm diameter to allow for resolution evaluation or MRI as well as PET.
For this study, an activity of around 400 MBq was injected into the phantom, yielding an activity concentration of around 12 kBq/ml. It was then measured with different MR protocols and PET acquisition times for the next 3 hours pi.
The large extent of the phantom was chosen to be able to assess PET and MRI on a whole body scale, potentially revealing geometric distortions when using large FOVs in MR and PET imaging. Due to the large amount of plastic in the phantom, that is not visible in MRI but contributes to attenuation of the PET signal, a CT scan of the phantom had to be acquired and registered to the MRI data in order to provide valid attenuation correction factors for PET reconstruction.

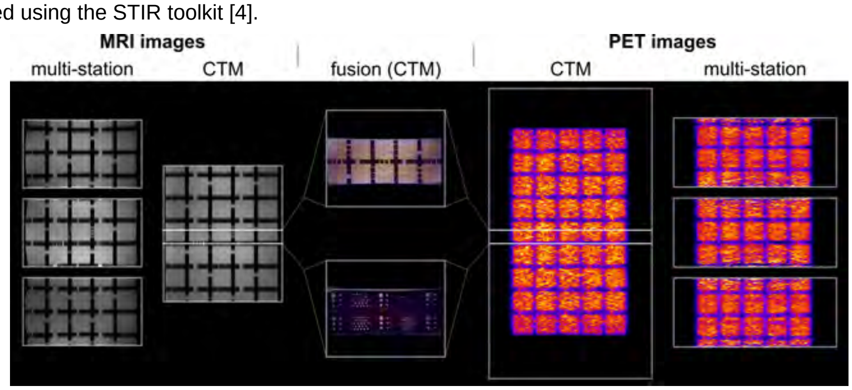

Figure 2: *Measured images of the custom built phantom. From left to right: MR images in MS mode (T1-weighted 2D FLASH, TR: 151 ms, TE: 1.23 ms, slice thickness: 5 mm, coronal reformat), MR images in CTM mode (parameters identical to MS scan but table speed: 7.9 mm/s, coronal reformat), fused axial MRI and PET images (CTM mode), PET images in CTM mode (table speed: 4.8 mm/s) and PET images in MS mode (iterative reconstruction [4], 3 iterations, 21 subsets).*

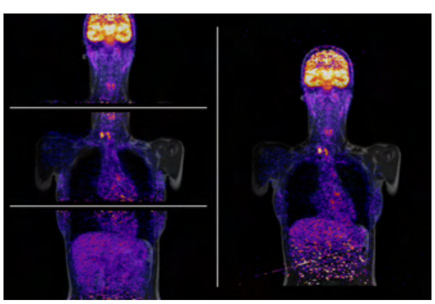

Figure 3: *Fused MRI (coronal T1 TSE) and PET datasets of a clinical patient. PET was acquired with MS mode (left) and with CTM (right).*

Results and Discussion: Measurements showed that data acquisition with CTM in simultaneous PET/MRI is technically feasible (Fig. 2) and has also been demonstrated to be feasible for clinical patient data (Fig. 3). In MRI, both the MS approach and CTM acquisitions have their own strengths. MS mode can be considered superior in terms of spatial resolution. CTM mode, however, is much less affected by geometric distortions in z-direction as data is always acquired in the isocenter which is the area of highest magnetic field homogeneity.
In PET, CTM acquisitions exhibit comparable characteristics as the standard MS approach. CTM is, however, better in terms of axial sensitivity and temporal efficiency. A current limitation is the long time needed for CTM acquired PET data reconstruction. This is due to the implementation of the reconstruction process, though, and could be greatly improved by the use of parallelized code and e.g. graphics card hardware.
In conclusion, continuous table movement for simultaneous PET/MR hybrid imaging has been developed and renders the PET/MRI data acquisition process much more flexible. This technique holds potential for simplified imaging workflow, reduced artifacts and higher patient throughput in PET/MR hybrid imaging.

[1] A. Boss, L. Stegger, S. Bisdas, et al. Eur Radiol. 2011 Volume 21(7):1439-1446
[2] O. Ratib and T. Beyer. Eur J Nucl Med Mol Imaging. 2011 Volume 38(6):992-995
[3] M. O. Zenge, M. E. Ladd, et al. Magn Reson Med. 2005 Volume 54(3):707-11
[4] K. Thielemans, S. Mustafovic and C. Tsoumpas. IEEE Nucl Sci Conf R. 2006:2174-6