Respiratory Time-Resolved 4D MR Imaging for RT Applications with Acquisition Times below One Minute

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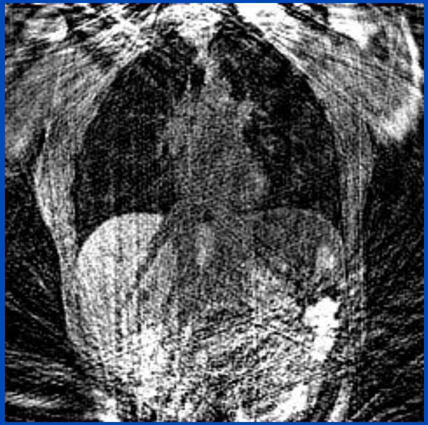
DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Introduction

- Radiotherapy of targets in the thorax and upper abdomen is challenging due to respiratory patient motion
- 4D CT is limited by radiation dose, such that multiple breathing cycles cannot be imaged on a daily basis
- 4D MRI has been proposed, however it requires long acquisition times of several minutes
- Simple approach: Gating
  - divide motion cycle into certain gates and reconstruct data from each gate separately
  - trade-off between acquisition time and an appropriate artifact and noise level
- Sophisticated approaches:
  - compressed sensing-based image reconstruction
  - motion-compensated image reconstruction

4D gated MR (40 s)

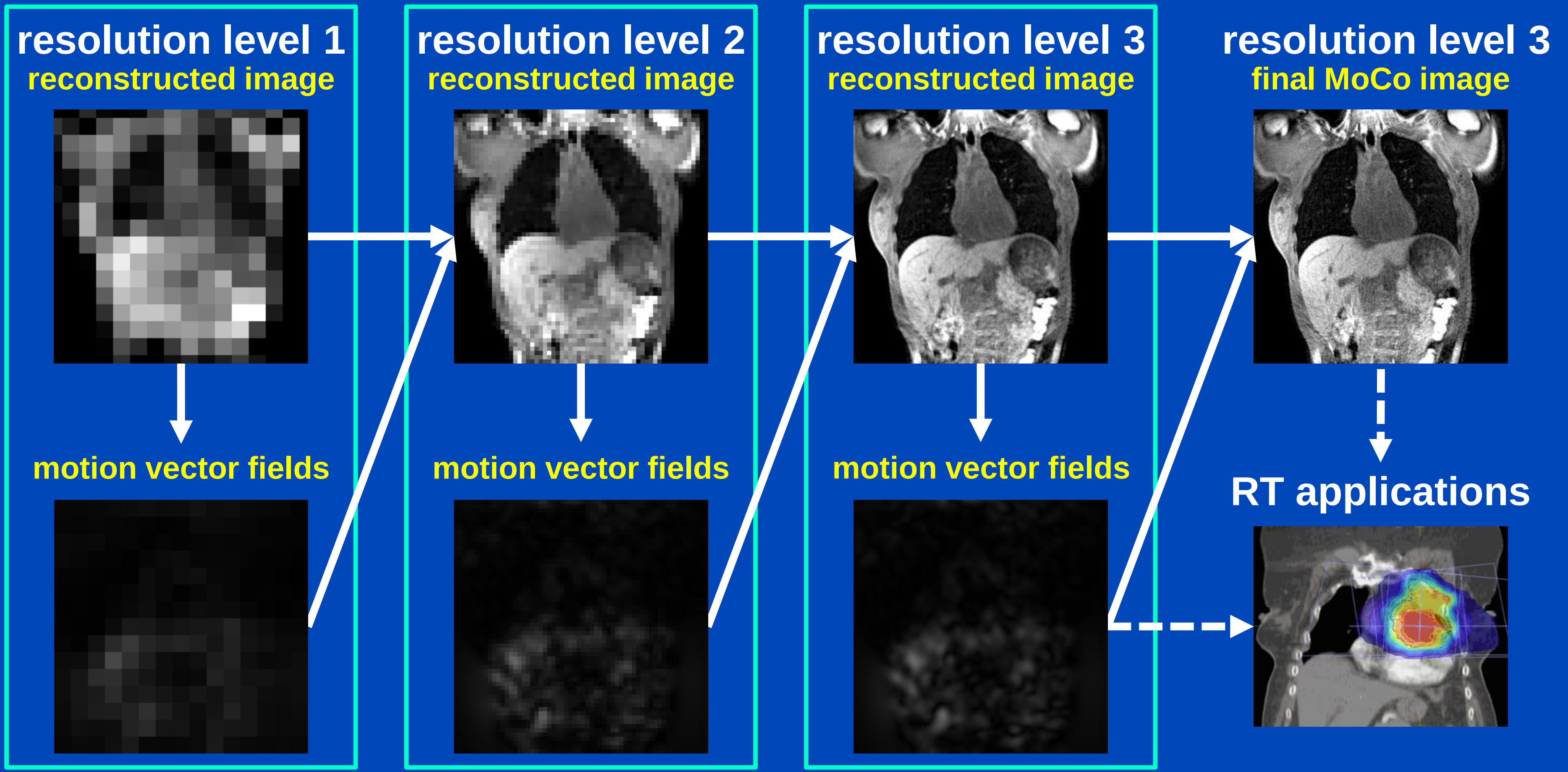


Aim of Work

- To reduce the acquisition time for 4D respiratory time-resolved MRI below 1 min
- Difficulty: suppress streak artifacts and noise effectively
- Solution: combine compressed sensing-based image reconstruction with motion compensation

4D joint MoCo-HDTV[1]

Schematic Overview



[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,* early view online.

Image Reconstruction
Cost Function[1,2]

- **Cost function:**

$$C = \underbrace{\|\mathrm{X}_{\mathrm{pc}} S f - p\|_2^2}_{\text{raw data fidelity}} + \underbrace{\mu \, \mathrm{HDTV}\, f}_{\text{total variation}}$$

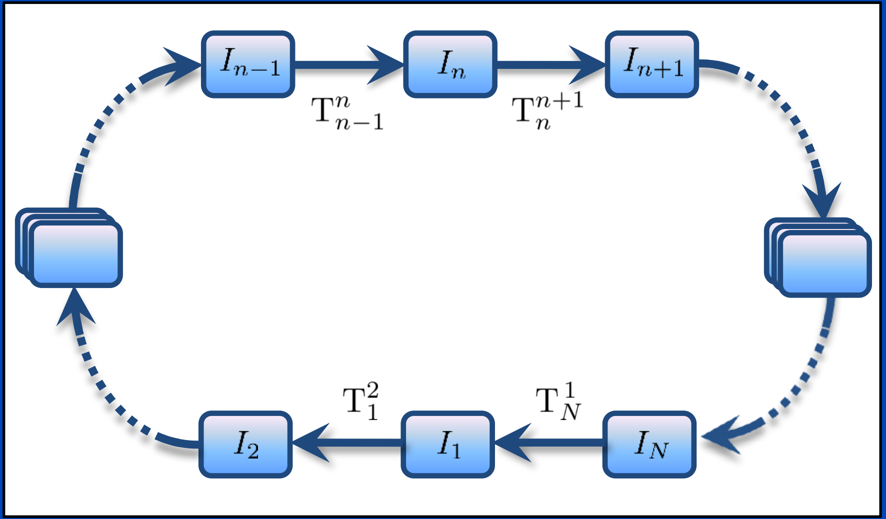
X_{pc} : motion phase-correlated forward transform
S : coil sensitivity profiles
f : 4D image volume
p : measured raw data
μ : weight
HDTV : spatial and temporal total variation

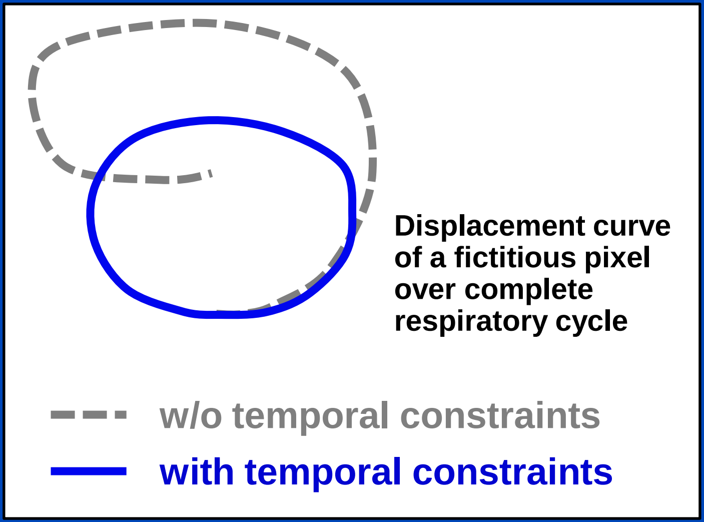
- **The first term optimizes the raw data fidelity**
- **The second term improves the image sparsity by optimizing the spatial and temporal total variation**
- **Both terms are optimized in an alternating manner**
- **The cost function is optimized for the complete 4D volume including all motion phases**

[1] Ritschl, Sawall, Knaup, Hess, Kachelrieß. Iterative 4D cardiac micro-CT image reconstruction using an adaptive spatio-temporal sparsity prior. *Phys. Med. Biol.* 2012.
[2] 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,* early view online.

Estimation of Motion Vector Fields
Cyclic Deformable Registration[1]

- Motion estimation only between adjacent phases
  - all other motion vector fields given by concatenation



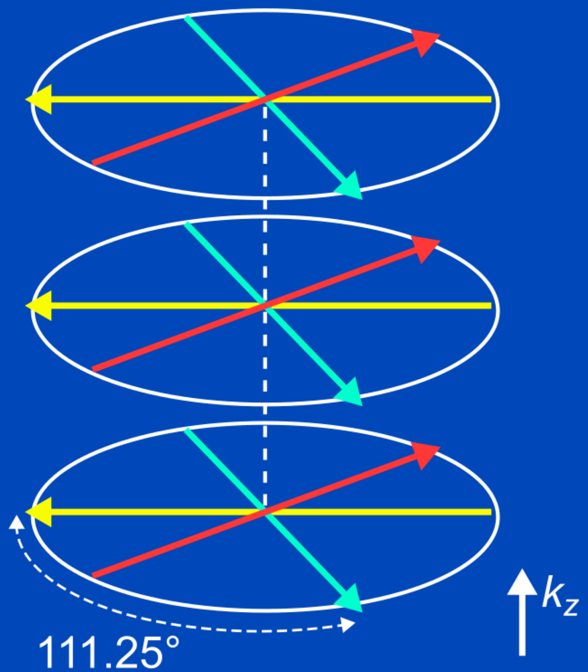


- Incorporate additional knowledge
  - a priori knowledge of quasi periodic breathing pattern
  - non-cyclic motion is penalized
  - error propagation due to concatenation is reduced

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

Data Acquisition and Processing

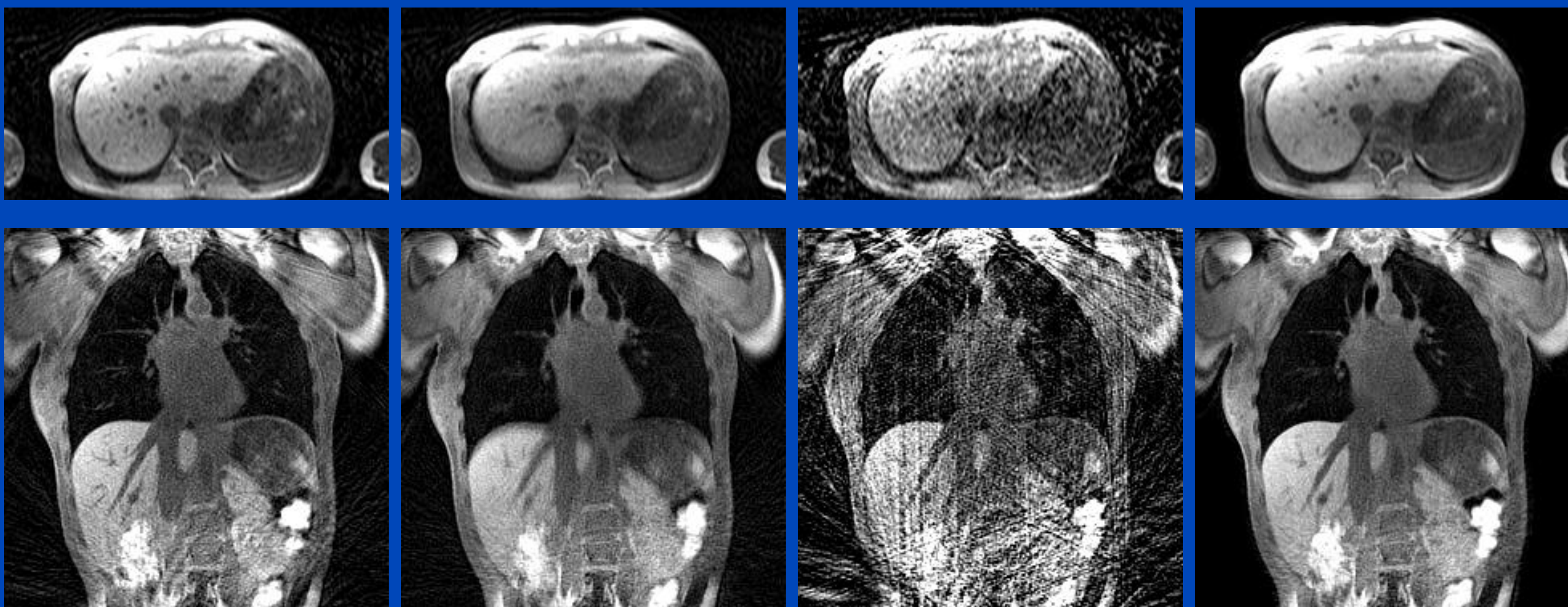
- Volunteer measurements of free-breathing thorax and upper abdomen at 1.5 T (Magnetom Aera, Siemens Healthcare)
- 3D-encoded gradient echo sequence with radial stack-of-stars sampling
- Radial sampling in read-out plane, Cartesian sampling in slice direction
- Golden angle (≈ 111.25°) radial spacing



- Data were sorted retrospectively into 20 overlapping respiratory motion phases (10% width)

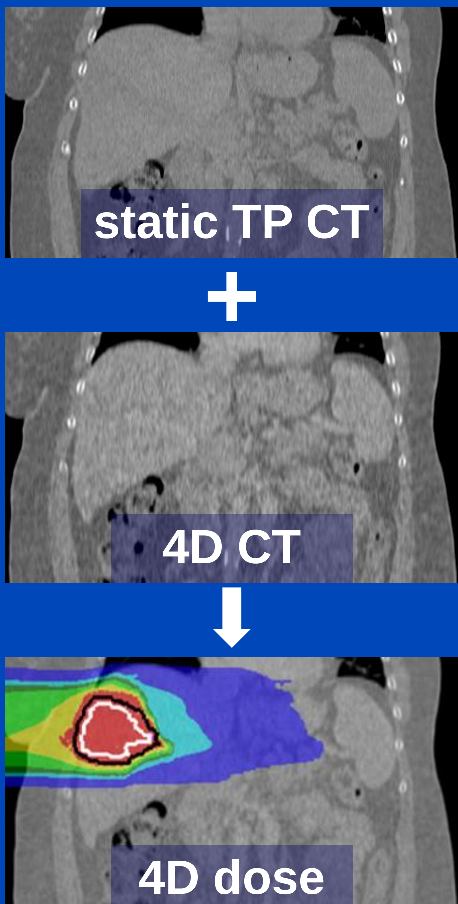
Results of 4D MR Reconstructions

4D reference gated	3D motion average	4D gated	4D joint MoCo-HDTV
6 min 51 s	40 s	40 s	40 s



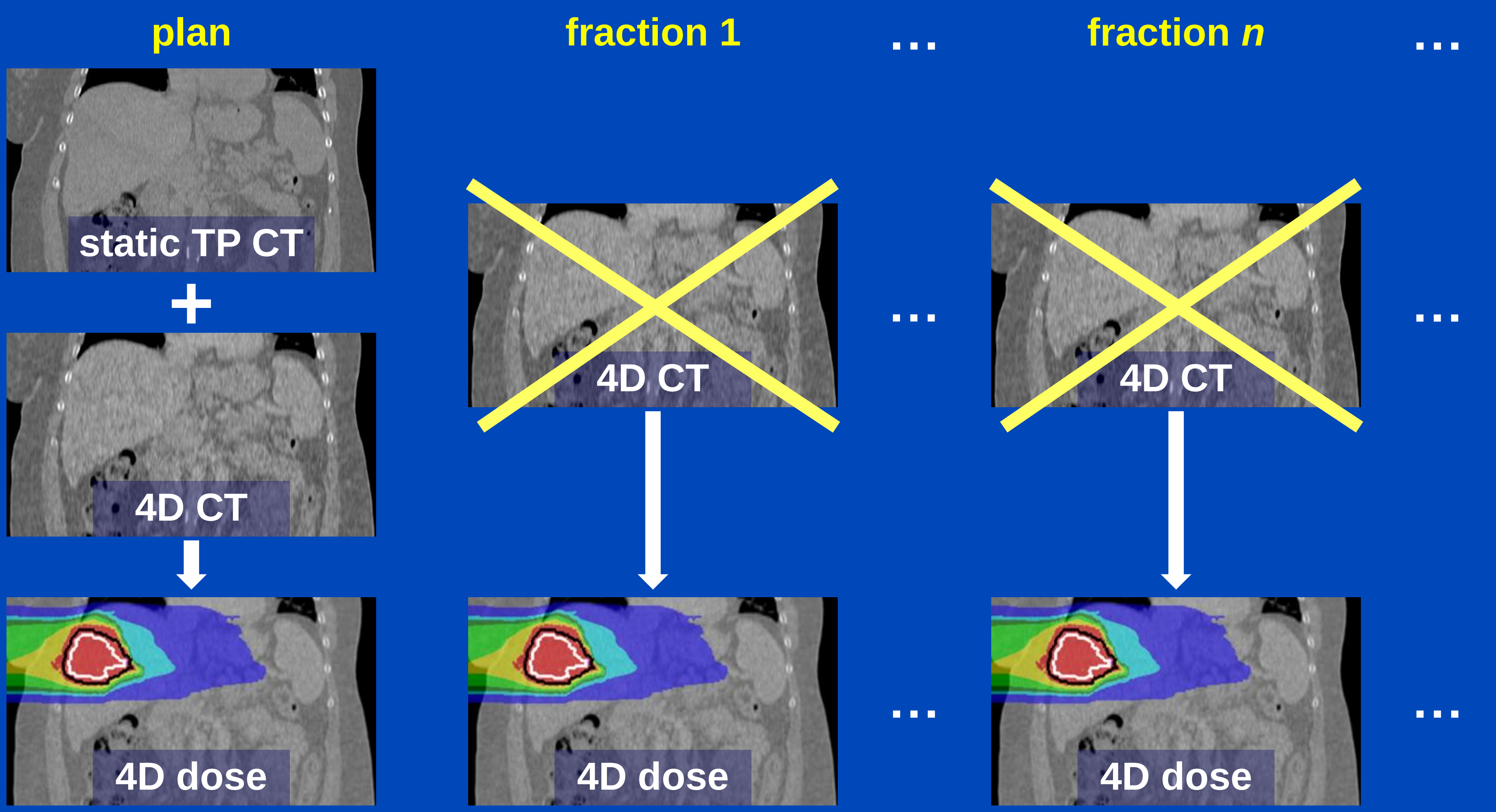
Adaptive RT Planning

plan



Courtesy of Vania Batista, University Hospital Heidelberg, Germany,
and Nami Saito, German Cancer Research Center, Heidelberg, Germany.

Adaptive RT Planning



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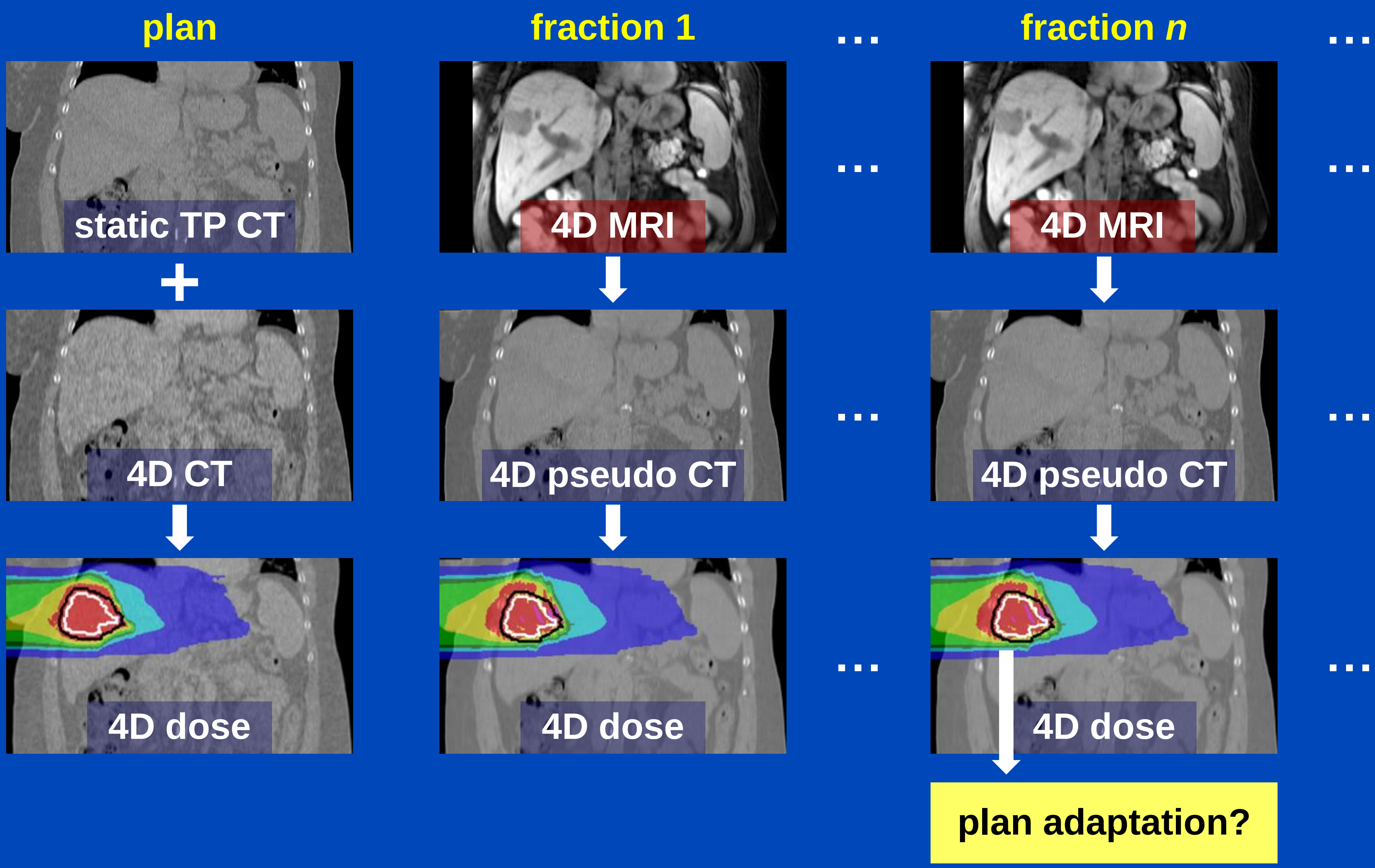
Adaptive RT Planning



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and Nami Saito, German Cancer Research Center, Heidelberg, Germany.

Summary and Outlook

- High quality 4D respiratory time-resolved MRI is possible based on acquisition times below 1 min
- Image quality is comparable to measurements with ten-fold acquisition time reconstructed with standard methods
- The reconstructed 4D images and the estimated motion vector fields might be employed for RT applications:
  - reliable target delineation of moving targets
  - patient-specific margin or gating window definition
  - adaptive RT planning
- Next steps:
  - test of geometric accuracy of MR sequence
  - reduction of computation time
  - application of algorithm in an ongoing MRI-guided RT study

Thank You!

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

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