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

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Introduction

One major obstacle to accurate quantification in simultaneous PET/MR imaging is involuntary patient motion during measurements, such as muscle relaxation, respiration and cardiac motion, which 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 were proposed, which 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 a) runs in parallel with the PET acquisition, b) can be interlaced with other MR sequences, and c) requires less than one minute 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. For each sampled *k*-space line, a static MR volume of a patient is deformed according to the respiratory amplitude at its specific position along the respiratory motion curve. We used 160 uniformly distributed radial spokes per partition to achieve an average of 16 radial spokes spread across a respiratory phase covering 10% of the respiratory cycle. Assuming 80 slices and a repetition time of 3.0 ms, our sampling scheme takes 38 s of the total MR scan time per bed position (10 min). For reconstruction, data were sorted retrospectively into 20 overlapping motion phase bins with a width of 10%. Based on these gated but strongly undersampled and thus artifact-contaminated 4D MR images, motion vector fields were estimated. Using cyclic constraints [1] and our newly-developed method to predict the shape and magnitude of the image artifacts [2], high fidelity MVFs were obtained (Fig. 2).

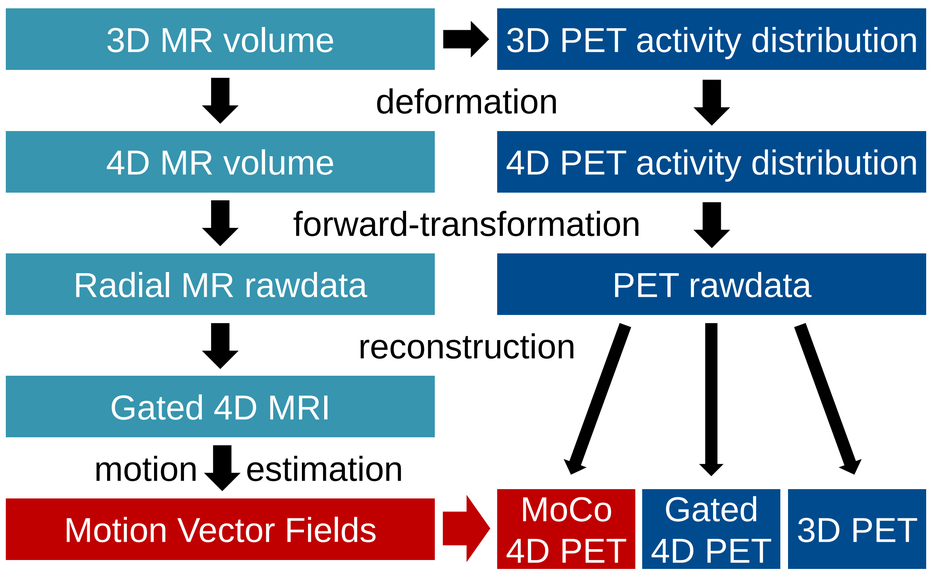

Fig. 1: Overview of MR and PET simulation

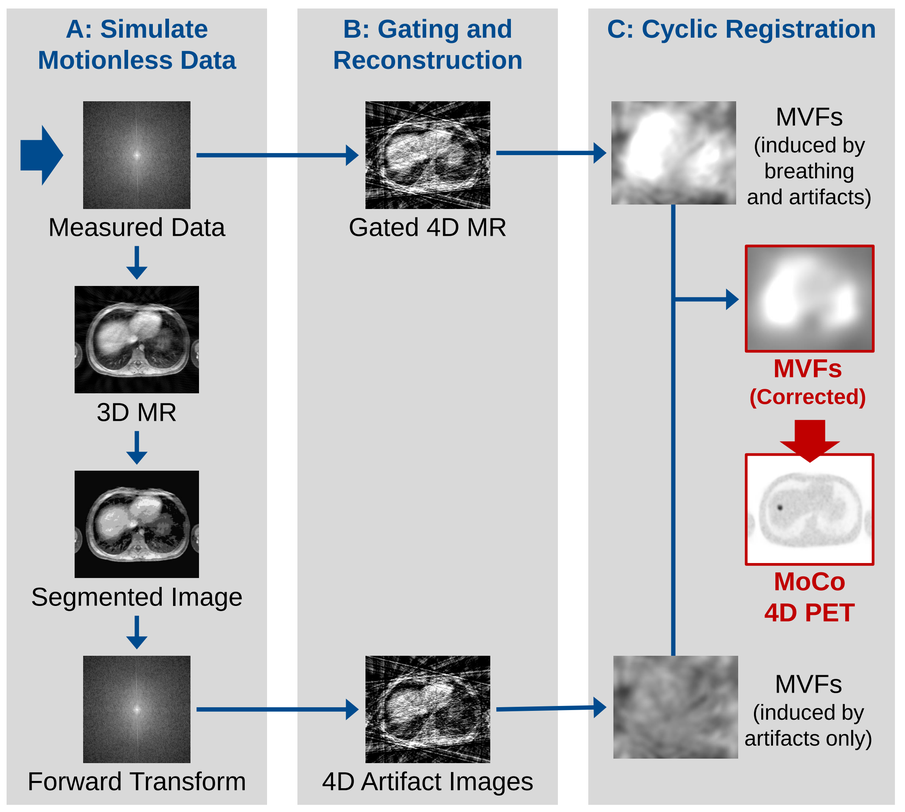

Fig. 2: Overview of motion estimation algorithm

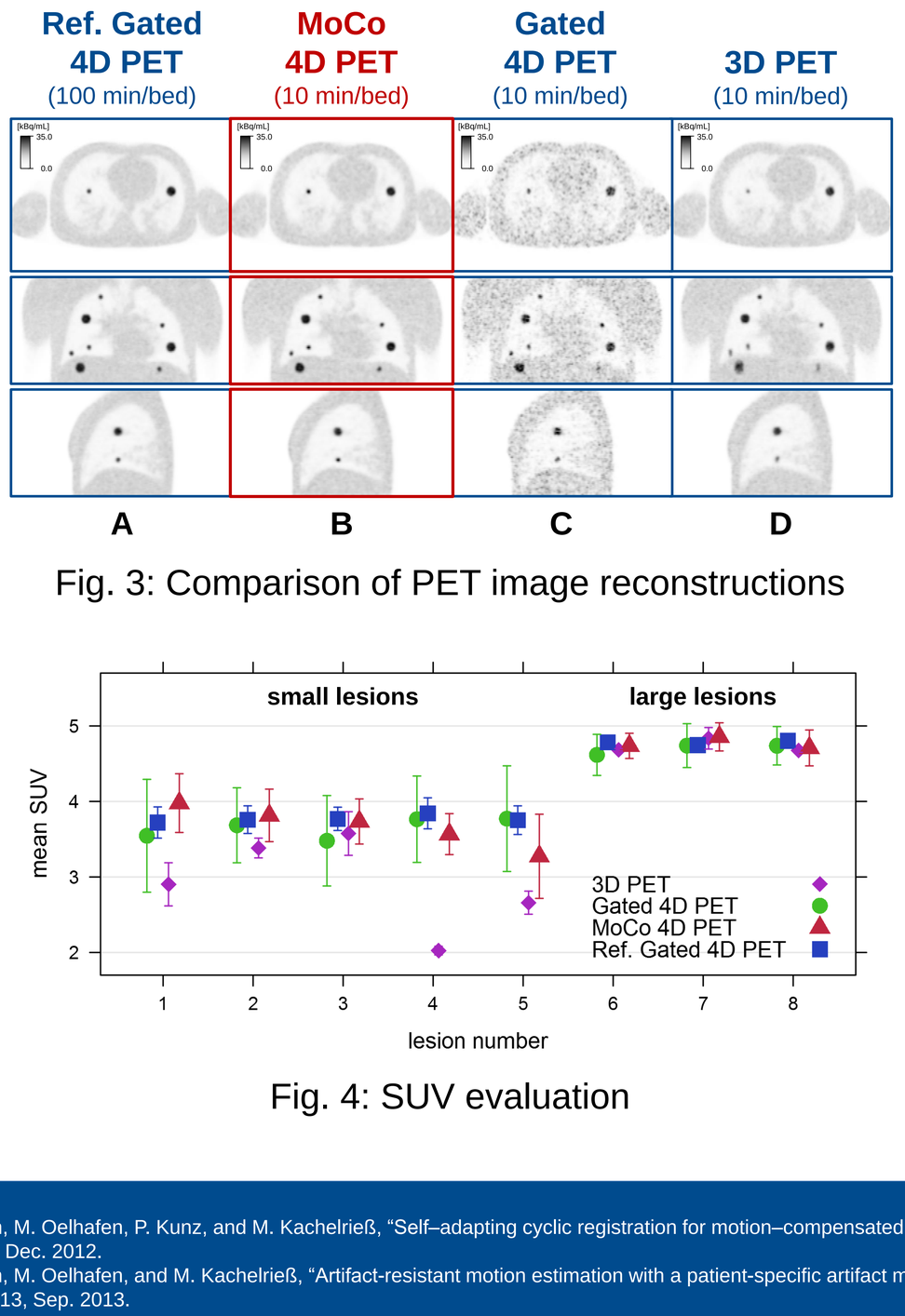

Fig. 3: Comparison of PET image reconstructions

Fig. 4: SUV evaluation

The applied artifact model was updated during three iterations of the MoCo cycle in order to improve prediction of artifacts at regions with a high degree of motion. Subsequently, we simulated a 4D PET volume of the breathing thorax (6.0 kBq/mL soft tissue activity) with 8 hot lesions (8 and 16 mm spheres, 30 kBq/mL activity) in the lungs and upper abdomen corresponding to the 4D MR image. This 4D activity distribution was forward-projected and Poisson noise was added. The simulated PET geometry corresponds to the Biograph mMR system (Siemens Healthcare, Erlangen, Germany). Gated PET images were reconstructed using a MoCo 3D OSEM algorithm, which incorporates MVFs derived from MR into the system matrix (Fig. 3 B). For quantification, SUV_{mean} values and standard deviations of the artificial lesions were calculated from all motion phases and compared to a reference gated 4D PET reconstruction with ten-fold measurement time (Fig. 3A).

Results

Visual inspection of the PET images showed that all 8 mm lesions were well detected on the MoCo 4D images but detectability was diminished on the 3D and gated 4D reconstructions for at least one small lesion (Fig. 3).

Quantitative evaluation showed a significant improvement in SUV_{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 SUV_{mean} values were underestimated due to motion blurring of images. In contrast, gated 4D reconstructions showed the highest standard deviations of SUV_{mean} values due to the low statistics. MoCo 4D 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] 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. 39:7603, Dec. 2012.

[2] M. Brehm, P. Paysan, M. Oelhafen, and M. Kachelrieß, “Artifact-resistant motion estimation with a patient-specific artifact model for motion-compensated cone-beam CT”, Med. Phys. 40:101913, Sep. 2013.