Motion Compensation for Simultaneous PET/MR Based on Strongly Undersampled Radial MR Data

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Introduction

One major challenge to accurate quantification in simultaneous PET/MR imaging is involuntary patient motion during measurements, such as respiration, cardiac motion or muscle relaxation. It leads to image blurring and, in case of PET, to an underestimation of the reconstructed activity. A widely used motion handling strategy is gating, which is typically a trade-off between temporal resolution and an appropriate signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the reconstructed images. Since the advent of fully-integrated PET/MR systems, several new approaches for motion handling have been proposed. They use MR information to estimate 4D motion vector fields (MVFs) that describe patient motion from phase to phase and allow for a motion-compensated (MoCo) PET reconstruction.

Here, we propose to compensate for respiratory patient motion using information from a strongly undersampled radial MR sequence that can be interlaced with clinical MR sequences and requires about 30 s of the total MR acquisition time per bed position.

Materials and Methods

In our MR simulation, we applied a 3D encoded radial stack-of-stars sampling scheme with golden angle radial spacing. For each sampled k-space line, a static MR volume of a patient was deformed according to the respiratory amplitude at its specific position along the respiratory motion curve. In total 120 radial spokes per partition were sampled and complex-valued Gaussian noise was added. Assuming 80 slices and a repetition time of 3.0 ms, our sampling scheme took 28.8 s of the total MR scan time per bed position (5 min). Before reconstruction, data were sorted retrospectively into 20 overlapping motion phase bins with a width of 10% of the entire respiratory cycle. For MR image reconstruction, we employed the iterative algorithm HDTV, which optimizes raw data fidelity and spatial and temporal smoothness of the 4D image volume[1]. This is achieved by minimizing the following cost function in an alternating manner:

$$C = \|\mathrm{X}f - p\|_2^2 + \alpha \|f\|_{\mathrm{TV,\,xyzt}}$$

X: forward transform
f: image
p: raw data
α: weight
$\|f\|_{\mathrm{TV,\,xyzt}}$: spatial and temporal total variation

Based on these HDTV-gated 4D MR images (Fig. 2 B), a cyclic registration employing the Demons algorithm was performed to obtain high fidelity MVFs[2].

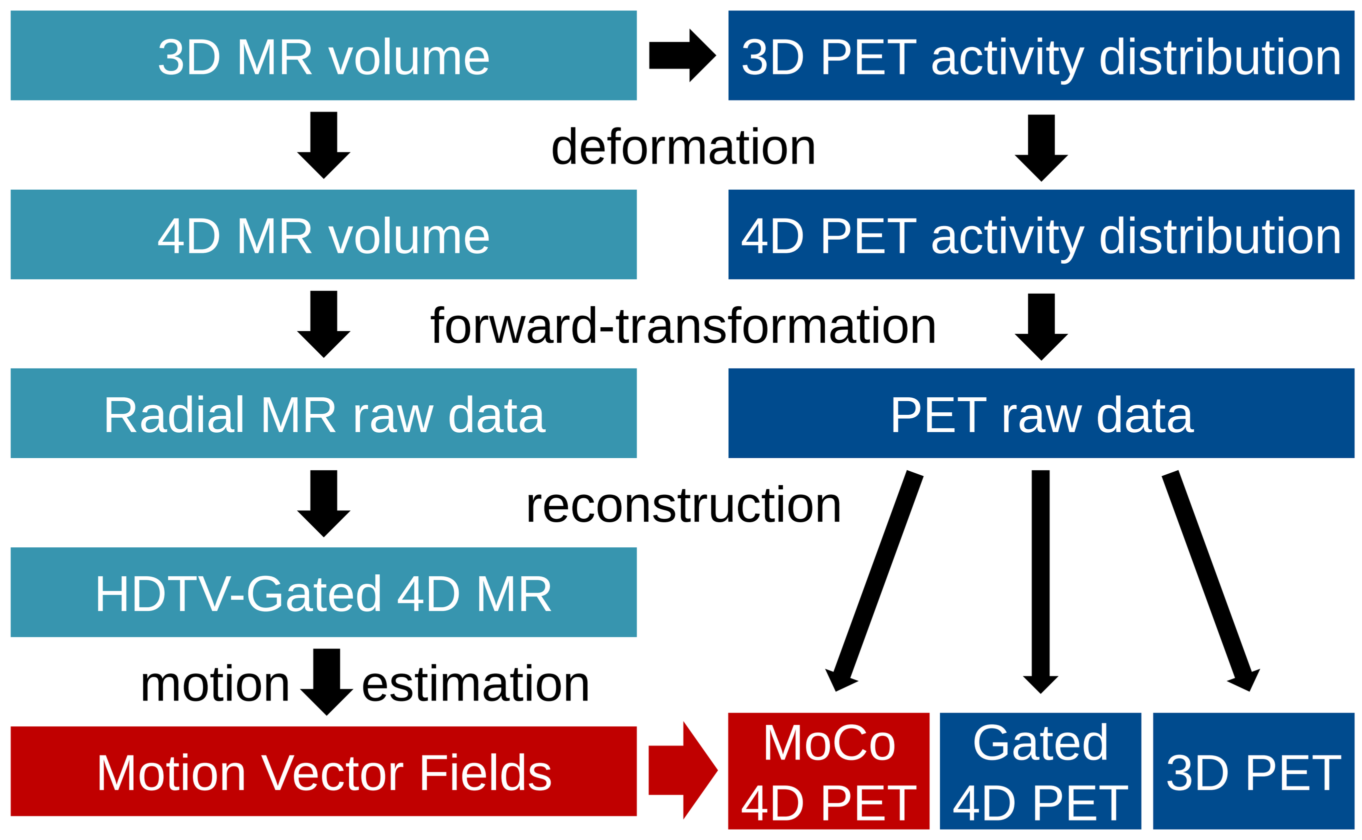

Fig. 1: Overview of MR and PET simulation

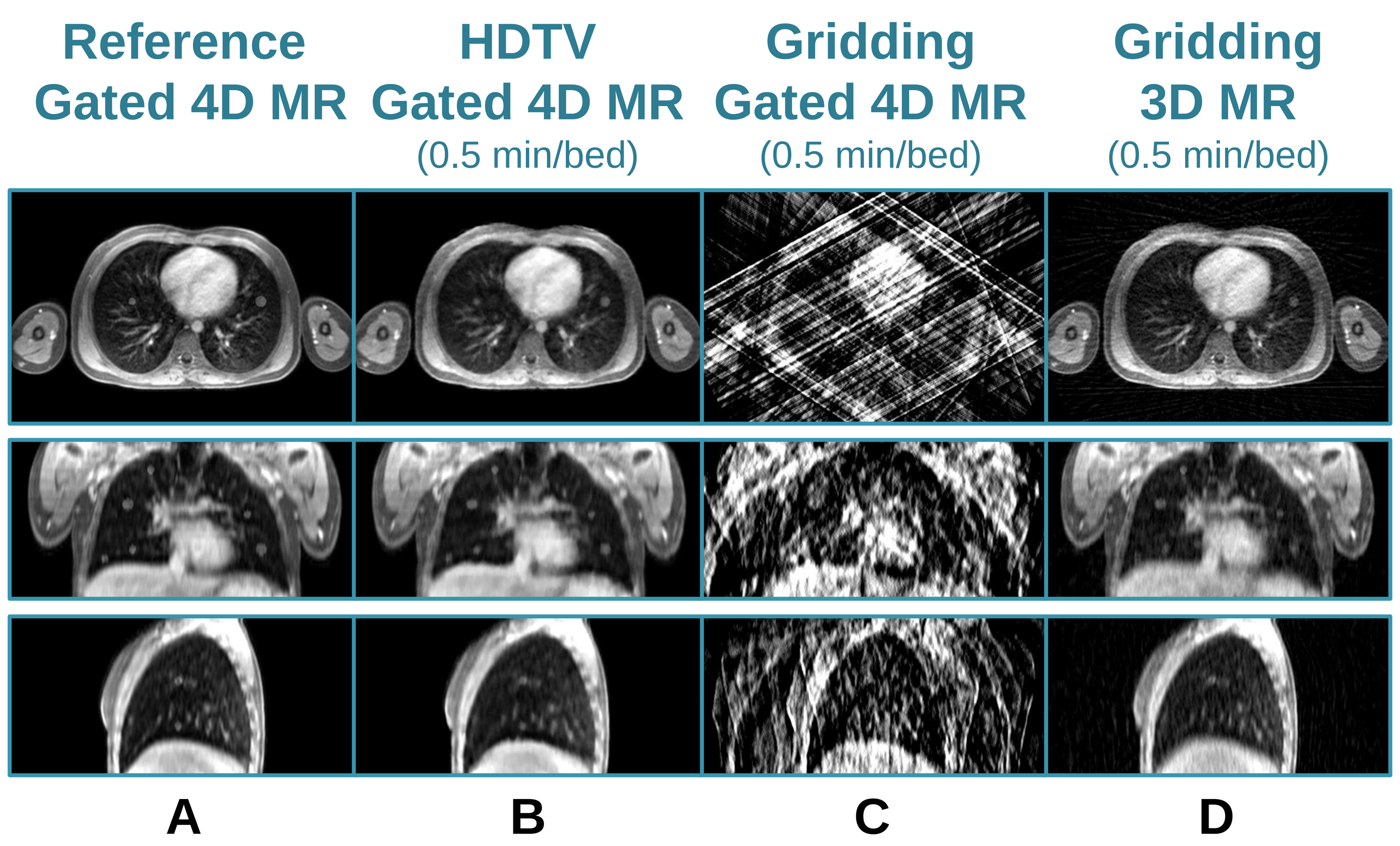

Fig. 2: Comparison of MR image reconstructions

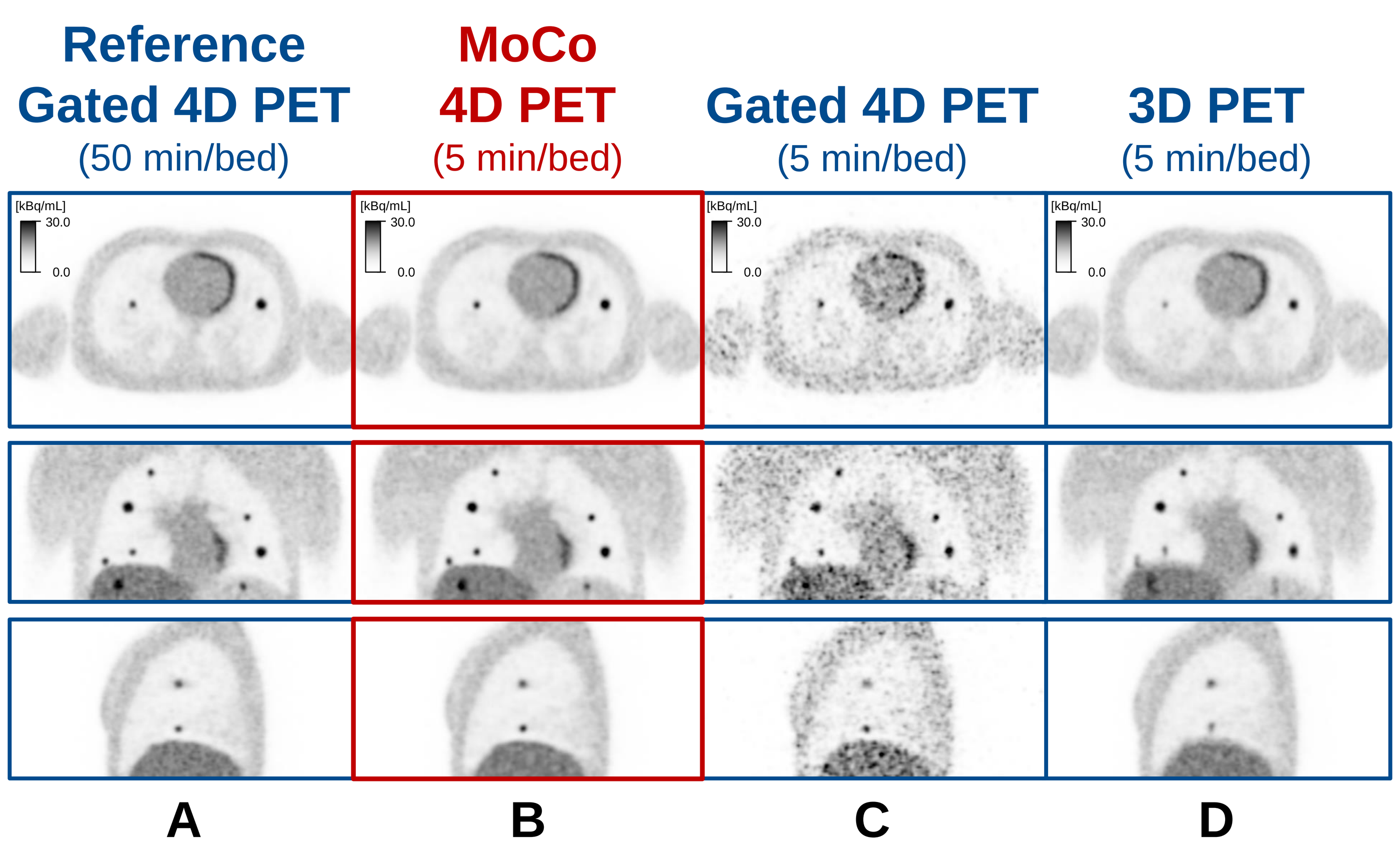

Fig. 3: Comparison of PET image reconstructions

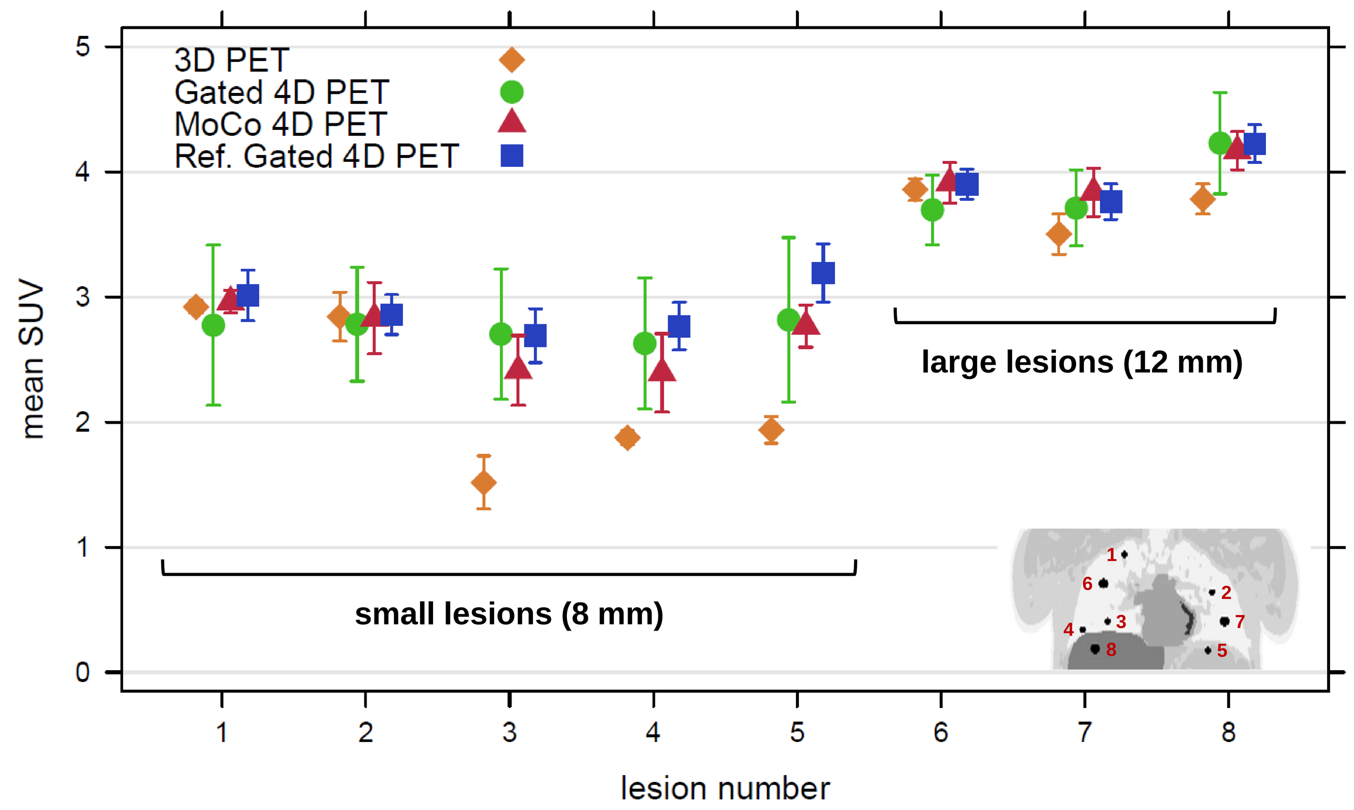

Fig. 4: SUV evaluation

Subsequently, we simulated a 4D PET volume of the breathing thorax with a realistic activity distribution and 8 hot lesions (8 and 12 mm spheres, SUV = 5) in the lungs and upper abdomen corresponding to the 4D MR volume. This 4D activity distribution was forward-projected and Poisson noise and scatter were added simulating 10^8 counts in total. The simulated PET geometry corresponded to the Biograph mMR system (Siemens Healthcare, Erlangen, Germany). MoCo 4D PET images were reconstructed using a MoCo 3D OSEM algorithm, which incorporates MVFs derived from MR into the system matrix (Fig. 3 B). For quantitative analysis, $\mathrm{SUV}_{\mathrm{mean}}$ values and standard deviations of the lesions were calculated from all motion phases and compared to a reference gated 4D PET reconstruction with ten-fold measurement time (Fig. 3 A).

Results

Visual inspection of the PET images showed that lesions were well detected on the MoCo 4D images but detectability was diminished on the 3D and gated 4D reconstructions (Fig. 3).

Quantitative evaluation showed a significant improvement in $\mathrm{SUV}_{\mathrm{mean}}$ measurements for lesions with a high degree of motion compared to the 3D reconstructions (Fig. 4). In all cases, 3D reconstructions yielded largest deviations as $\mathrm{SUV}_{\mathrm{mean}}$ values were underestimated due to motion blurring of images. In contrast, gated 4D reconstructions showed the highest standard deviations of $\mathrm{SUV}_{\mathrm{mean}}$ values due to the low statistics. MoCo 4D PET reconstructions were only slightly affected by these two sources of uncertainty. Whereas temporal resolution was comparable to the gated 4D images, SNR and CNR were close to the 3D reconstructions.

Acknowledgements

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[1] L. Ritschl, S. Sawall, M. Knaup, A. Hess, and M. Kachelrieß. "Iterative 4D cardiac micro-CT image reconstruction using an adaptive spatio-temporal sparsity prior". *Phys. Med. Biol.* 2012.

[2] M. Brehm, P. Paysan, M. Oelhafen, P. Kunz, and M. Kachelrieß. "Self–adapting cyclic registration for motion–compensated cone–beam CT in image-guided radiation therapy". *Med. Phys.* 2012.