Sliding Organ Motion Regularization for Motion-Compensated Cone-Beam CT (CBCT) in Image-Guided Radiation Therapy

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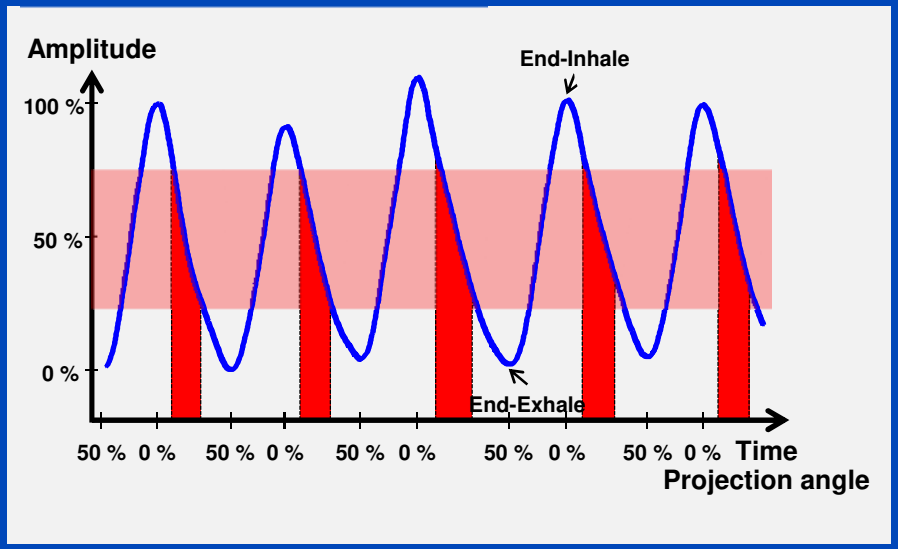
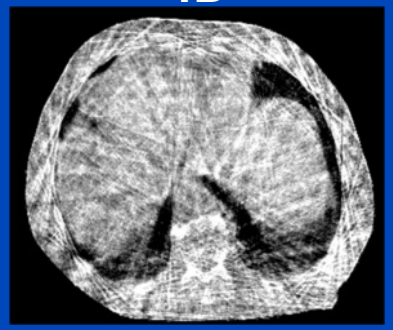
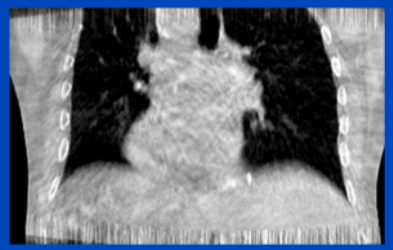
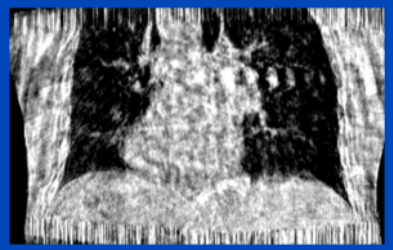
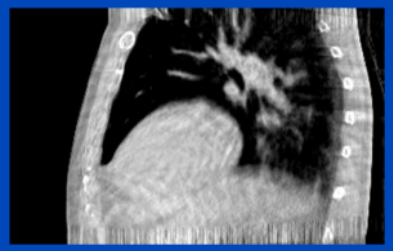
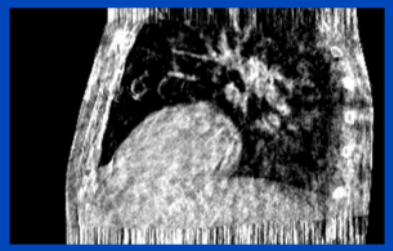
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Introduction



Conventional: Motion blurring 3D

With gating: Sparse-view artifacts 4D

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C = -100 HU, *W* = 1200 HU
Patient data provided by Wilko Verbakel, VU University Medical Center, Amsterdam.

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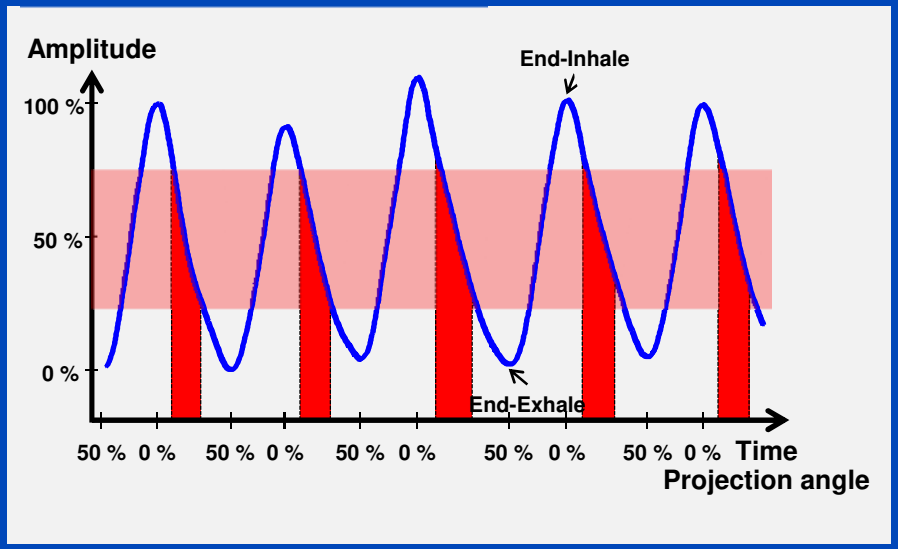
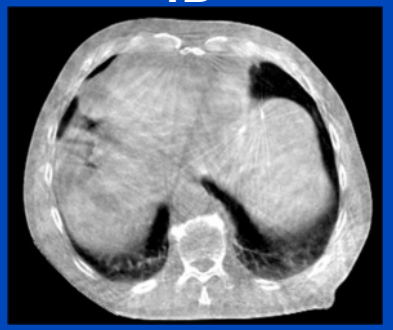
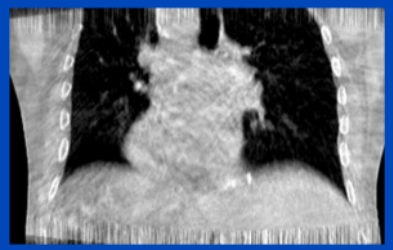
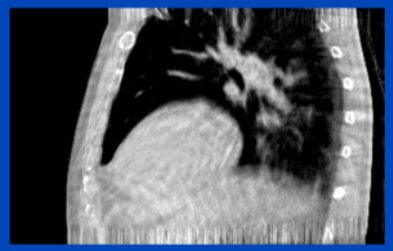
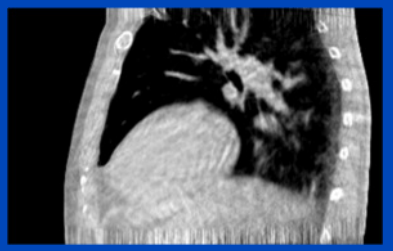


Conventional: Motion blurring 3D

acMoCo[12] PTAR[3] 4D

[1] Brehm, Paysan, Oelhafen, Kunz, and Kachelrieß, "Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy," Med. Phys. 39(12):7603-7618, 2012.

[2] Brehm, Paysan, Oelhafen, and Kachelrieß, "Artifact-resistant motion estimation with a patient-specific artifact model for motion-compensated cone-beam CT" Med. Phys. 40(10):101913, 2013.

[3] Sauppe, Kuhm, Brehm, Paysan, Seghers, Kachelrieß. Motion vector field phase-to-amplitude resampling for 4D motion-compensated cone-beam CT. Phys. Med. Biol. 63:035032, 2018.

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Patient data provided by Wilko Verbakel, VU University Medical Center, Amsterdam.

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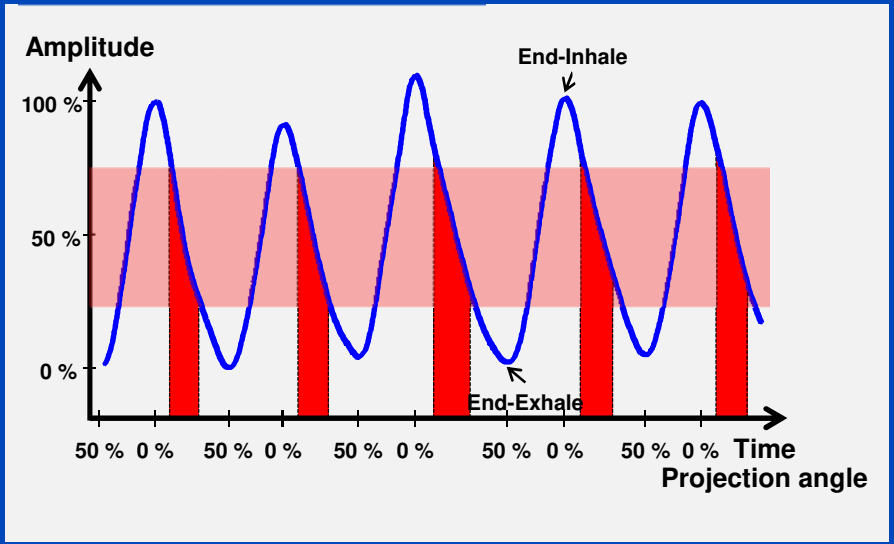
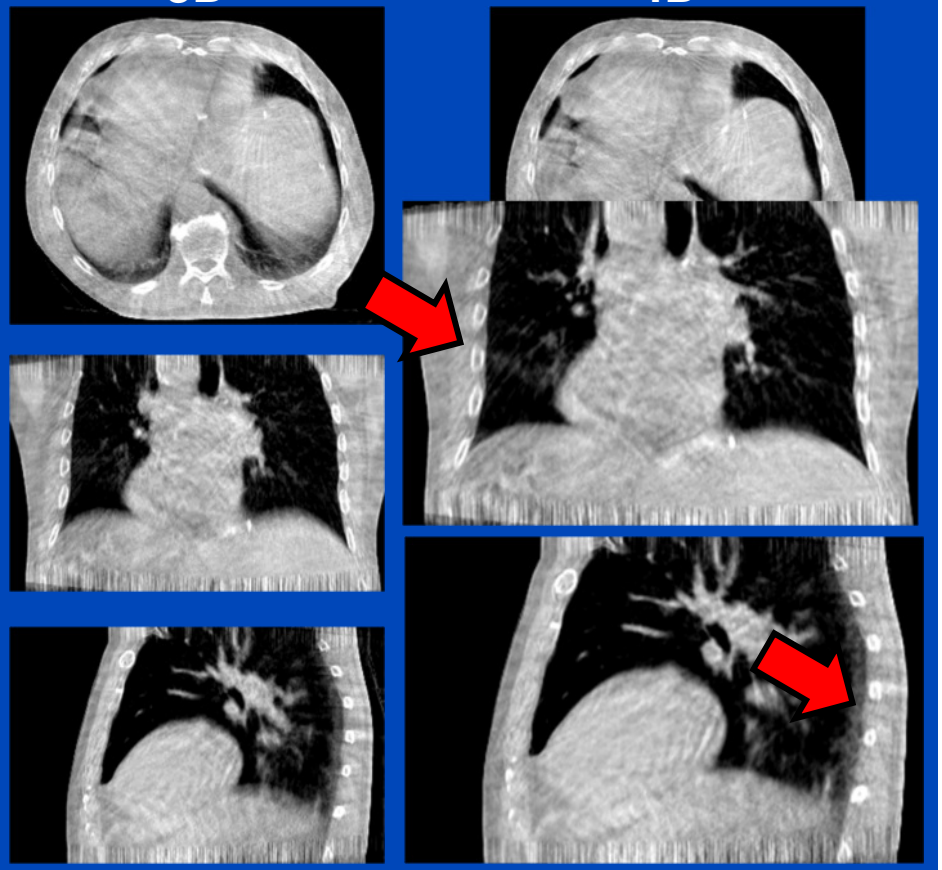


Conventional: Motion blurring 3D

acMoCo[12] PTAR[3] 4D



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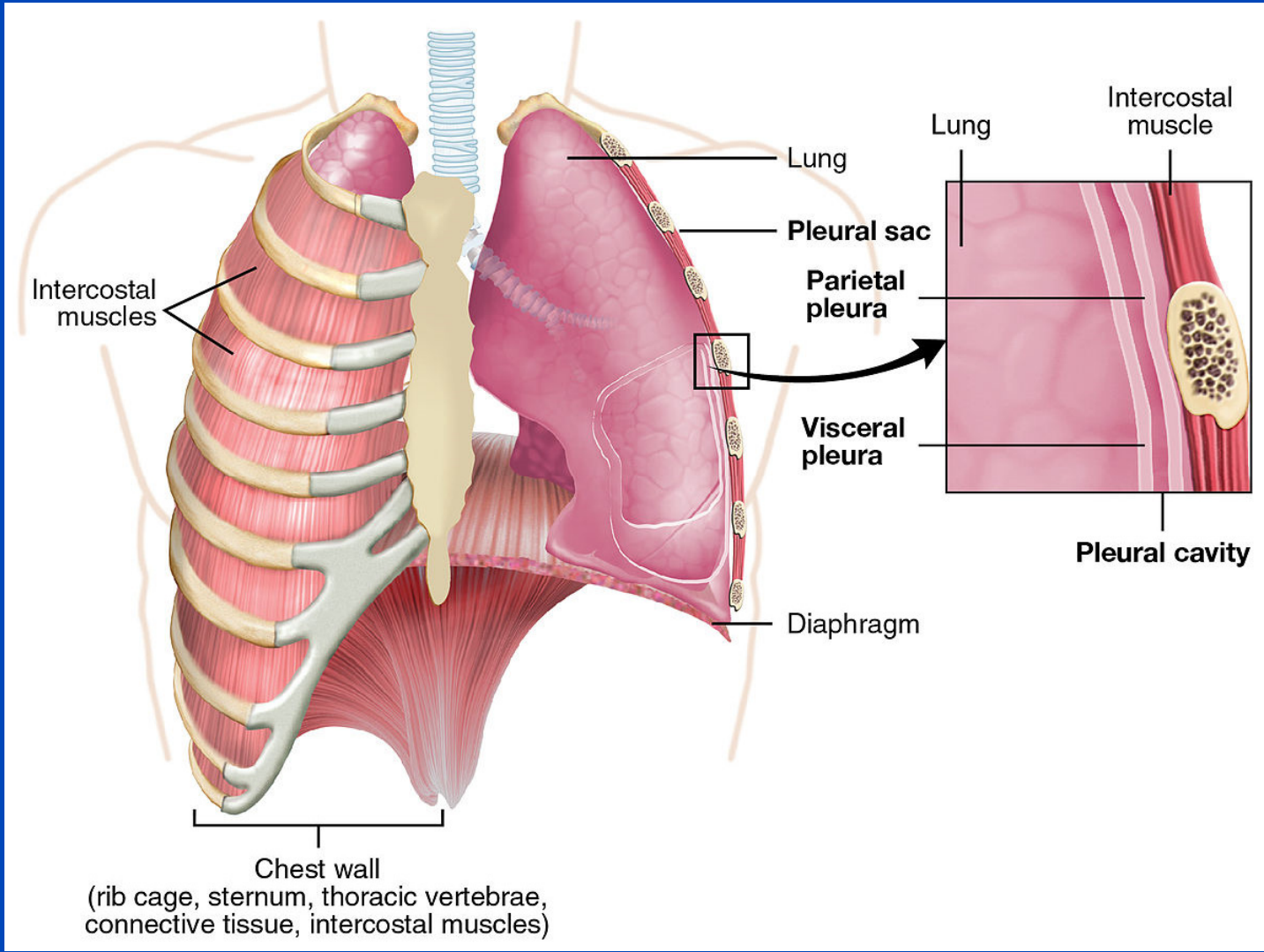
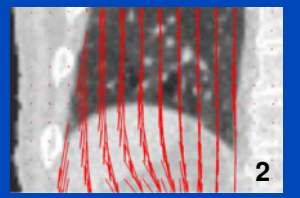
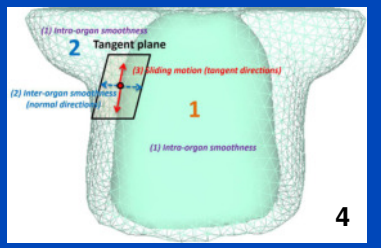


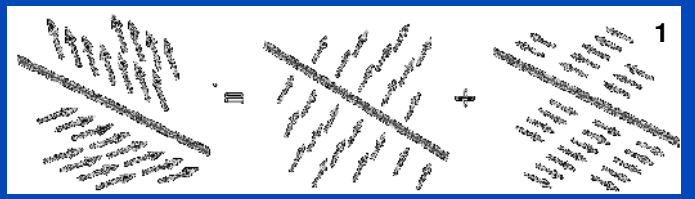
Source: Wikipedia

Prior Art on Sliding Lung Motion (SLM)

- **What has been done in the literature:**
  - Separate smoothing filters for tangential and perpendicular motion vectors[1]
  - Automated segmentation of a 3D lung border volume (motion mask) and application to patient data[2]
  - Adaptive bilateral filter smoothing[3]
  - Application to CBCT data[4]





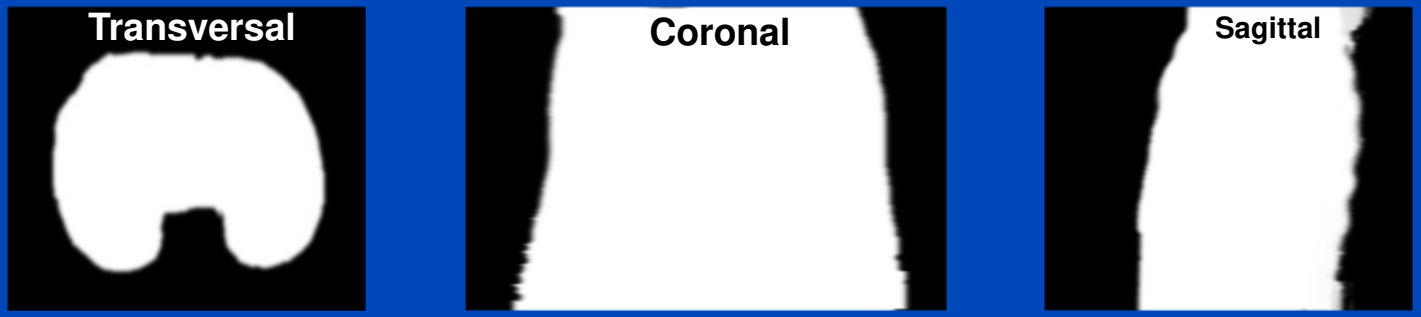


- **Our proposal:**
  - Couple a bilateral filter regularization with a MoCo algorithm.
  - Apply the SLM filter to MoCo of very sparse CBCT data.

[1] Pace et al.: Deformable Image Registration Of Sliding Organs Using Anisotropic Diffusive Regularization, *Proc IEEE Int Symp Biomed Imaging*, 2011
[2] Vandemeulebroucke et al.: Automated Segmentation Of A Motion Mask To Preserve Sliding Motion In Deformable Registration Of Thoracic CT, *Med Phys*, 2012
[3] Papiez et al.: An Implicit Sliding Motion Preserving Regularisation Via Bilateral Filtering For Deformable Image Registration, *Medical Image Analysis*, 2014
[4] Zhong et al.: 4D Cone Beam CT Reconstruction Using Multi Organ Meshes For Sliding Motion Modeling, *Physics in Medicine and Biology*, 2016

SLM Filter

- Generate a prior image representing lung and non-lung regions.
- The prior image incorporates knowledge of the organ‘s motion behaviour.



- Use the prior image to guide the MVF-regularizing filter step:

$$\mathrm{MVF}_p = \frac{1}{W} \sum_{q \in \Omega} G_{\sigma_\mathrm{e}}(p-q) \cdot G_{\sigma_\mathrm{g}}(\mathrm{PRIOR}_p - \mathrm{PRIOR}_q) \cdot \mathrm{MVF}_q$$

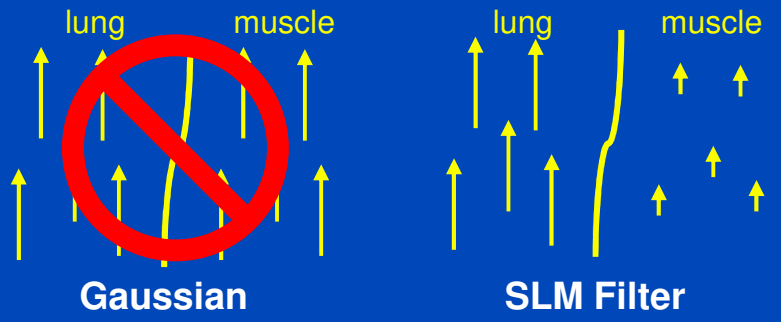
Euclidean distance

gray-value difference of prior image

Tangential vs. Perpendicular Filtering

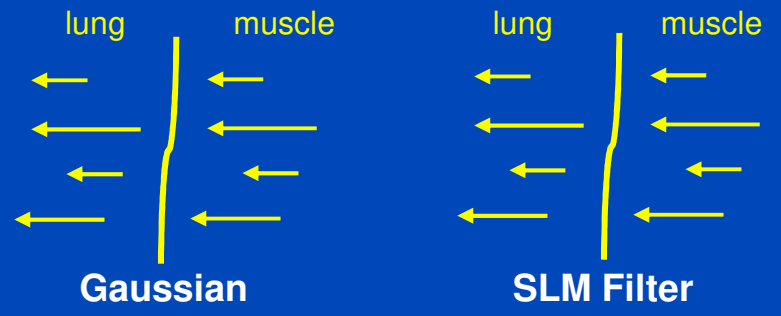
- **Tangential motion transfer at the organ border**

$$\hat{\boldsymbol{d}}_{\parallel}(\boldsymbol{\rho}) = \frac{\int dx\, dy\, dz\, G_{\sigma_e}(\boldsymbol{r},\boldsymbol{\rho}) G_{\sigma_g}(\boldsymbol{r},\boldsymbol{\rho}) \boldsymbol{d}_{\parallel}(\boldsymbol{\rho})}{\int dx\, dy\, dz\, G_{\sigma_e}(\boldsymbol{r},\boldsymbol{\rho}) G_{\sigma_g}(\boldsymbol{r},\boldsymbol{\rho})}$$



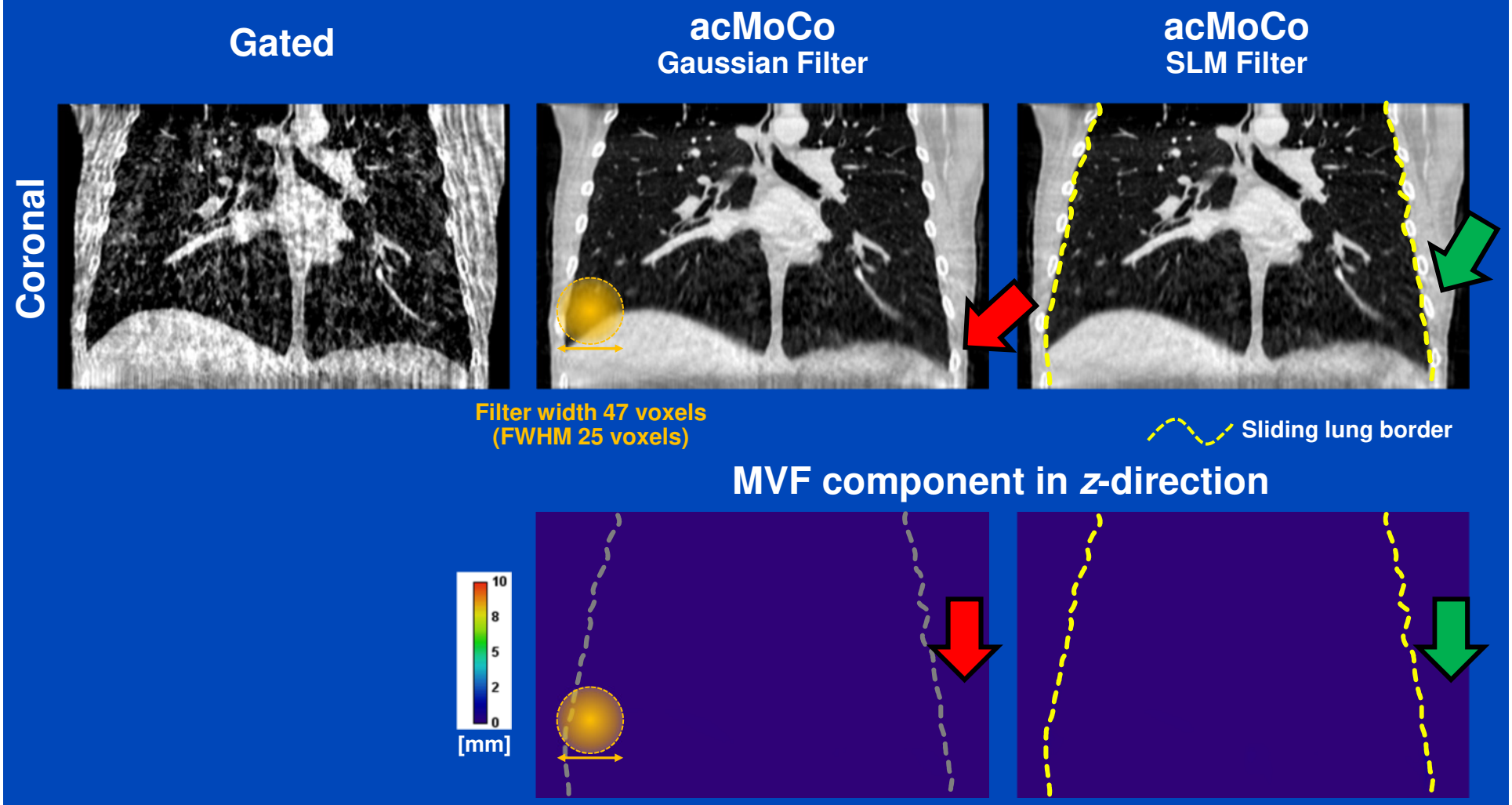
- **Perpendicular motion transfer at the organ border**

$$\hat{\boldsymbol{d}}_{\perp}(\boldsymbol{\rho}) = \frac{\int dx\, dy\, dz\, G_{\sigma_e}(\boldsymbol{r},\boldsymbol{\rho}) \boldsymbol{d}_{\perp}(\boldsymbol{\rho})}{\int dx\, dy\, dz\, G_{\sigma_e}(\boldsymbol{r},\boldsymbol{\rho})}$$



Simulated Data

Realistic Situation: Images with Streak Artifacts



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

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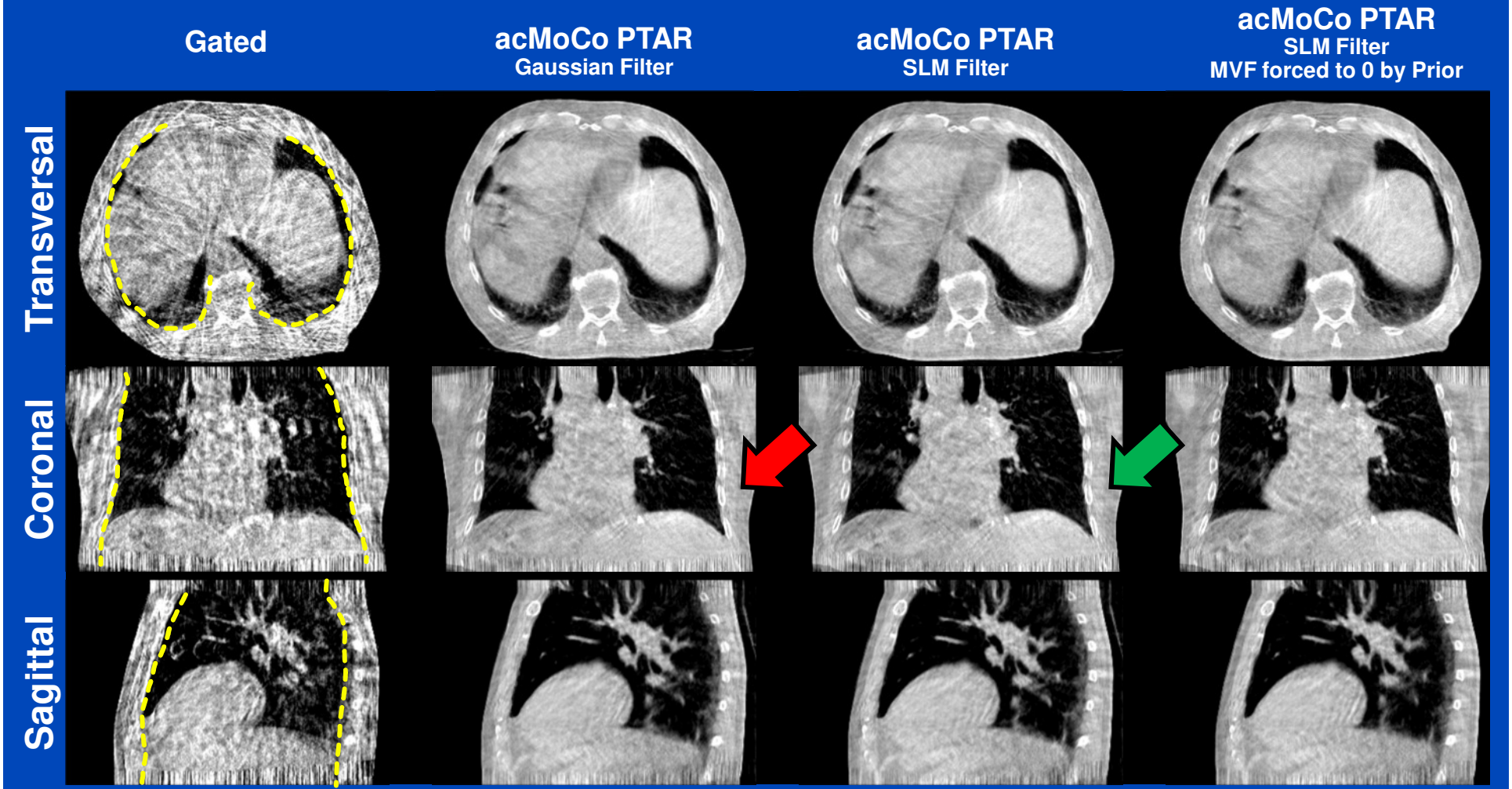
Patient Data

4D MoCo with SLM Filter for MVFs



SLM: sliding lung motion

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C = -100 HU, *W* = 1200 HU
Patient data provided by Wilko Verbakel, VU University Medical Center, Amsterdam.

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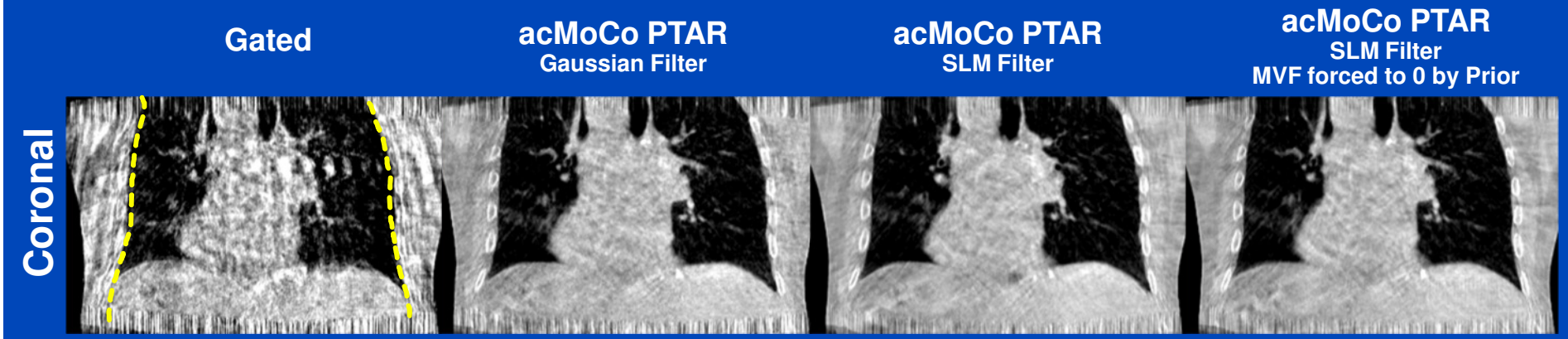
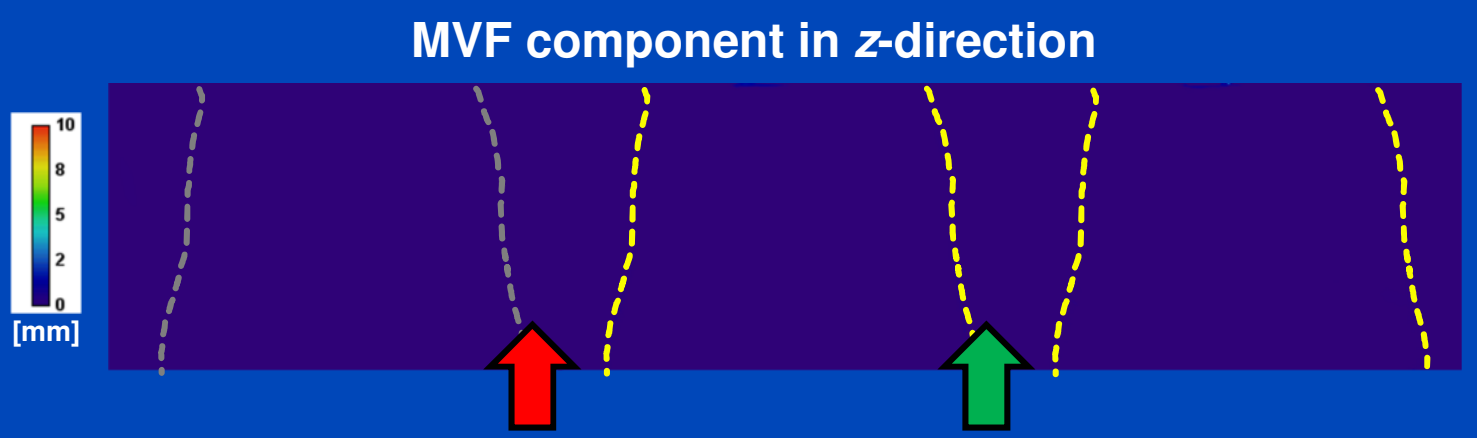
Patient Data

4D MoCo with SLM Filter for MVFs





C = -100 HU, *W* = 1200 HU

Patient data provided by Wilko Verbakel, VU University Medical Center, Amsterdam.

Conclusions

- The SLM filter allows for the suppression of non-physiological bone motion.
- Streak artifact-induced motion in potentially static regions cannot be reduced without further prior knowledge.

Thank You!

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

Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (marc.kachelriess@dkfz.de).

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