

# Artifact-Resistant Motion-Compensated On-Board Cone-Beam CT Imaging

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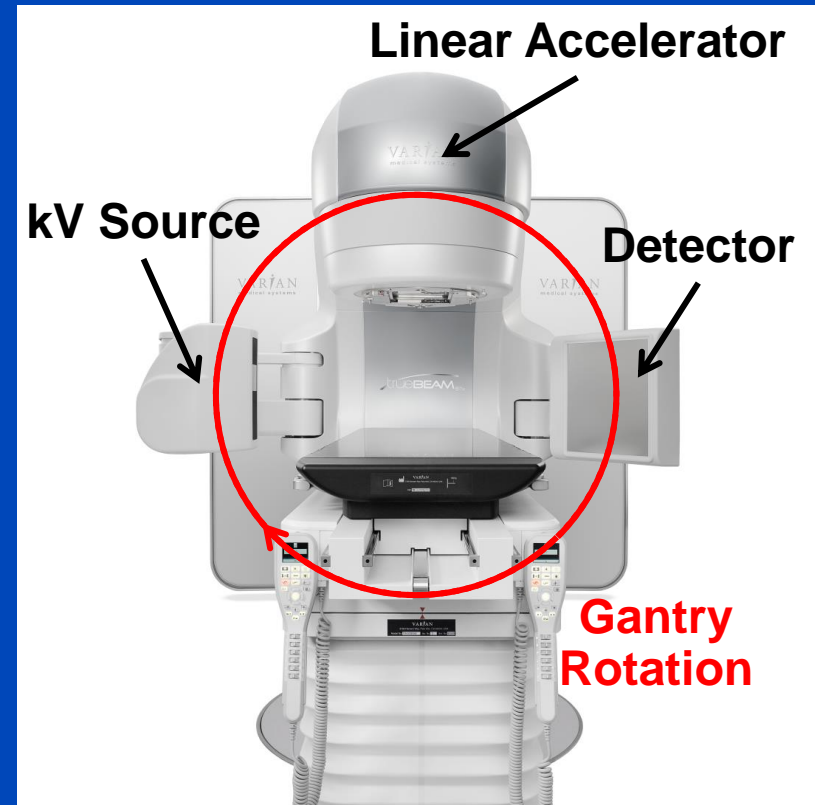
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# Slowly Rotating CBCT Devices

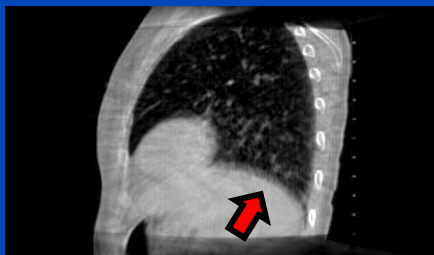
- Image-guided radiation therapy (IGRT)
  - CBCT imaging unit mounted on gantry of a LINAC treatment system
  - E.g. used for patient positioning
- Maximum gantry rotation speed of  $6^\circ$  per second
- Breathing cycle about 2 to 5 seconds
  - i.e. 12 to 30 respirations per minute (rpm) and thus per scan



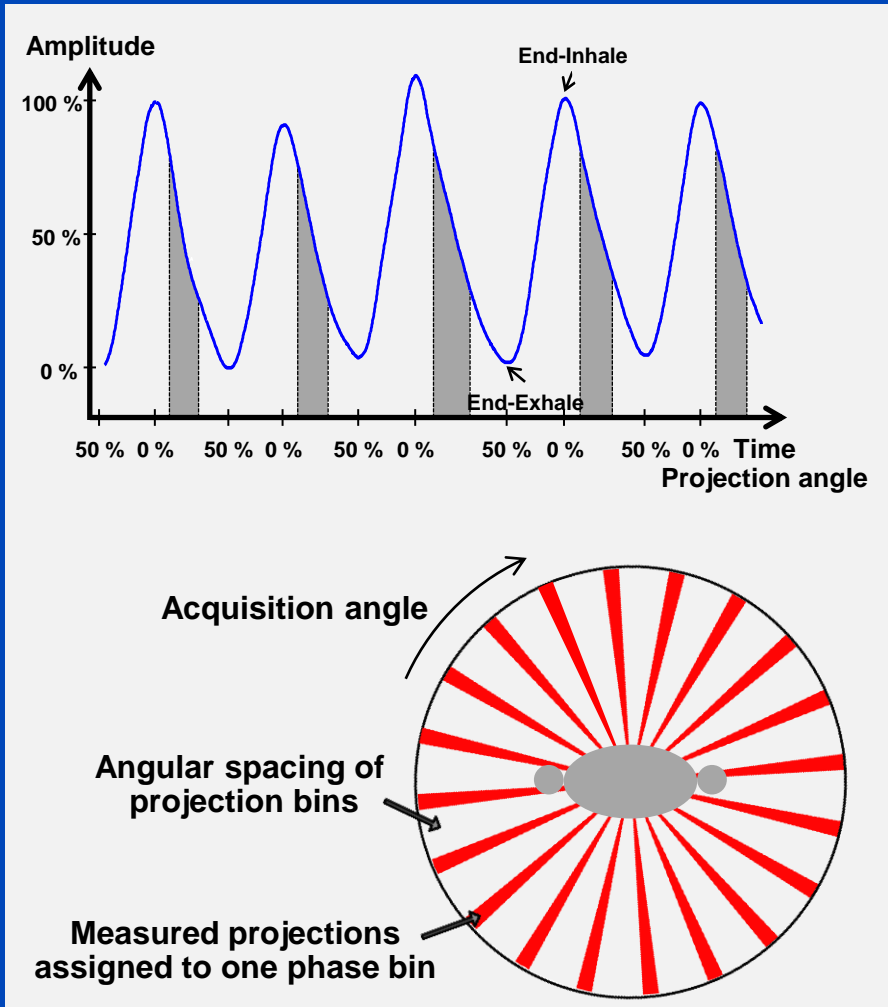
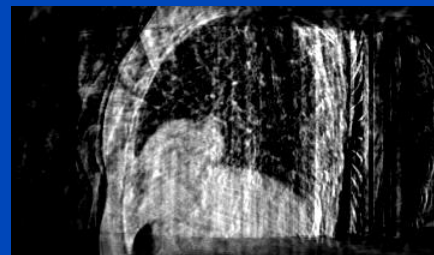
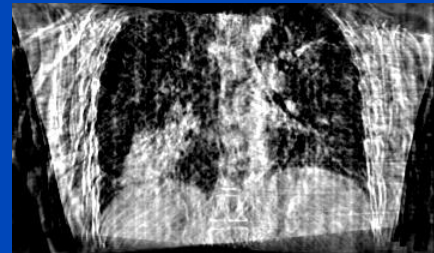
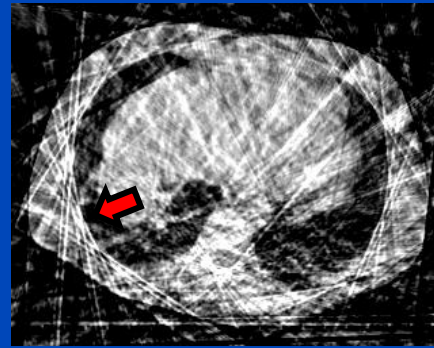
⇒ Account for respiratory motion!

# Retrospective Gating

Without gating (3D):  
Motion artifacts



With gating (4D):  
Sparse-view artifacts



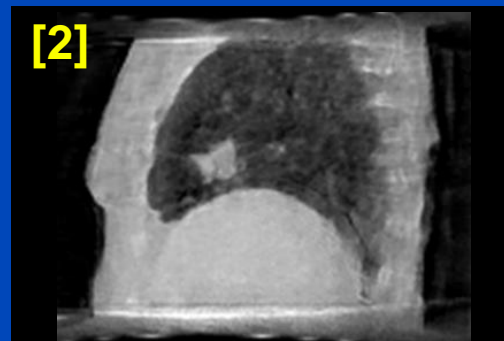
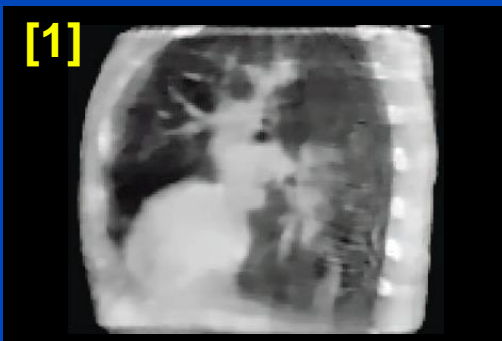
# Prior Art in IGRT (Respiratory-Correlated Reconstructions)

- **Respiratory gating and independent reconstruction**
  - Sparse-view artifacts deteriorate image quality
    - » Streak artifacts and image noise
  - Increased patient dose required
- **Dedicated acquisition techniques**
  - Long acquisition times
  - Limited capability to reduce artifacts without increasing patient dose
- **Adaptive respiratory-correlated reconstruction**
  - Artifacts remain in area of interest subjected to motion
- **Motion-compensated reconstruction**
  - Necessary motion estimation requires (so far)
    - » increased patient dose,
    - » or additional knowledge, e.g. planning CT

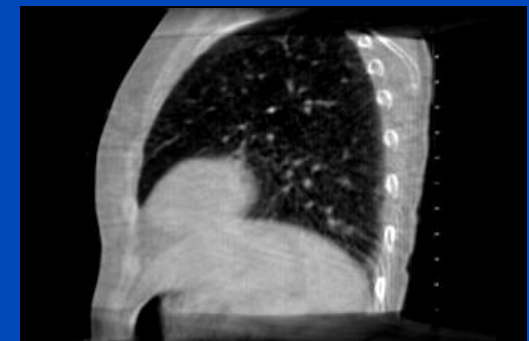
# Aim

- Provide high quality respiratory-correlated 4D volumes from on-board CBCT scans
  - Image quality comparable to that of motionless regions (e.g. neck)
- Do this with a standard acquisition protocol
- Do this without other prior information of higher temporal sampling such as a 4D planning CT
  - Account for inter-fractional variations in breathing motion

## Results of recent publications from other groups



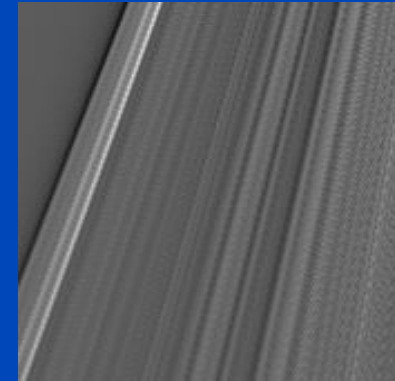
## Desired Results



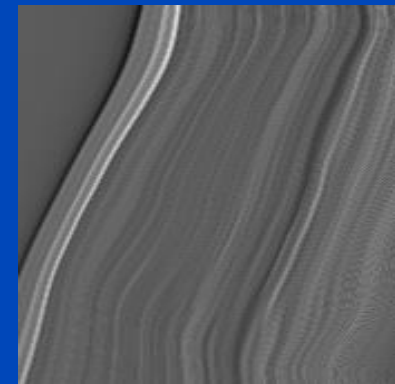
# Motion Compensation (MoCo)

- **Use all projection data for each phase to be reconstructed**
  - Even those of other respiratory phase bins (100 % dose usage)
  - Compensate for motion applying motion vector fields (MVFs)
  - In our case MVFs are estimated from conventional gated reconstructions
- **Use MVFs during reconstruction**
  - Modified filtered backprojection
  - Backproject the sparse data along straight lines, then warp with respect to the MVFs

Straight backprojection



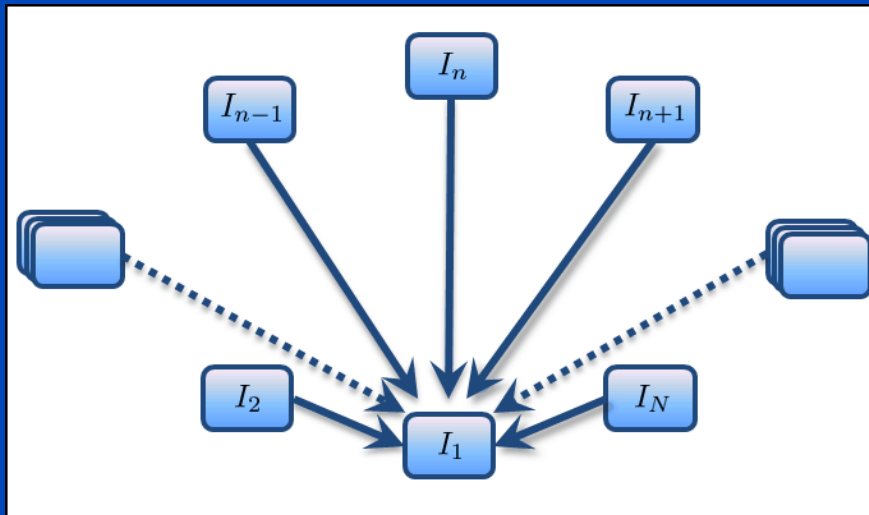
Warped backprojection





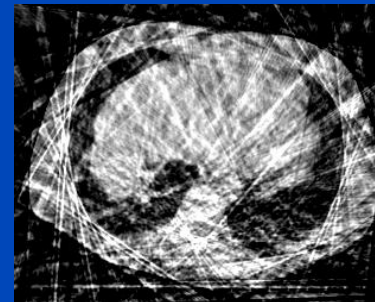
# A Standard Motion Estimation and Compensation Approach (sMoCo)

- Motion estimation via standard 3D-3D registration

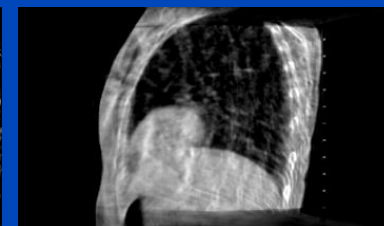
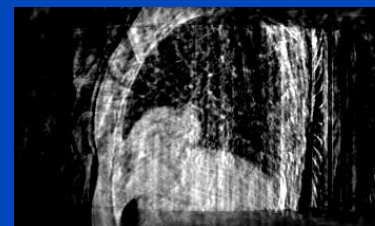
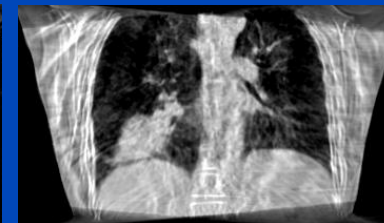
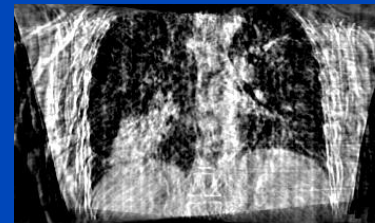
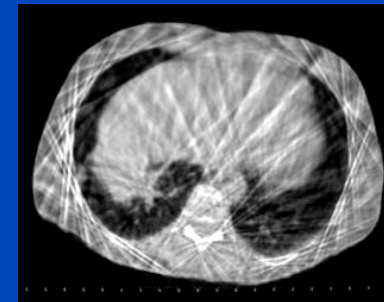


- Has to be repeated for each reconstructed phase
- Streak artifacts from gated reconstructions propagate into sMoCo results

Gated 4D CBCT

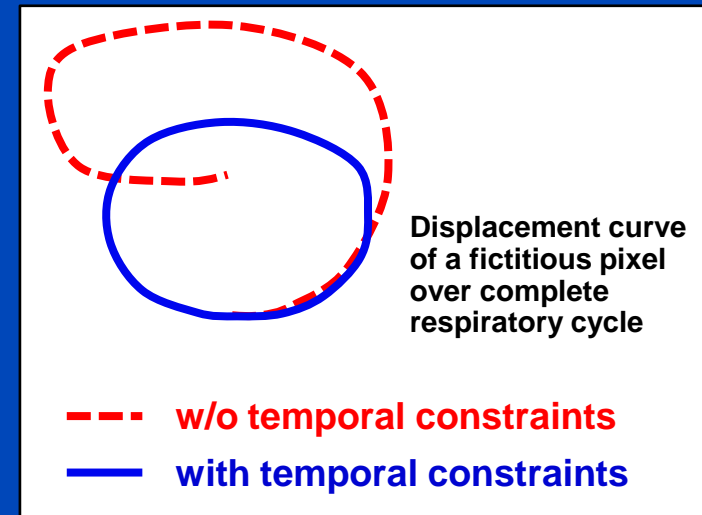
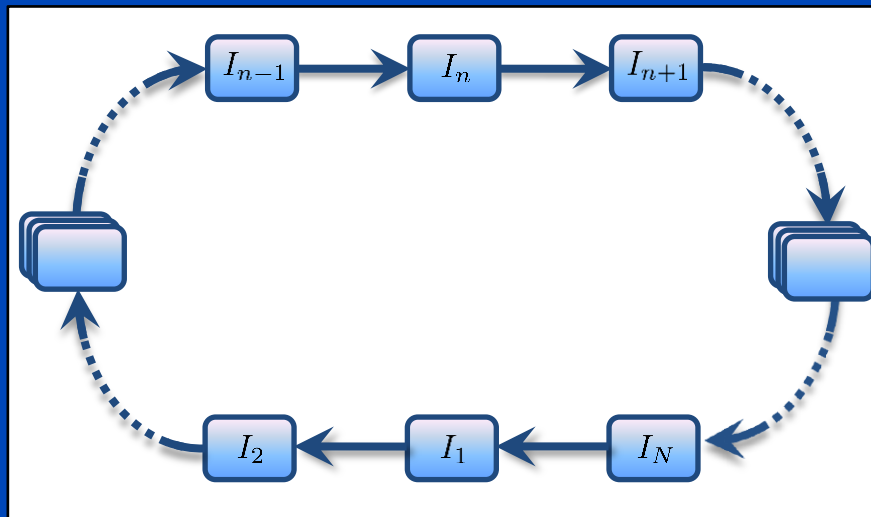


sMoCo



# A Cyclic Motion Estimation and Compensation Approach (cMoCo)

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

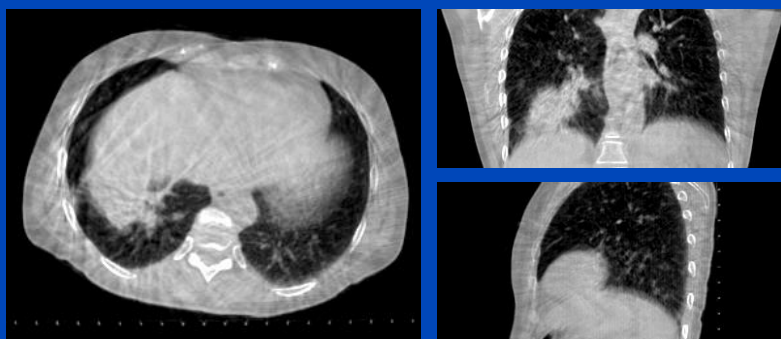


- Incorporate additional knowledge
  - A priori knowledge of quasi periodic breathing pattern
  - Non-cyclic motion is penalized
  - Error propagation due to concatenation is reduced

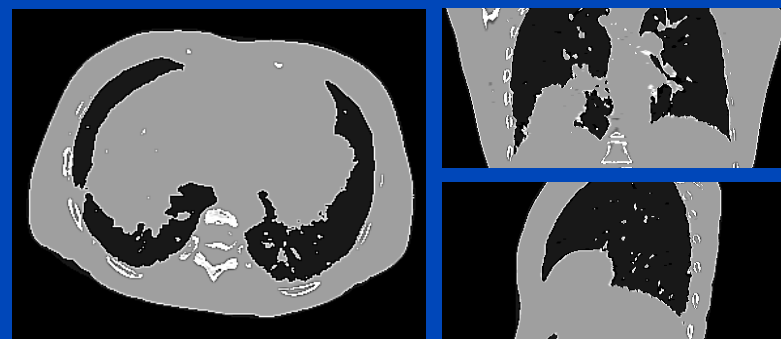


# Angular Sampling Artifact Model

- Create second series of images with sparse-view artifacts but without breathing motion
- Eliminate breathing motion information
  - Threshold-based segmentation of 3D CBCT
- Simulate measurement and reconstruction process
  - Forward projection of segmented image
  - Backprojection at same angles as for gated 4D CBCT



3D CBCT

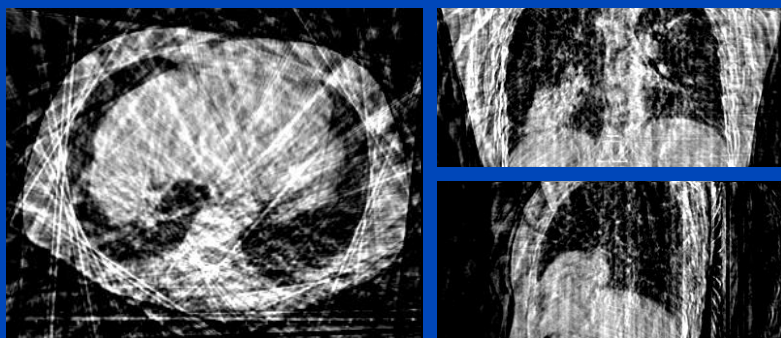


Segmented Image

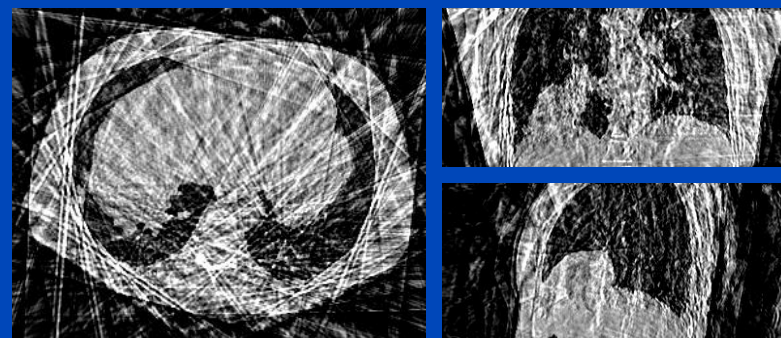
$C = -200 \text{ HU}$ ,  $W = 1400 \text{ HU}$

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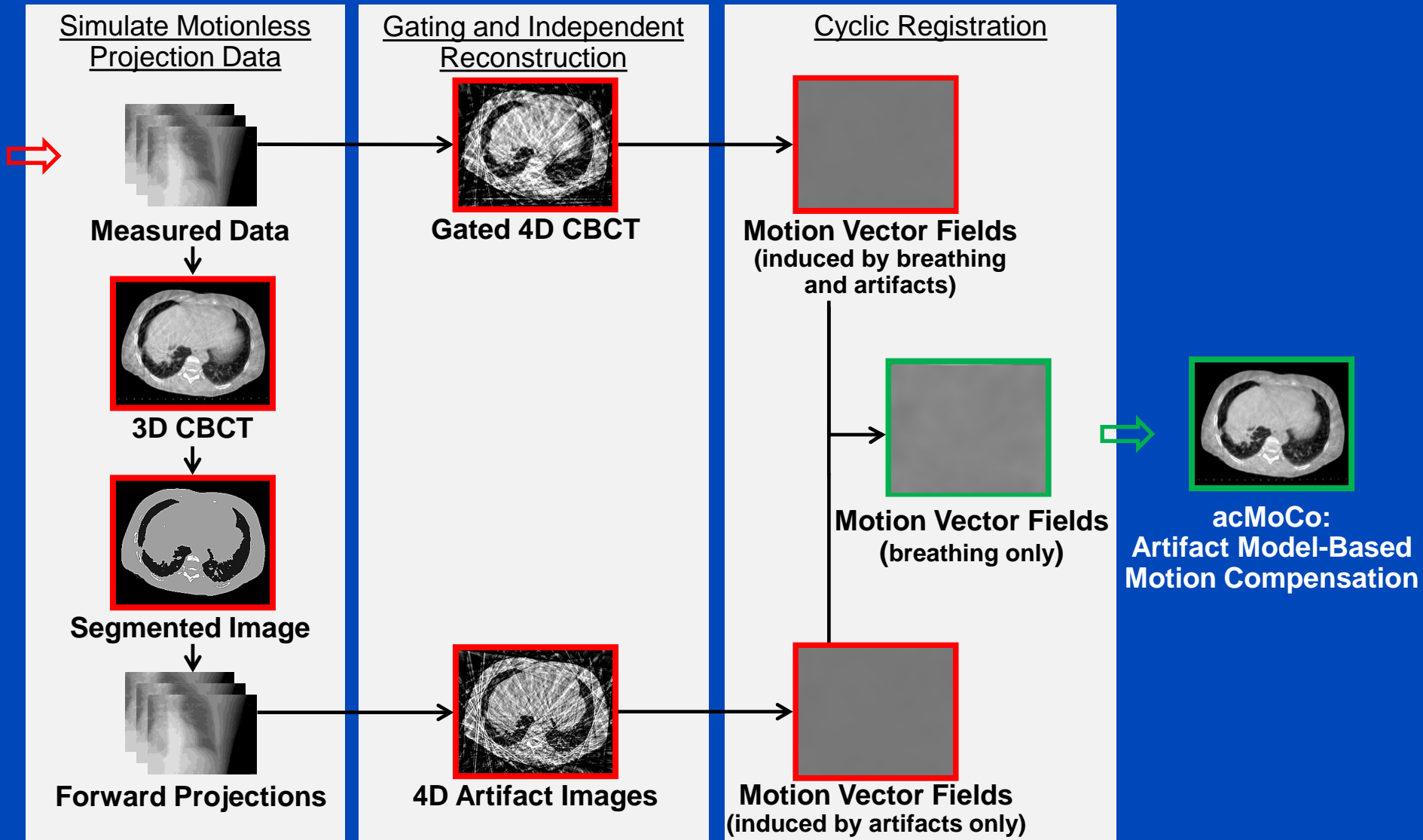
Gated 4D CBCT



4D Artifact Images

$C = -200 \text{ HU}$ ,  $W = 1400 \text{ HU}$

# Motion Estimation using an Patient-Specific Artifact Model



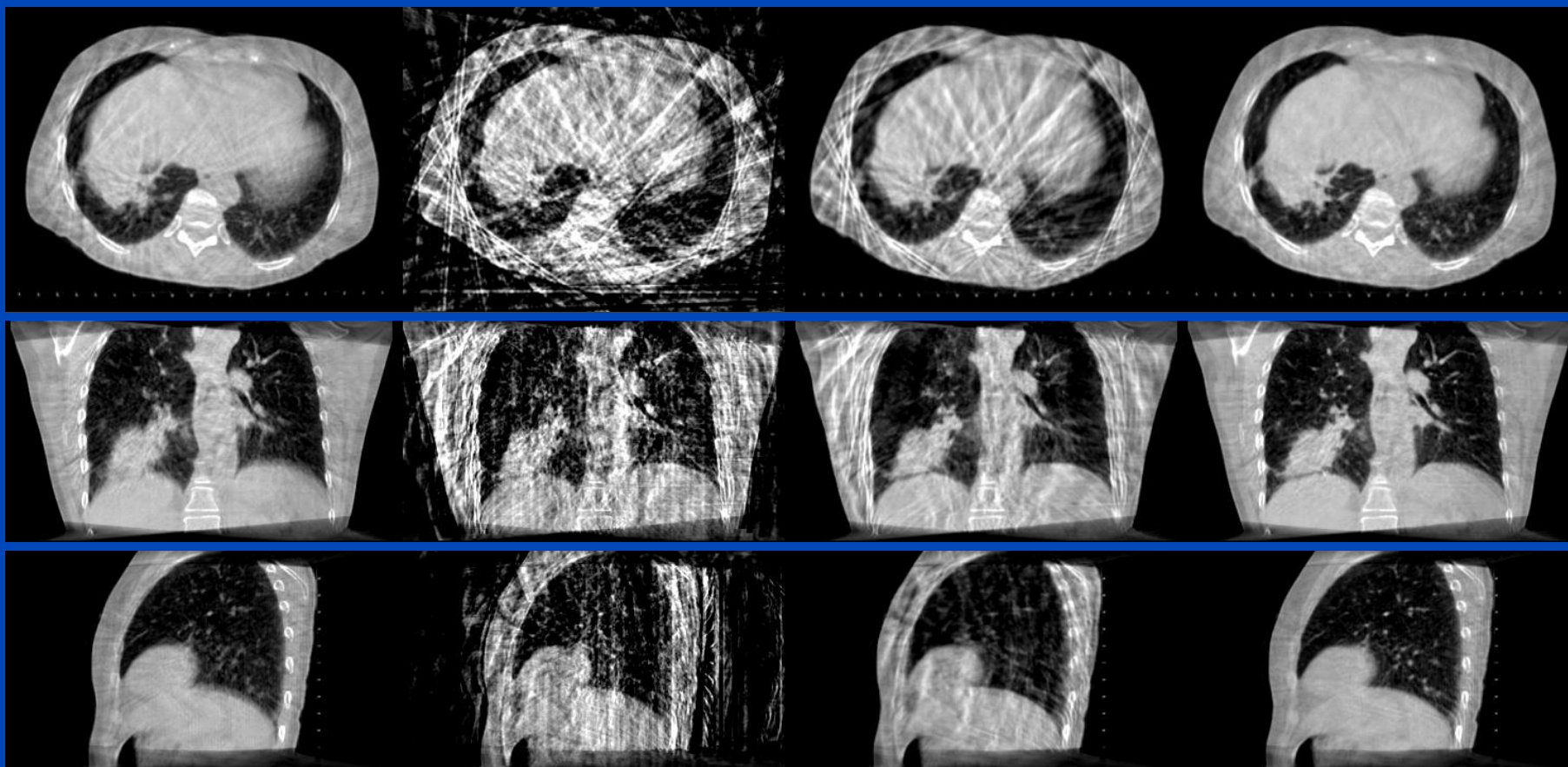
# Patient Data – Results

**3D CBCT**  
Standard

**Gated 4D CBCT**  
Conventional  
Phase-Correlated

**sMoCo**  
Standard Motion  
Compensation

**acMoCo**  
Artifact Model-Based  
Motion Compensation



C = -200 HU, W = 1400 HU

# Summary

- Severe sparse-view artifacts deteriorate image quality of conventional phase-correlated images.
- Standard deformable 3D-3D registration is sensitive to these artifacts.
- Highly decreased sensitivity to sparse-view artifacts by combination of cyclic registration and artifact model.
- Motion-compensated image reconstruction using MVFs obtained by combination of cyclic registration and artifact model appears to be suitable for application in IGRT.



# Thank You!

This study was supported by a research grant from Varian Medical Systems, Palo Alto, CA.

This presentation will soon be available at [www.dkfz.de/ct](http://www.dkfz.de/ct).

Parts of the reconstruction software were provided by RayConStruct<sup>®</sup> GmbH, Nürnberg, Germany.