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

Christopher M Rank[1], Thorsten Heußer[1], Andreas Wetscherek[1], Heinz-Peter Schlemmer[1], and Marc Kachelrieß[1]

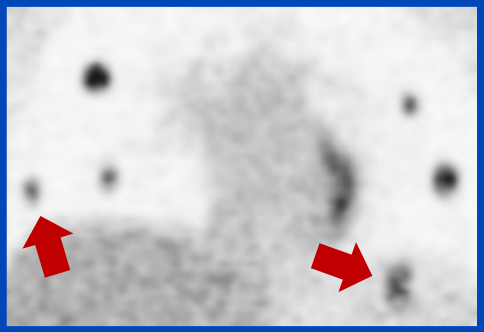
[1] German Cancer Research Center (DKFZ), Heidelberg, Germany

DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

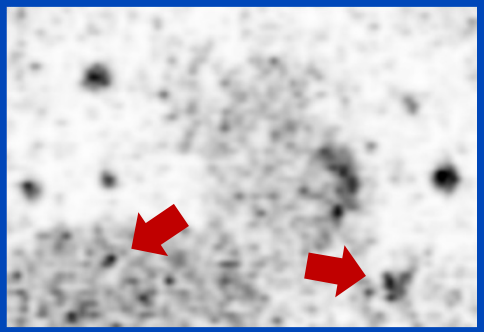
# Introduction

- One major challenge in PET image reconstruction is patient motion (respiratory, cardiac, involuntary motion).
- Motion causes image blurring and an underestimation of the reconstructed activity up to 25%.[1]
- Gating
  - divide motion cycle into certain gates and reconstruct data from each gate separately
  - trade-off between temporal resolution and an appropriate CNR of the PET images

3D PET



4D gated PET



- Recent approach: PET/MR motion compensation (MoCo)[2,3]
  - use MR information to estimate 4D motion vector fields (MVFs)
  - 4D MoCo PET reconstruction from 100% of rawdata

[1] Kinahan , Fletscher. PET/CT Standardized Uptake Values (SUVs) in Clinical Practice and Assessing Response to Therapy. Semin Ultrasound CT MR 2010.
[2] Grimm et al. Self-gated MRI motion modeling for respiratory motion compensation in integrated PET/MRI. *Med. Image Anal.* 2015.
[3] Fürst et al. Motion Correction Strategies for Integrated PET/MR. *J. Nucl. Med.* 2015.

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# Aims

- Develop a framework for respiratory motion compensation of PET images.
- Use information from a strongly undersampled radial MR sequence with an acquisition time of 1 minute.
- Difficulty: obtain high-fidelity MVFs from strongly undersampled MR data.

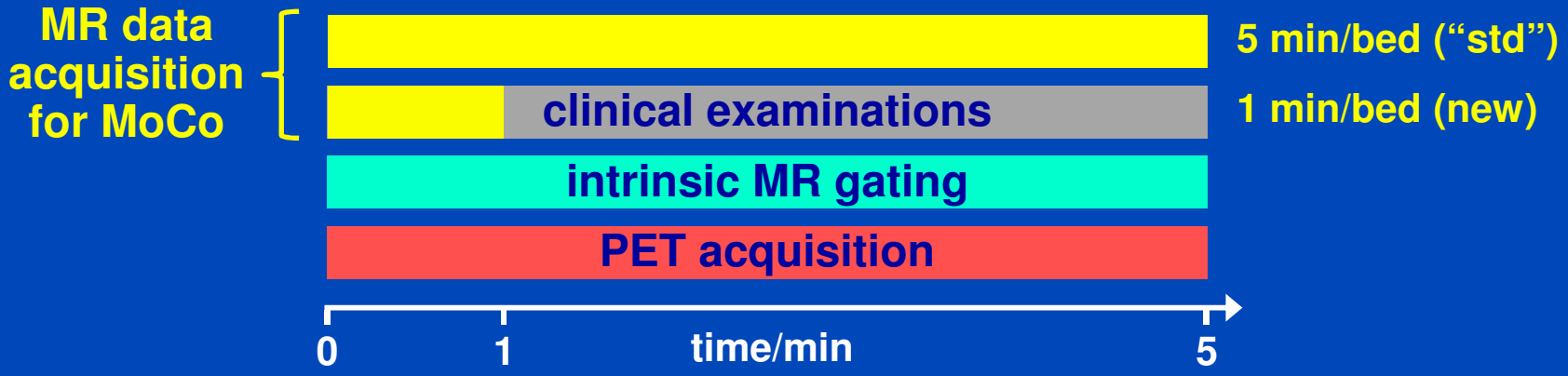
# Related Work

| Authors | MR sequence | MR acquisition time | Voxel size / $mm^3$ | No. of gates | Motion estimation |
|---|---|---|---|---|---|
| Würslin et al. 2013 | 2D multi-slice | 3.0 min | 2.0×2.0×10.0 $mm^3$ | 4 | 3D |
| Petibon et al. 2014 | 2D multi-slice | 3.0 min | 2.0×2.0×8.0 $mm^3$ | 7 | 3D |
| Dutta et al. 2015 | 2D radial | 5.5 to 7.0 min | 2.0/2.3×2.0/2.3×5.0/8.0 $mm^3$ | 6 | 3D |
| Fayad et al. 2015a | 2D multi-slice | 1.5 min | 2.0×2.0×10.0 $mm^3$ | 4 | 3D |
| Fayad et al. 2015b | 2D multi-slice | 3.0 min | 2.0×2.0×10.0 $mm^3$ | 4 | 3D |
| Fürst et al. 2015 | radial stack-of-stars | 10 min | 1.7×1.7×5.0 $mm^3$ | 5 | 3D |
| Grimm et al. 2015 | radial stack-of-stars | 3.0 to 10 min | 1.7×1.7×5.0 $mm^3$ | 5 | 3D |
| Manber et al. 2015 | 2D multi-slice | 1.0 and 2.7 | 1.8×1.8×10.0[a] $mm^3$ | 10[b] | 2D |
| proposed | radial stack-of-stars | 1.0 min | 1.6×1.6×4.5 $mm^3$ | 20[b,c] | 3D |

[a] 25 mm gap between slice centers
[b] discrimination between inhalation and exhalation
[c] motion phases have an overlap of 50%

# Data Acquisition and Processing

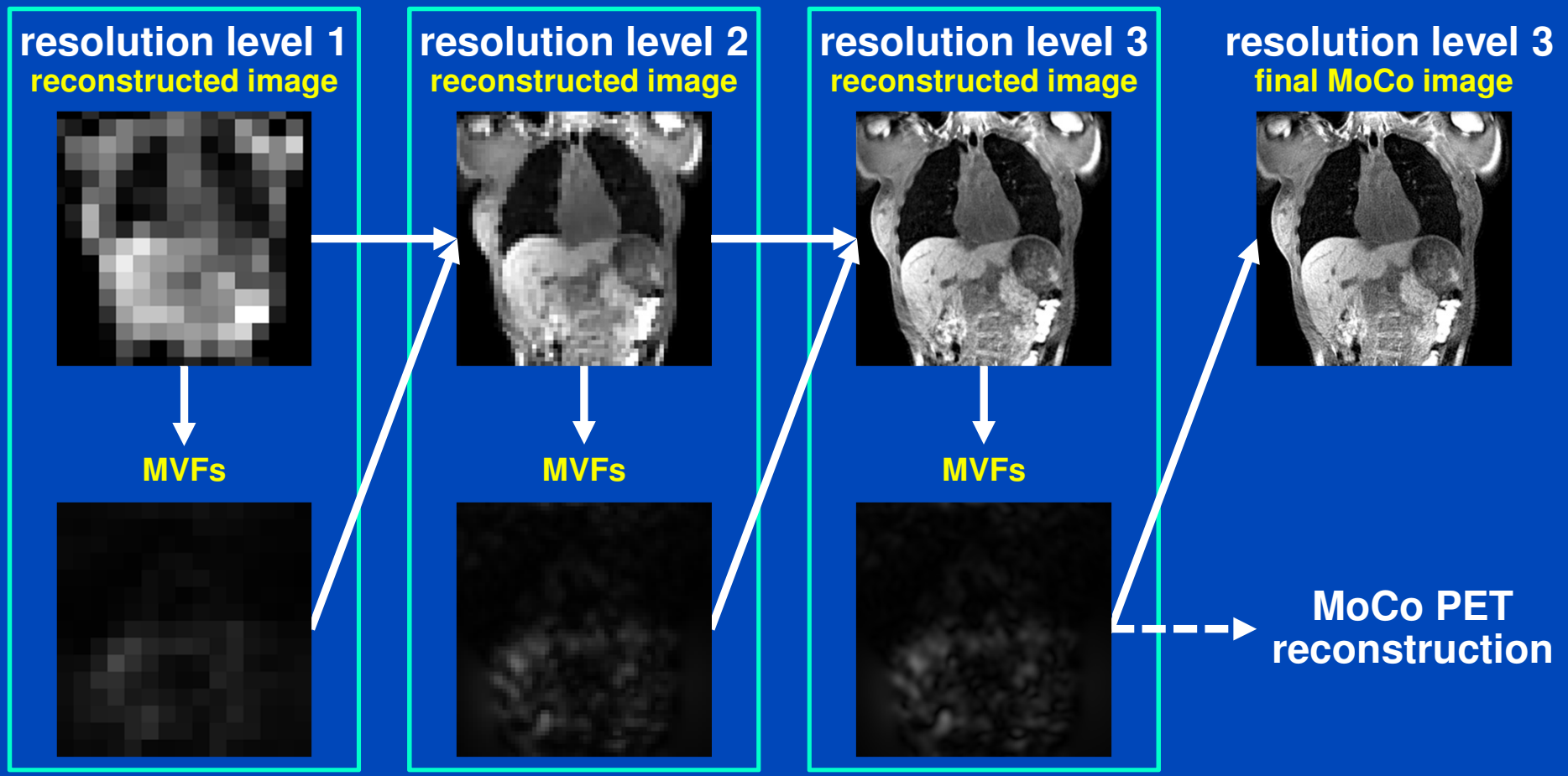
- Simultaneous PET/MR acquisition at Biograph mMR
  - tracer: fluorodeoxyglucose ($^{18}$F-FDG)
  - MR sequence: 3D-encoded gradient echo sequence with radial stack-of-stars sampling scheme and golden angle radial spacing
- Retrospective generation of undersampled MR rawdata




- MR and PET data were sorted retrospectively into 20 overlapping motion phase bins (10% width)

# Estimation of MVFs

## Schematic Overview (4D joint MoCo-HDTV[1])




[1] Rank, Heußer, Buzan, Wetscherek, Freitag, Dinkel, Kachelrieß. 4D respiratory motion-compensated image reconstruction of free-breathing radial MR data with very high undersampling. *Magn Reson Med,* accepted for publication.

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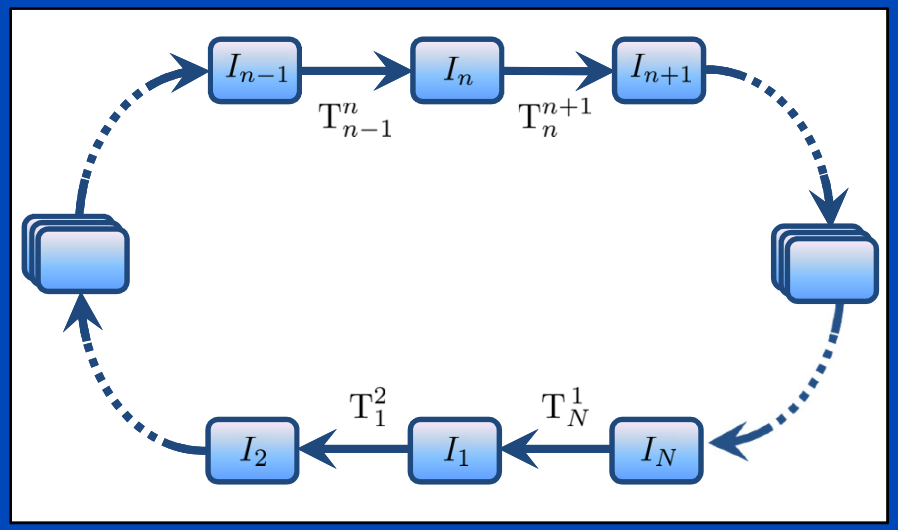
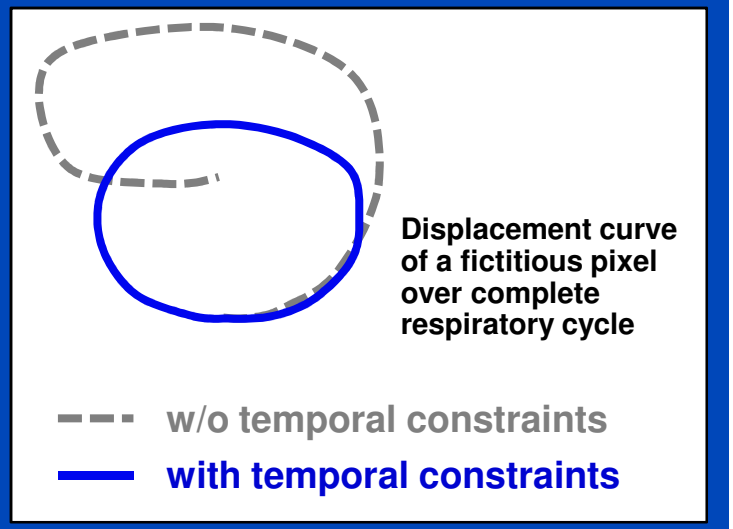
# Estimation of MVFs
## Cyclic Deformable Registration[1]

- **Motion estimation only between adjacent phases**
  - all other MVFs given by concatenation




- **Incorporate additional knowledge**
  - a priori knowledge of quasi periodic breathing pattern
  - non-cyclic motion is penalized
  - error propagation due to concatenation is reduced

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

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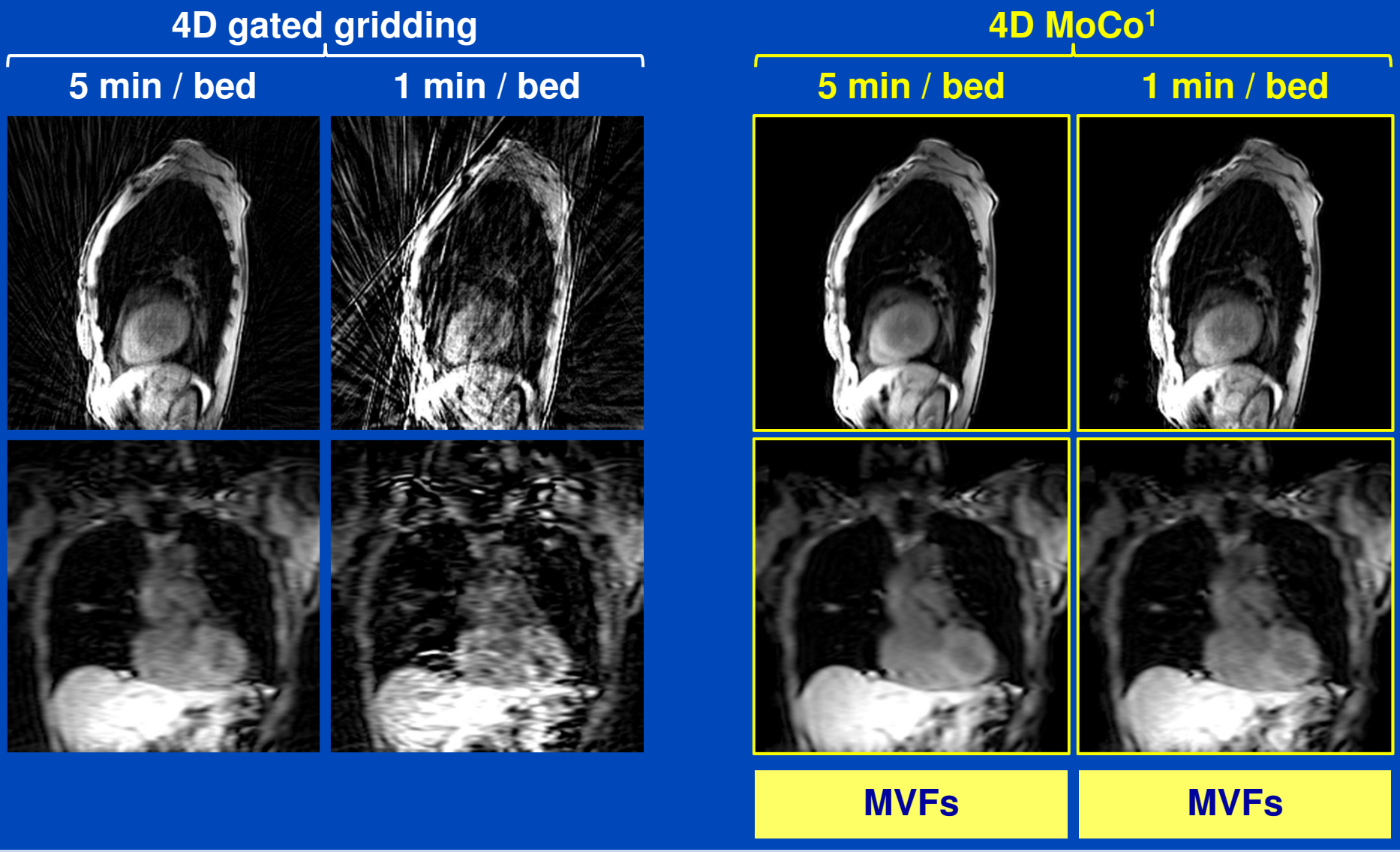
# Results of MR Reconstruction

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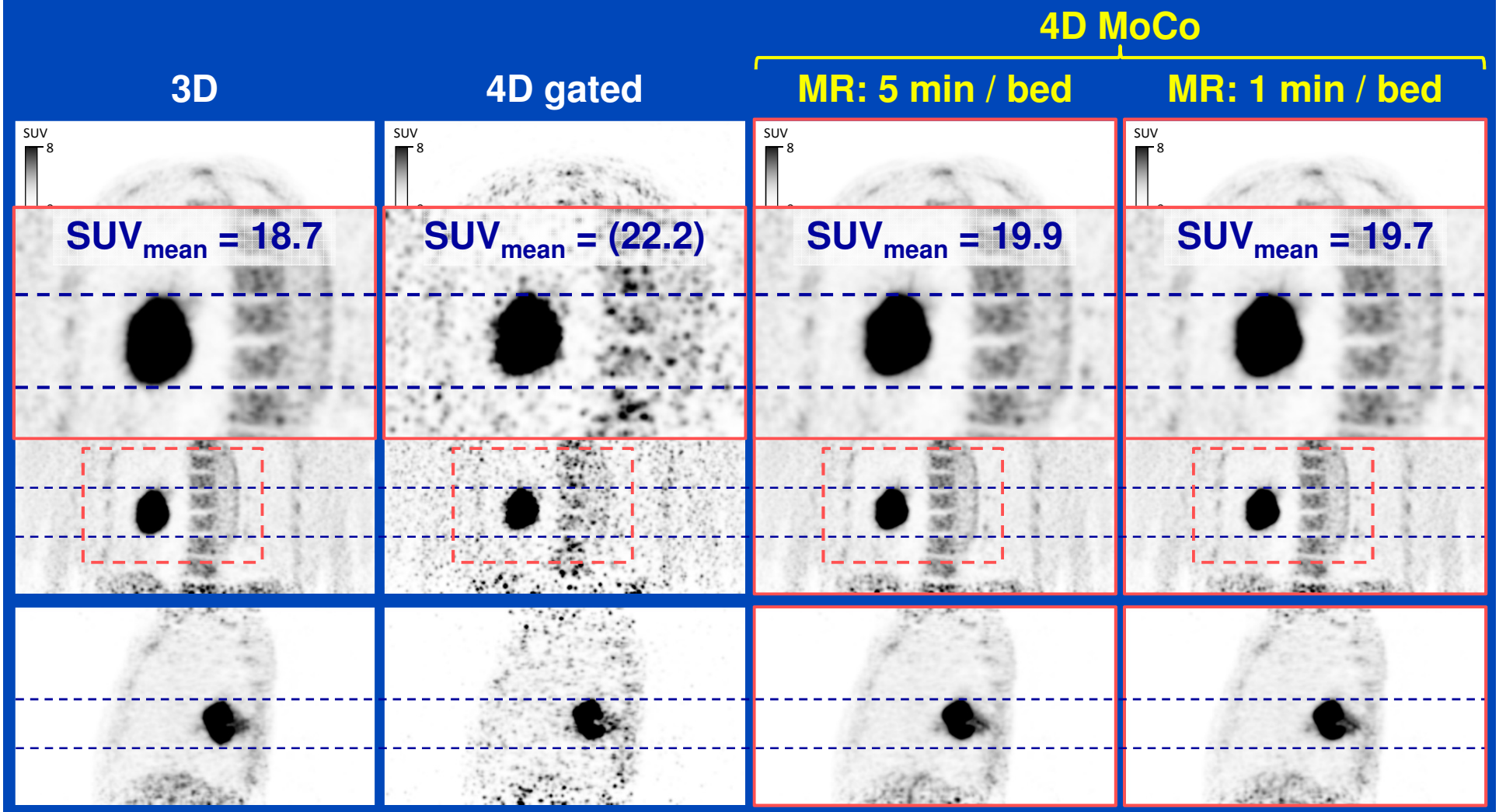
# Results of PET Reconstruction (I)




due to the high noise level of 4D gated PET,
$SUV_{mean}$ was systematically overestimated

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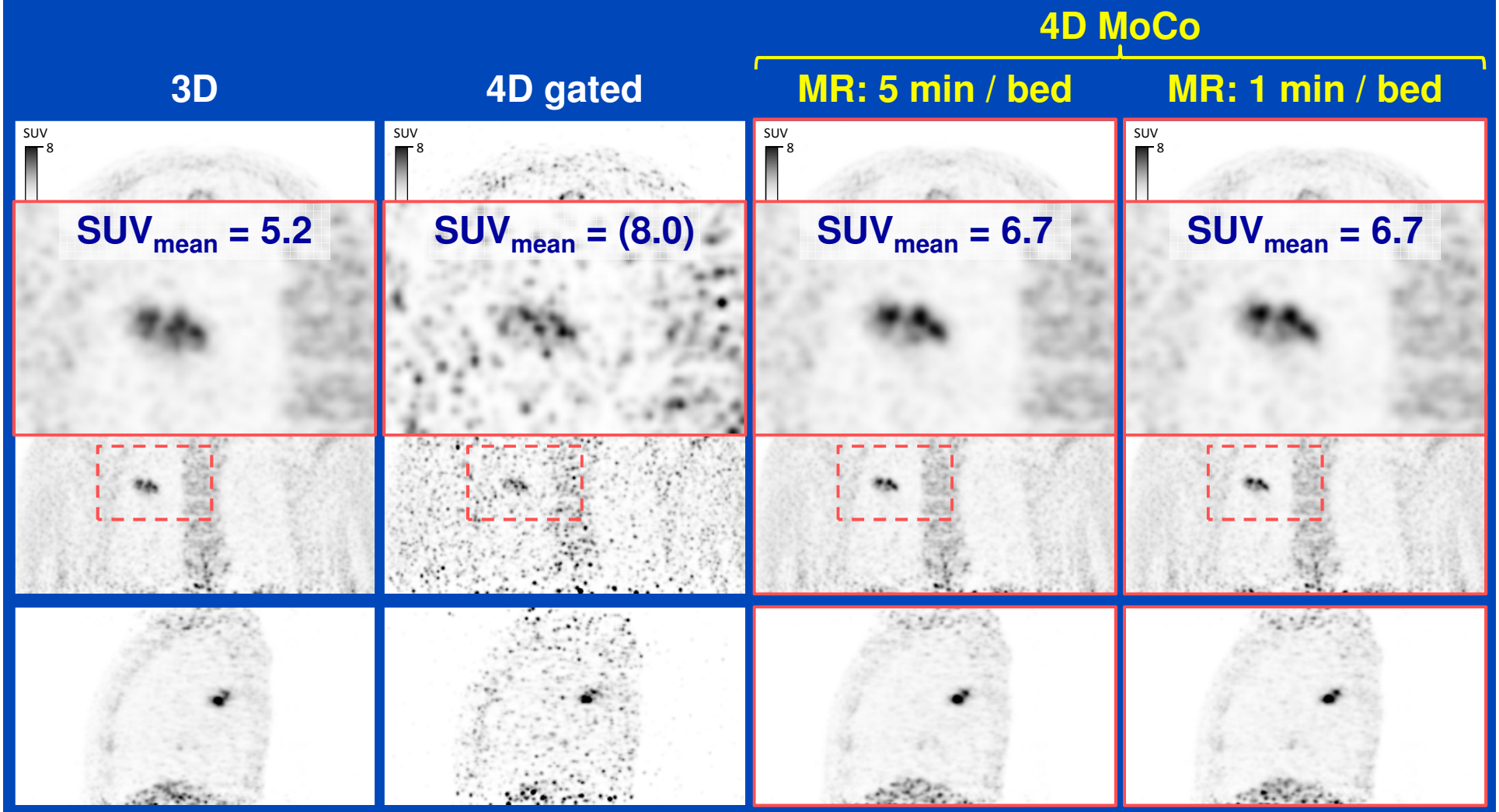
# Results of PET Reconstruction (II)




due to the high noise level of 4D gated PET,
SUV$_{mean}$ was systematically overestimated

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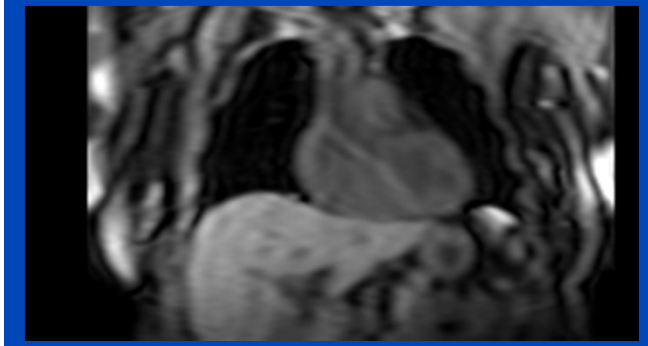
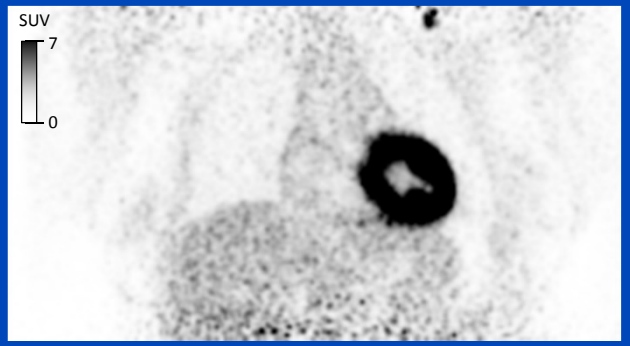
# Summary and Outlook

- High quality PET respiratory MoCo is possible based on a 1 minute MR acquisition or even less.
- The strong undersampling requires to reconstruct MVFs and MR images in an alternating manner.
- MoCo for PET improves PET quantification, image quality, temporal resolution and noise level.
- Outlook:

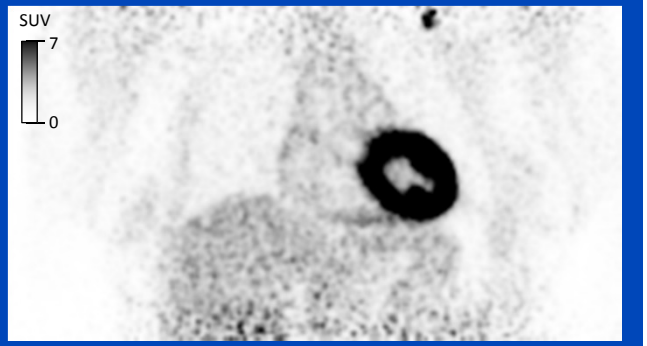
5D MoCo MR



3D PET




5D MoCo PET



# Thank You!

The 4th International Conference on

**Image Formation in X-Ray Computed Tomography**


Conference Chair

Marc Kachelrieß, German Cancer Research Center (DKFZ), Heidelberg, Germany

**This presentation will soon be available at www.dkfz.de/ct.**

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