Respiratory and Cardiac Motion-Compensated 5D Cone-Beam CT of the Thorax Region

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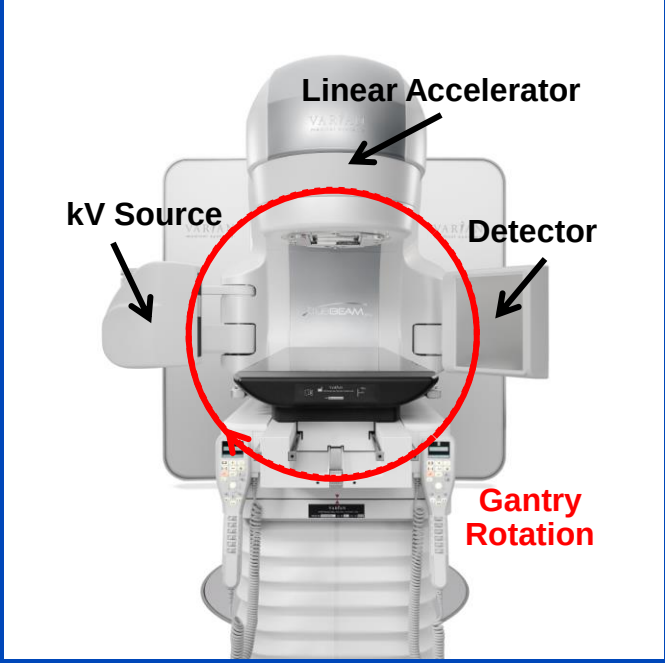
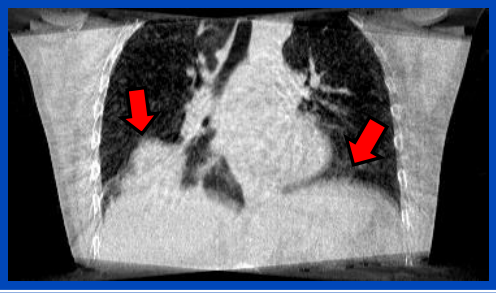
Slowly Rotating CBCT Devices

- **Image-guided radiation therapy (IGRT)**
  - Cone-beam CT (CBCT) imaging unit mounted on gantry of a LINAC treatment system
  - Accurate information about patient motion required for radiation therapy
- **Slow gantry rotation speed of 6° per second (60 s/360°)**
  - Much slower than clinical CT devices (0.25 s /360°)
- **Breathing about 10 to 30 respiration cycles per minute (and thus per scan)**
- **Heartbeat about 50 to 80 times per minute**

Task: Account for respiratory and cardiac motion





Motion blurring in standard 3D reconstruction

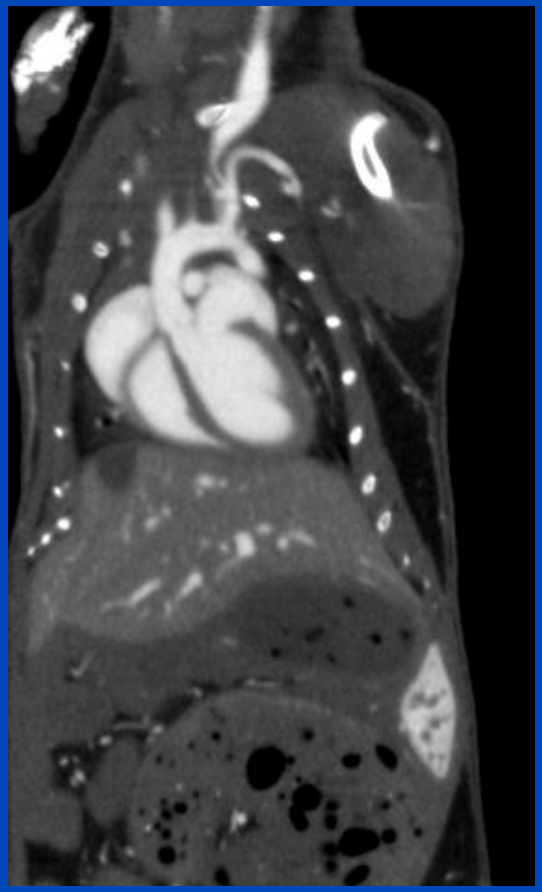
Aim

Provide high fidelity respiratory- and cardiac-correlated volumes (5D volumes) from on-board CBCT scans without using dedicated acquisition techniques or prior knowledge from planning scans.

- **Use case:**
  - Accurate patient positioning
  - Treatment verification
  - Online treatment adaption

5D MoCo Mouse Data[1]

Mouse with 180 rpm and 240 bpm



5D data displayed as:
Heart: 280 bpm
Lung: 150 rpm

- 20 respiratory windows with Δr = 10%
- 10 cardiac windows with Δc = 20%

- rpm and bpm signal for gating intrinsically determined

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[1]M. Brehm et al. - Cardiorespiratory motion-compensated micro-CT image reconstruction using an artifact model-based motion estimation. Med. Phys. 42(4):1948-1958, April 2015.

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5D MoCo Mouse Data[1]

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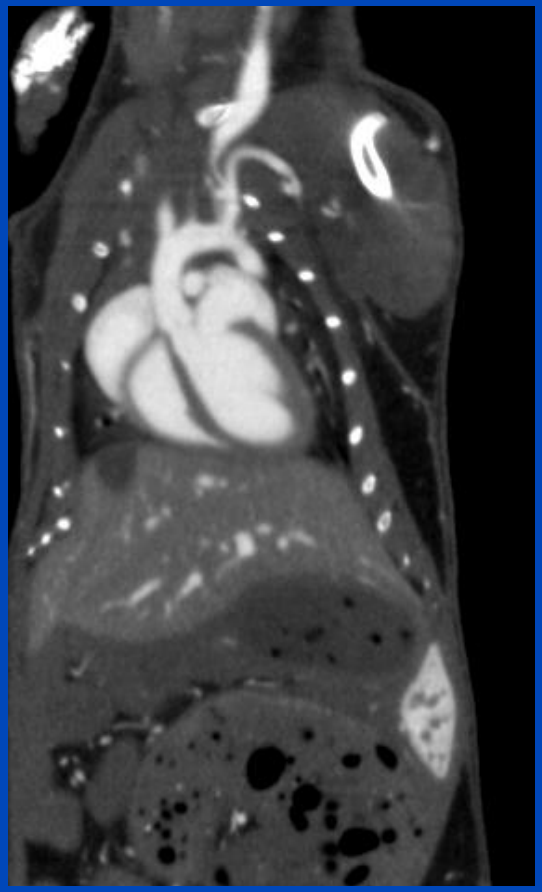

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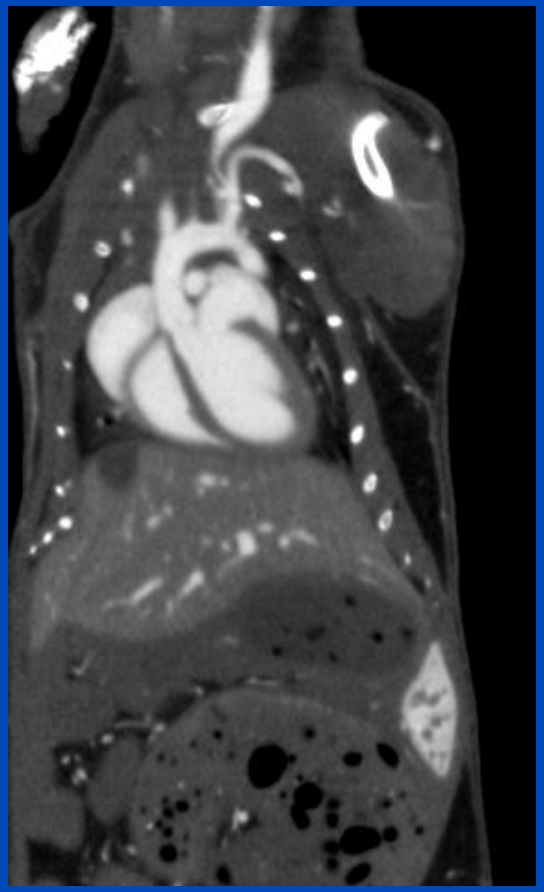
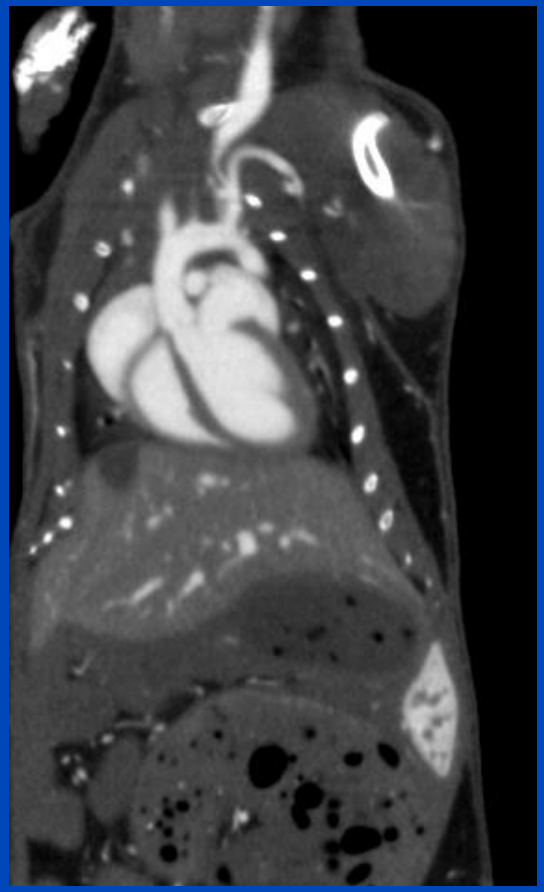


5D data displayed as:
Heart: 0 bpm
Lung: 90 rpm



5D data displayed as:
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Lung: 0 rpm

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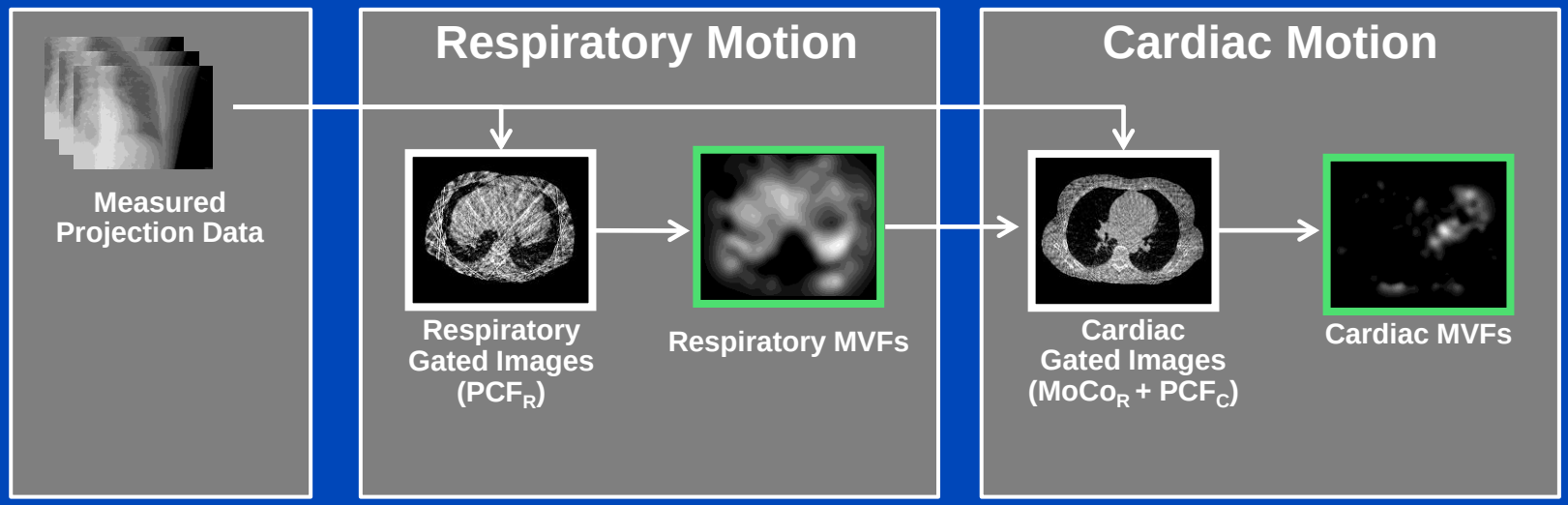
5D Motion Compensation

Simplified Illustration of Workflow[1]



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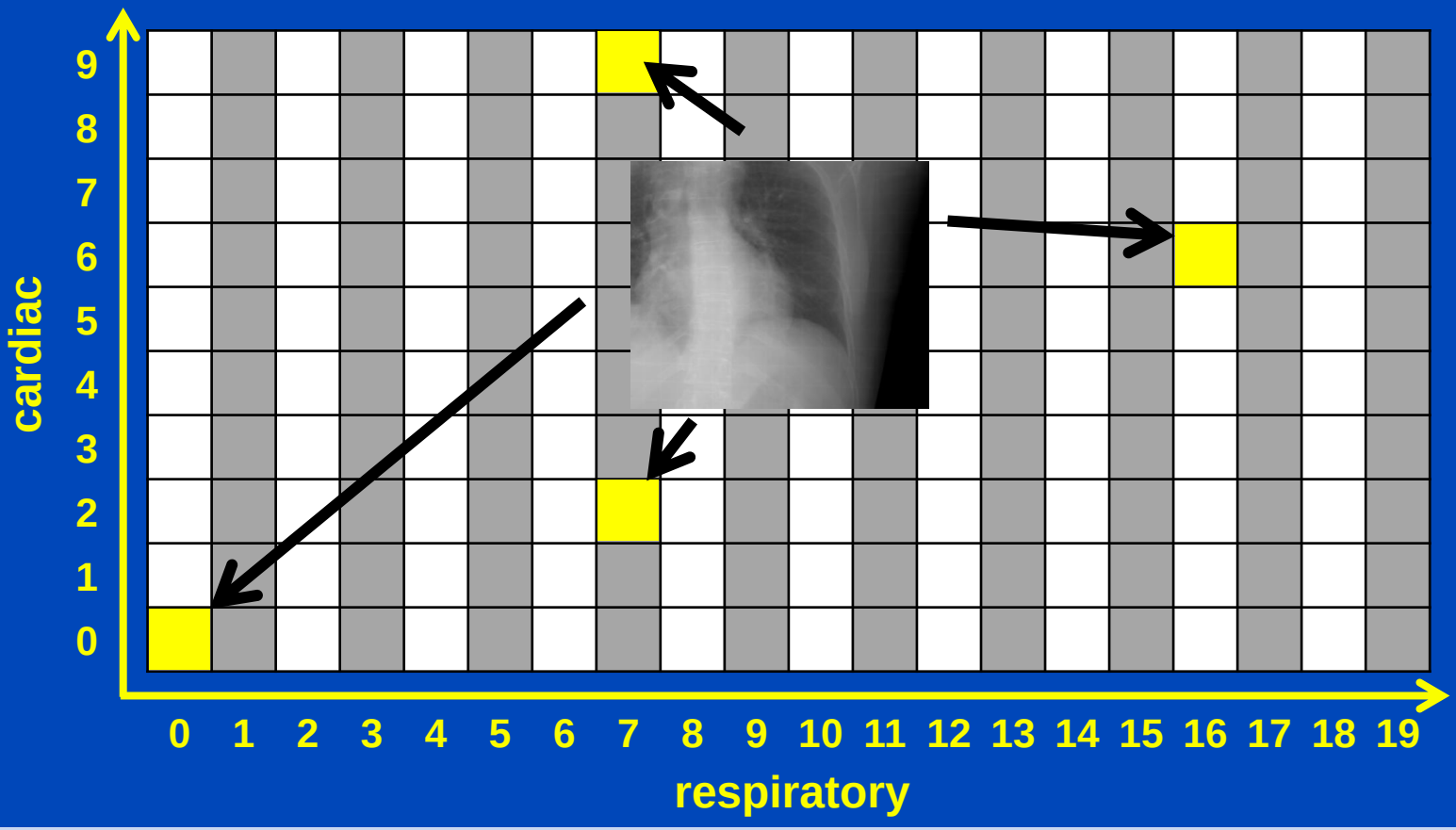
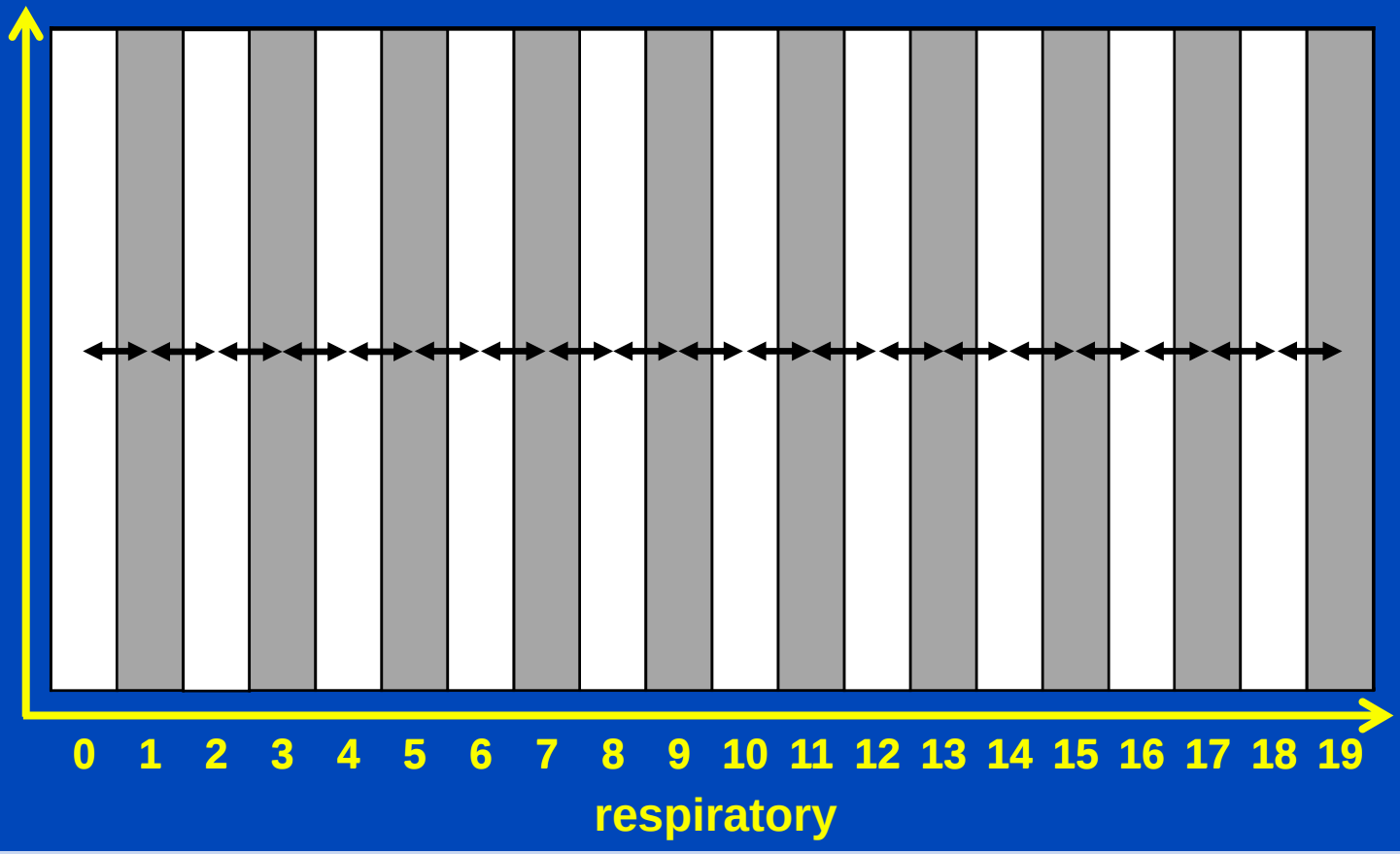
5D Motion Compensation
Respiratory Motion Estimation

- Matrix represents all rawdata, sorted into different cardiac and respiratory bins (double gating)



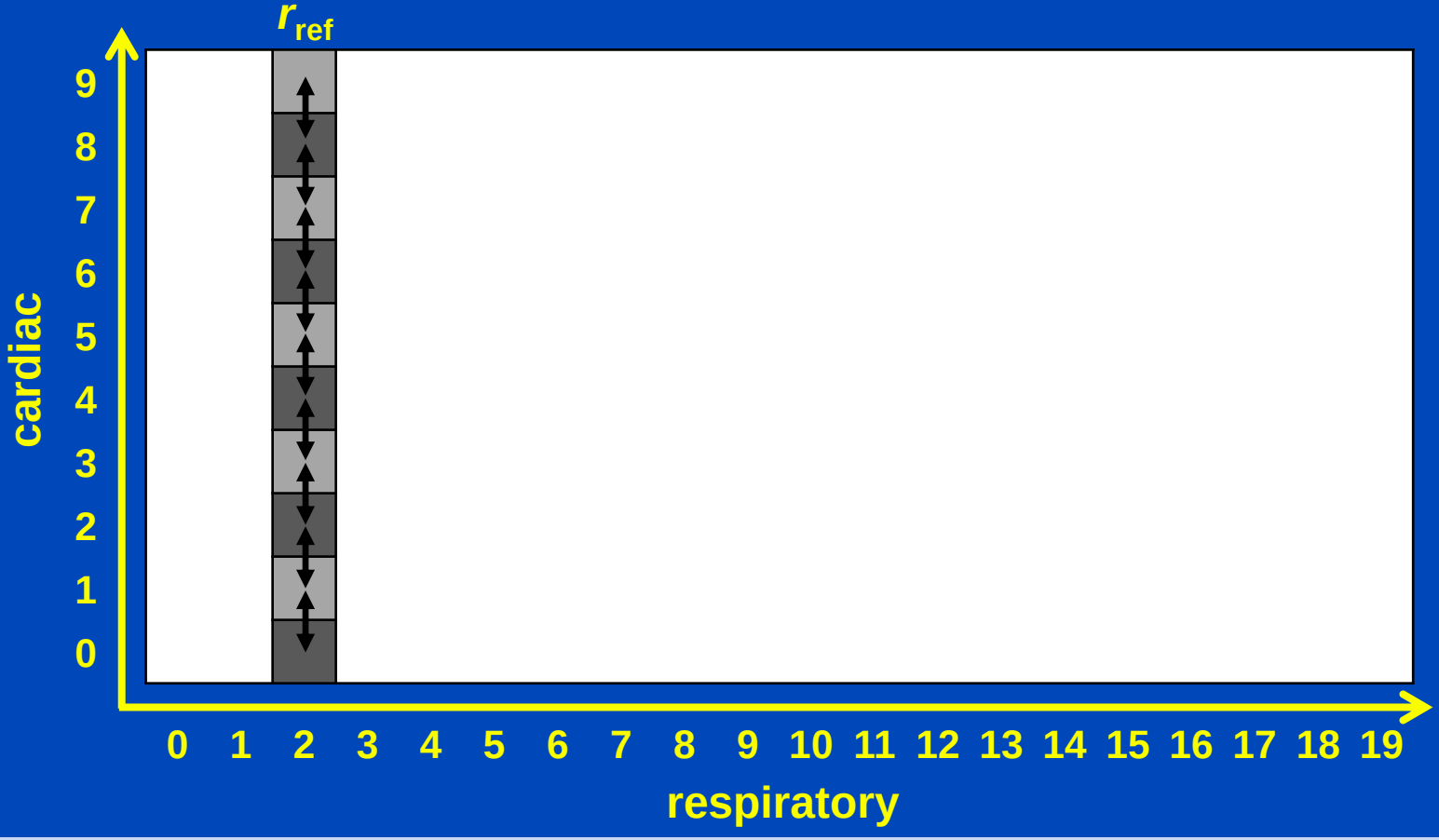
5D Motion Compensation
Respiratory Motion Estimation

- Respiratory MVFs are estimated neglecting the effect of cardiac motion



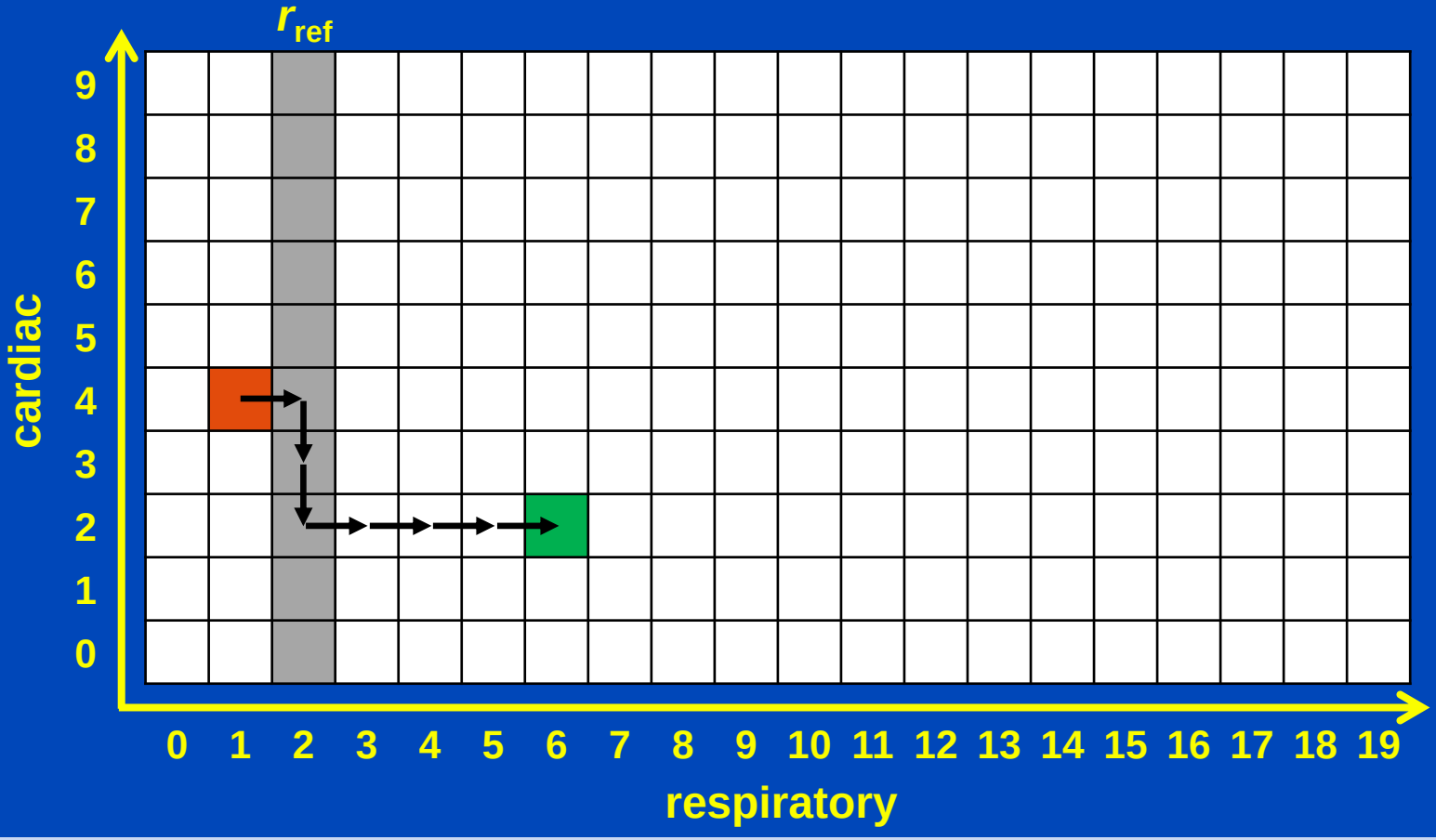
5D Motion Compensation
Cardiac Motion Estimation

- Cardiac MVFs are estimated employing respiratory motion-compensated and cardiac-gated images



5D Motion Compensation
MoCo Reconstruction

- Employing 5D double gated images, any arbitrary combination of respiratory and cardiac phase can be reconstructed



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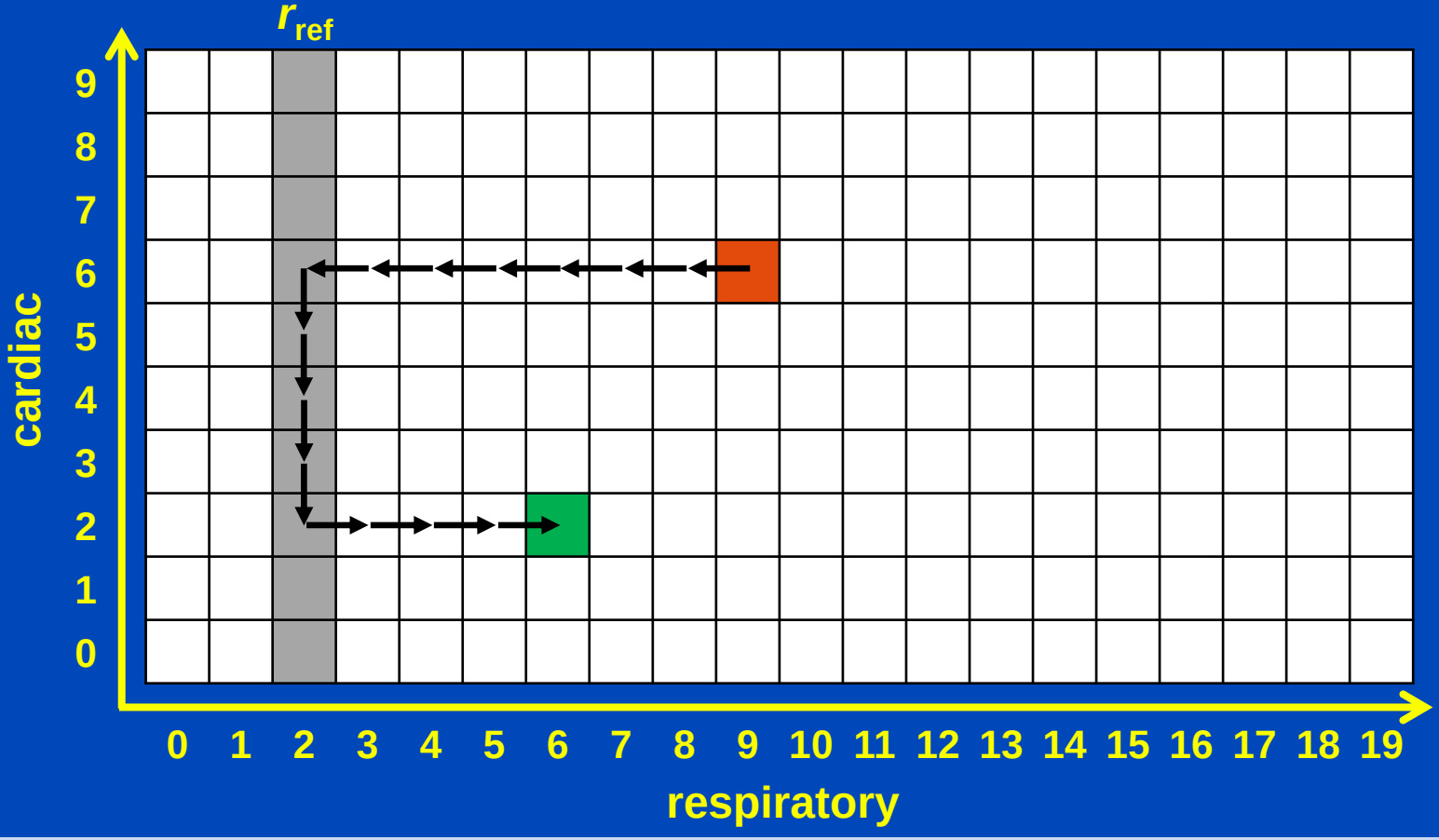

5D MoCo Results

20 respiratory phases of 10% width, 10 cardiac phases of 20% width

5D Reconstruction Respiratory & Cardiac Gated	**5D Reconstruction** Respiratory Compensated & Cardiac Gated	**5D MoCo** Respiratory & Cardiac Compensated	**5D MoCo** Respiratory & Cardiac Compensated
***r* = 0%, *c*-loop**	***r* = 0%, *c*-loop**	***r* = 0%, *c*-loop**	**r-loop, *c* = 0%**

2% dose	40% dose	100% dose	100% dose

***C* = -250 HU, *W* = 1400 HU**

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5D MoCo Results

20 respiratory phases of 10% width, 10 cardiac phases of 20% width

3D Reconstruction
Standard
3D Feldkamp

5D MoCo
Respiratory & Cardiac
Compensated
***r-loop*, *c*-loop**

3D Reconstruction
Region of interest

5D MoCo
Region of interest

Displayed with real patient motion 28 rpm and 83 bpm

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***C* = -250 HU, *W* = 1400 HU**

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Summary

- True 5D imaging in IGRT
  - Same noise level and spatial resolution as 3D CBCT
  - 100% dose usage
- Two-step motion estimation
- Method applicable for other modalities
  - E.g. C-arm systems, MR, PET-MR

- There was more on MoCo at this RSNA:
  - Rank, Kachelrieß. Respiratory MoCo for Simultaneous PET/MR. Mo, Nov 30, 3:10 PM, Room S403A
  - Hahn, Kachelrieß. MoCo from Short-Scan Data in Cardiac CT. Tue, Dec 1, 10:40 AM, Room S403B

Thank You!

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

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