AAPM Annual Meeting 2021

Session Title: Real-time Tracking and Adaptive Radiation Therapy

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Implementation of High-Quality Motion-Compensated Simultaneous Algebraic Reconstruction Technique (mc-SART) Cone-Beam CT (CBCT) Imaging Using the 5D Model in a Prospective Patient Study

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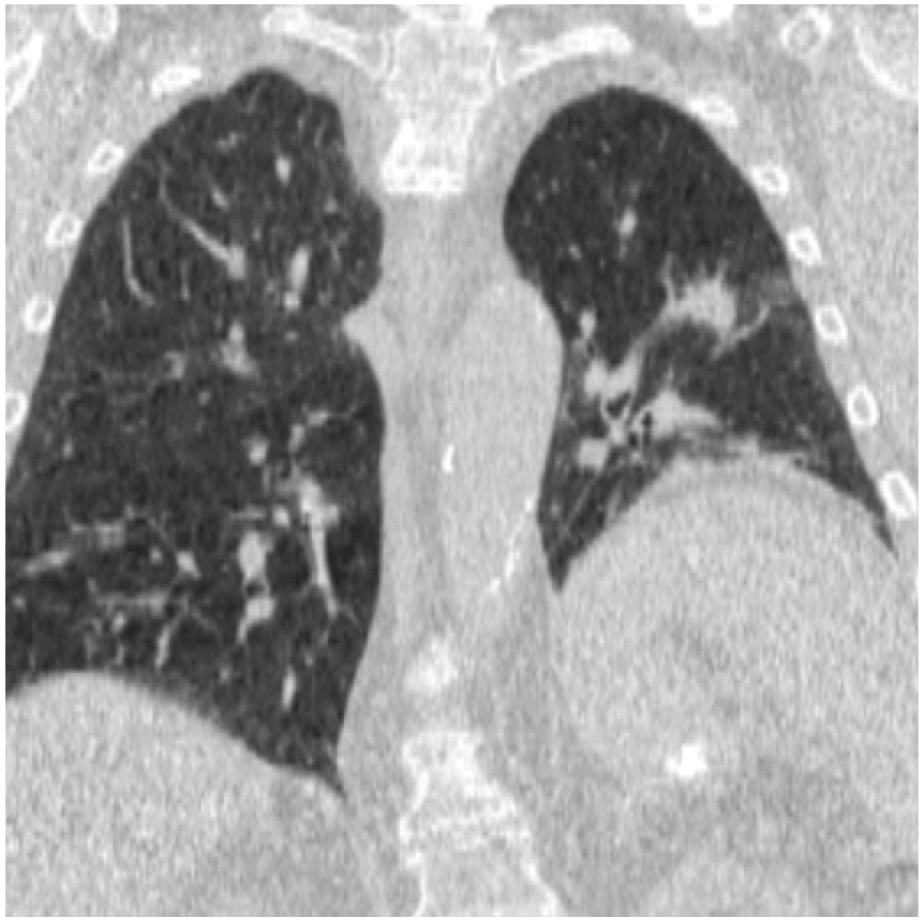
Volumetric Deformation Assessment

3DCBCT image of the lung [1]

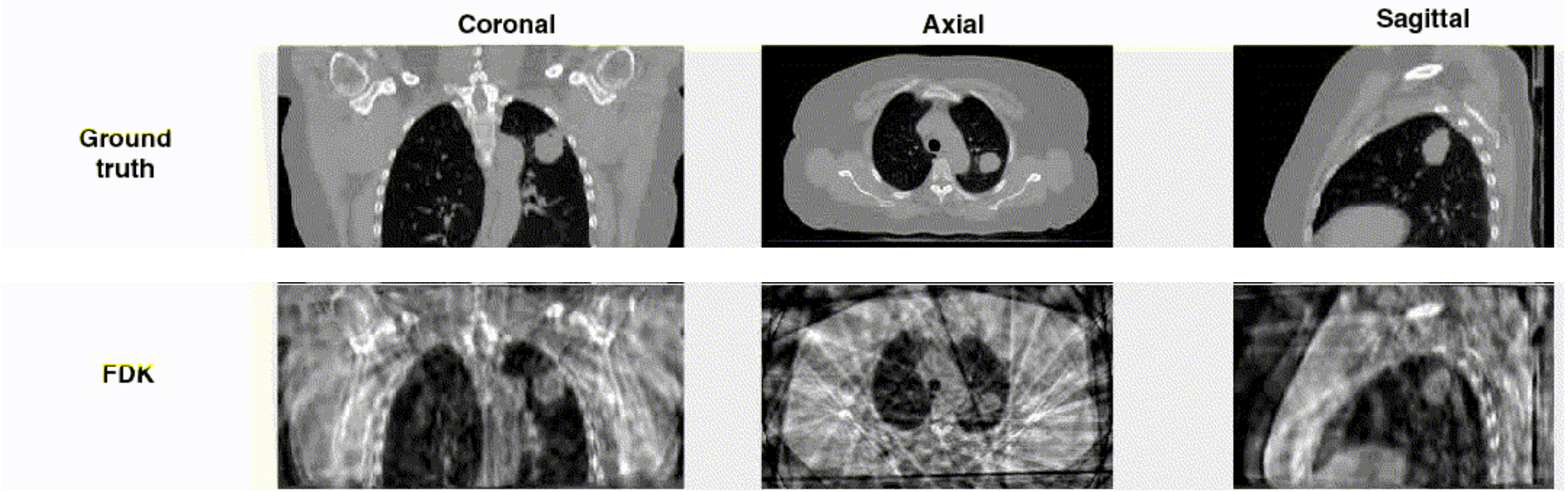


4DCBCT image of the lung [2]

[1] R. E. Kincaid, Jr., E. D. Yorke, Med Phys,2013
[2] R. Werner., C. Hoffmann et al, Radiat Oncol, 2017

Limitations of 4DCBCT

Blurring artifacts without motion compensation

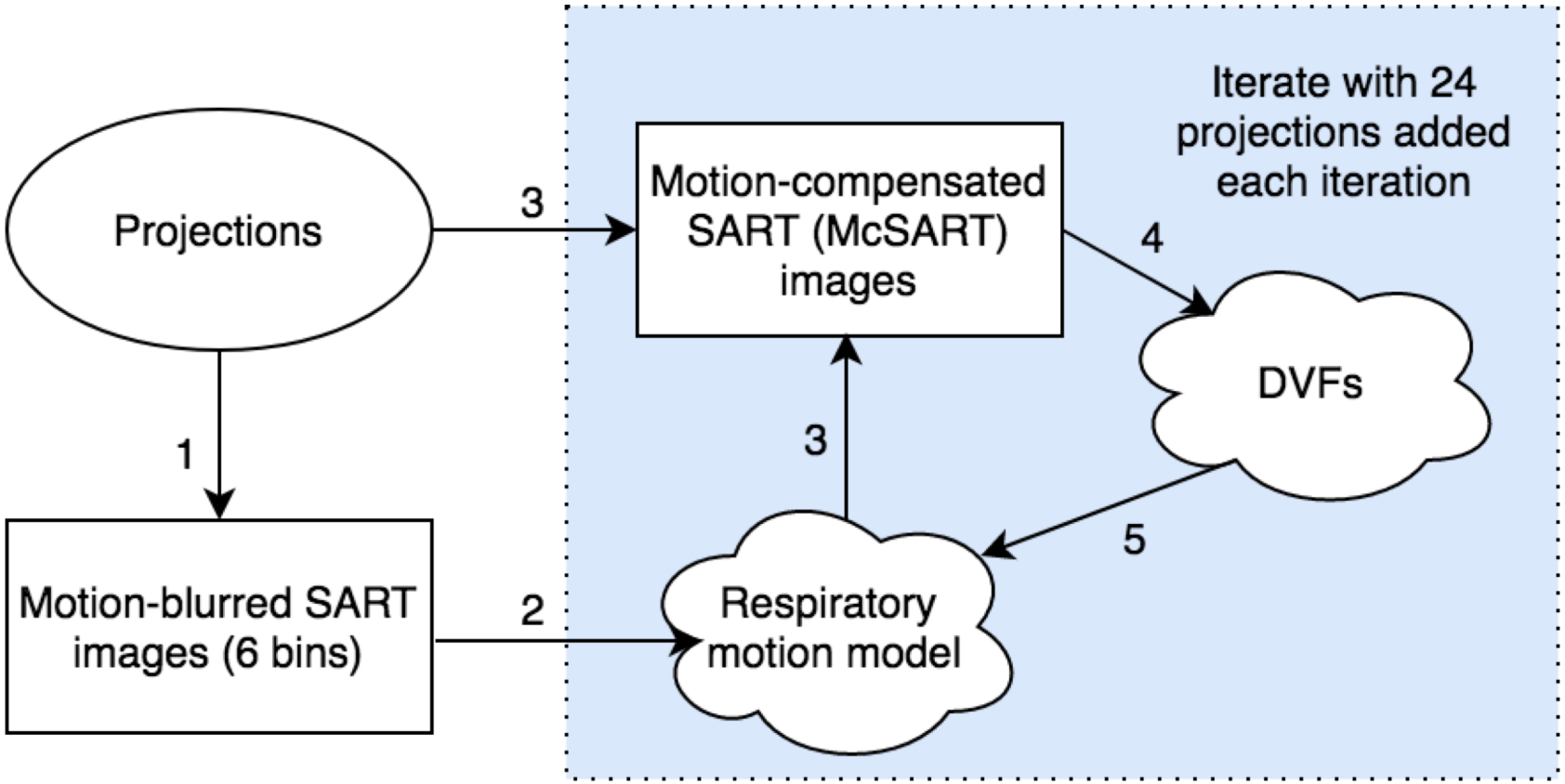


Simulated 4DCBCT image without motion compensation [1]

[1] Y. Zhang, J. Yang et al, Computerized Medical Imaging and Graphics, 2015

Motion Compensated SART (mcSART) Workflow

Proposed Method: work the model building into the reconstruction, using projection data and an external surrogate. Develop the model and image simultaneously.



Proposed mcSART workflow[1]

[1] G Chee et al, Phys Med Biol, 2019

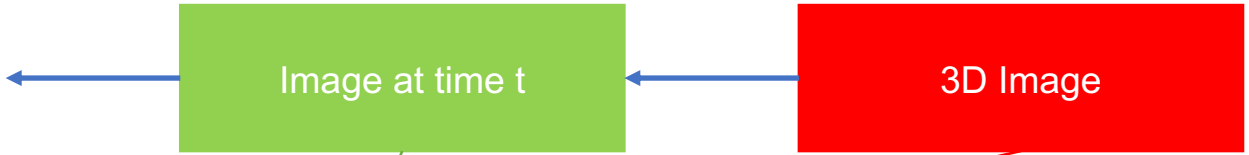
mcSART Iterative Formulation

$$f_{k+1} = f_k + \lambda \sum_t \Psi^{-t} \frac{A^T(p^t - A\Psi^t f_k)}{w^T w},$$

f_k: 3D reference image at iteration k
Ψ^t: transformer from reference image to angle t
Ψ^{-t}: inverse transformer
A, A^T: projector and backprojector

w, w^T:weighting parameters
λ: relaxation factor, set to 1

mcSART Iterative Formulation



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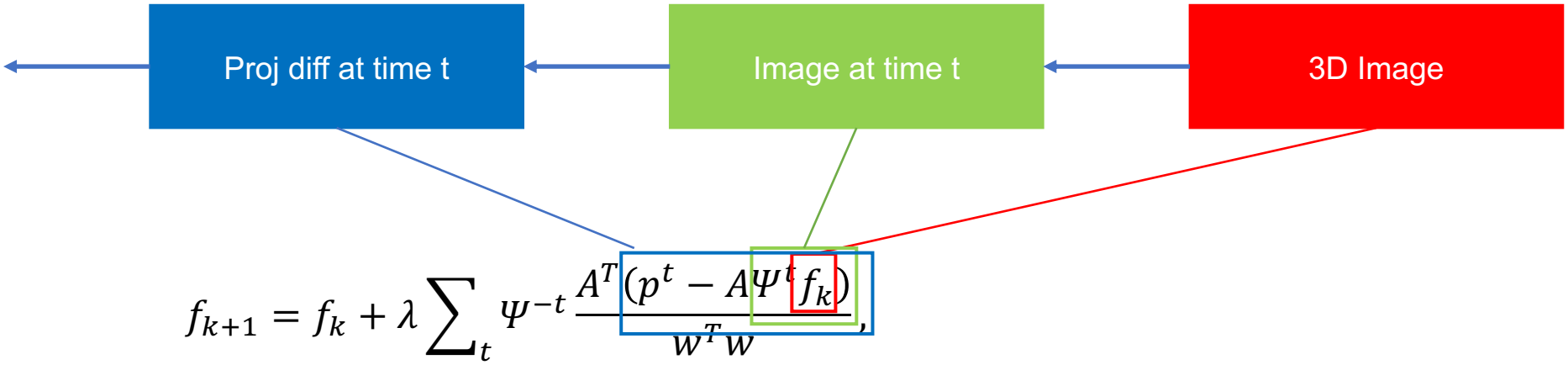

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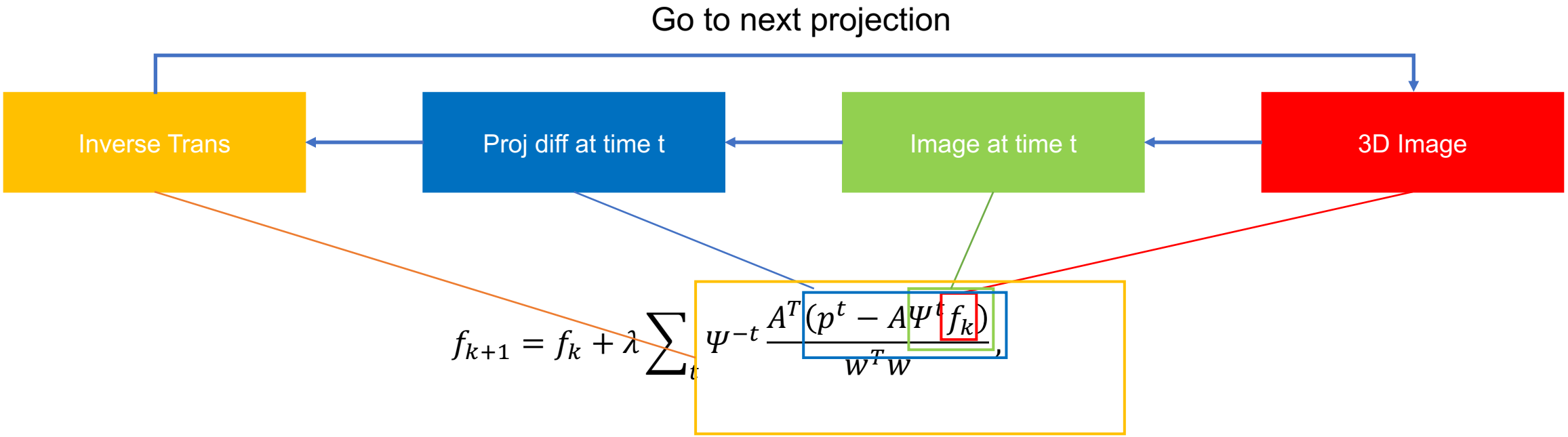
mcSART Iterative Formulation



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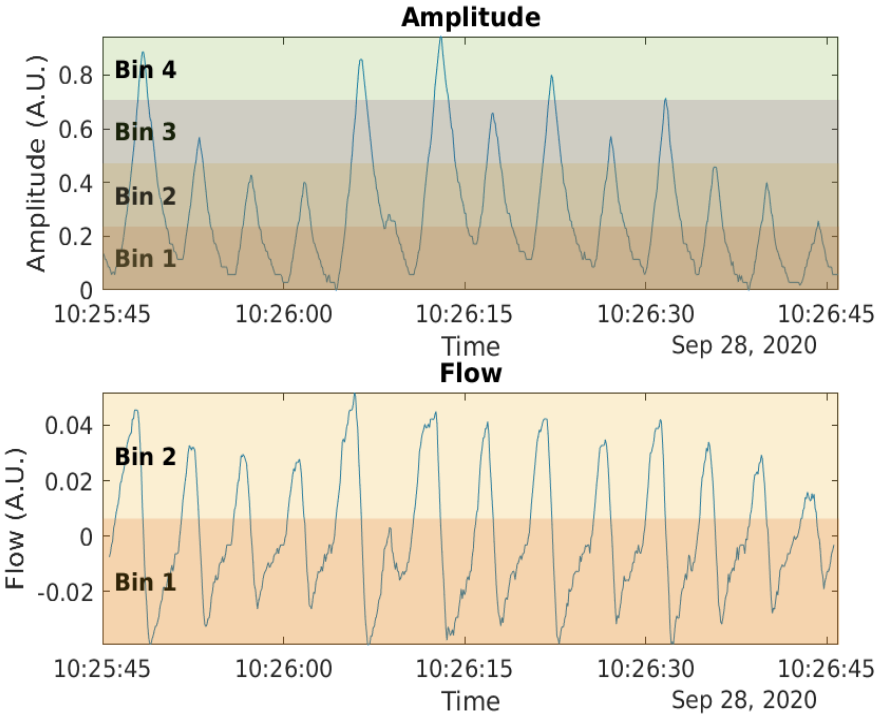
A, A^T: projector and backprojector

w, w^T:weighting parameters
λ: relaxation factor, set to 1

5D Motion Model

- Measure surrogate data during projection data acquisition
- Use deeds to deformably register each binned image set
- Obtain deformation vector field (DVF) from images
- Update motion model



5D respiratory motion model [1]

$$\text{New spatial location } \vec{X}(v, f, \vec{X}_0) = \vec{X}_0 + \vec{\alpha}(\vec{X}_0)v + \vec{\beta}\,(\vec{X}_0)f$$

$\vec{X}_0$: Spatial location in reference image

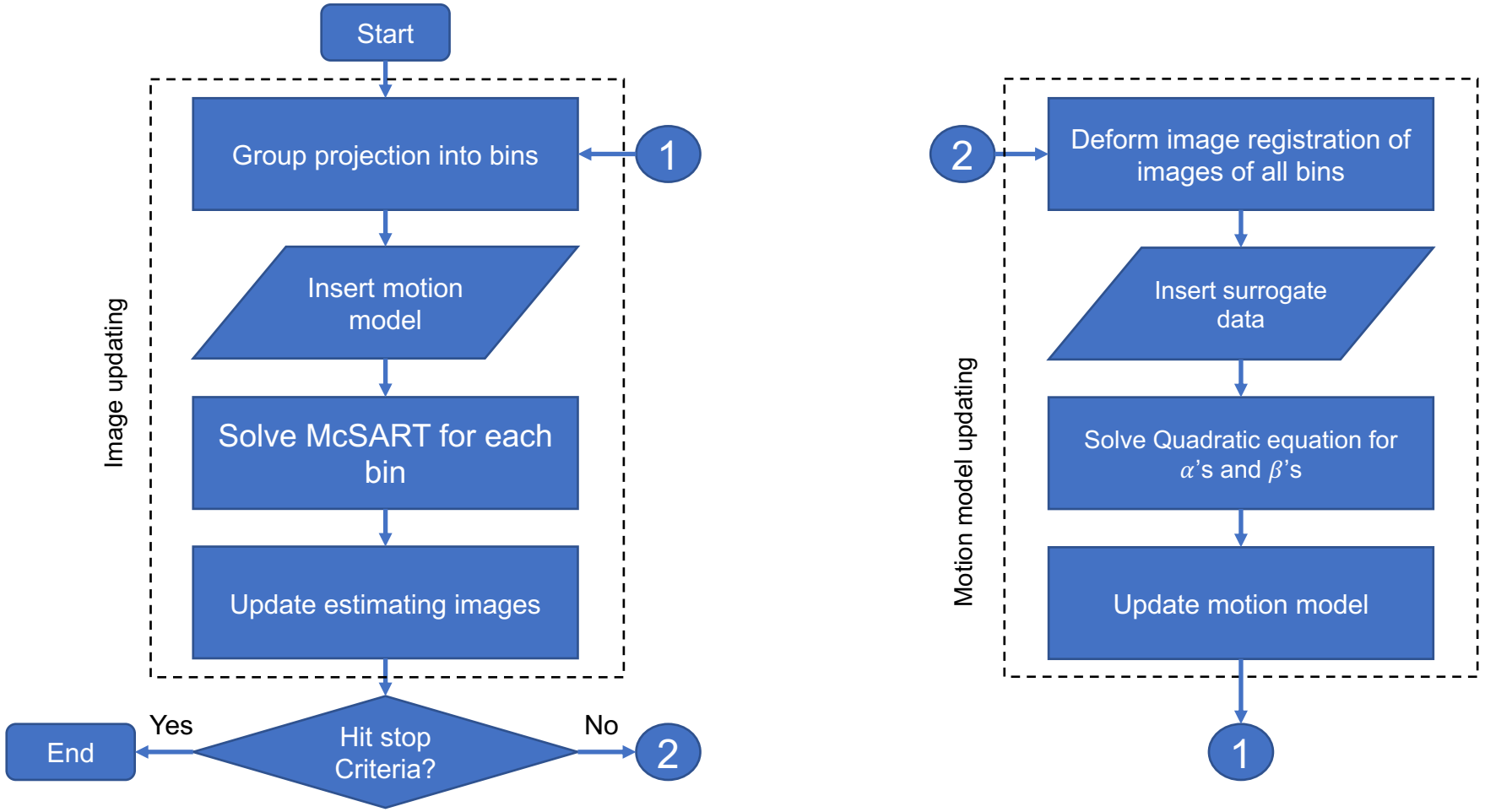
$\vec{\alpha}(\vec{X}_0)\ and\ \vec{\beta}(\vec{X}_0)$: deformation of the tissue position

v: tidal volume surrogate data

f: airflow surrogate data

[1] Zhao T, Lu W, et al, Med Phys, 2009

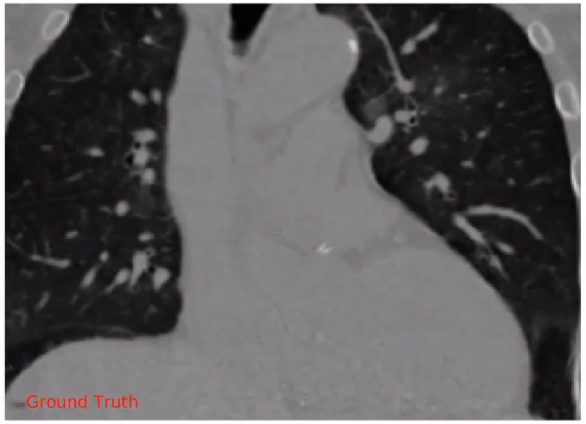
Iterating mcSART



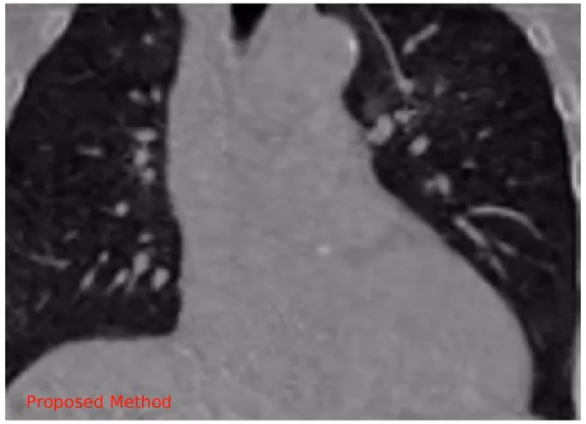
Progress on mcSART

mcSART simulations using XCAT phantom

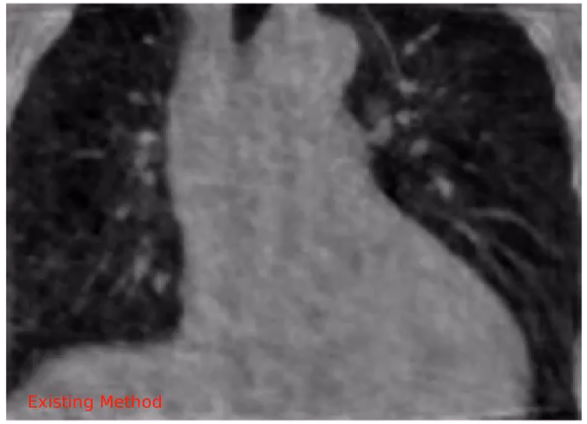
Ground Truth

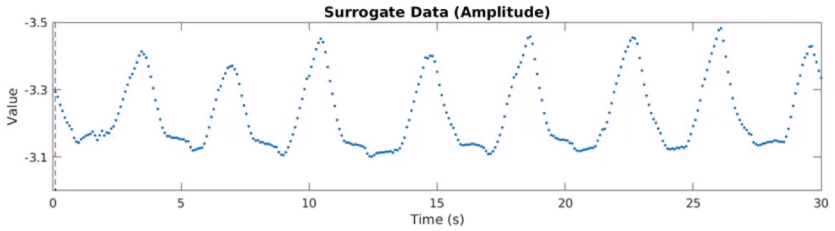


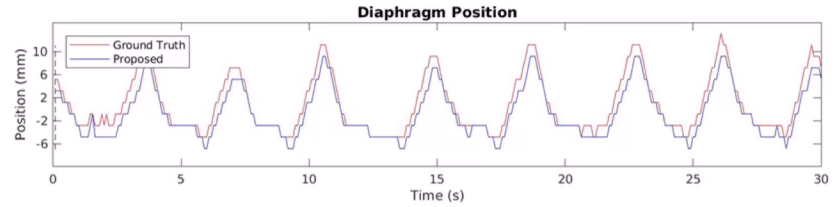
mcSART

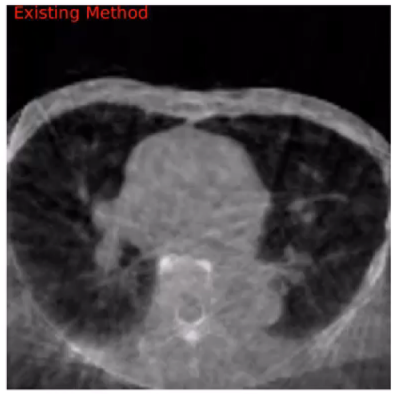


4D SART



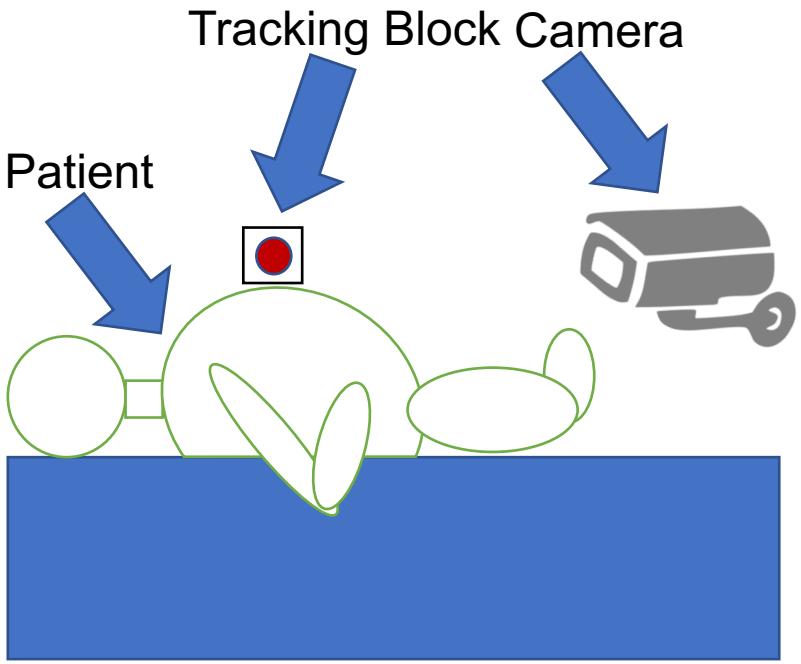


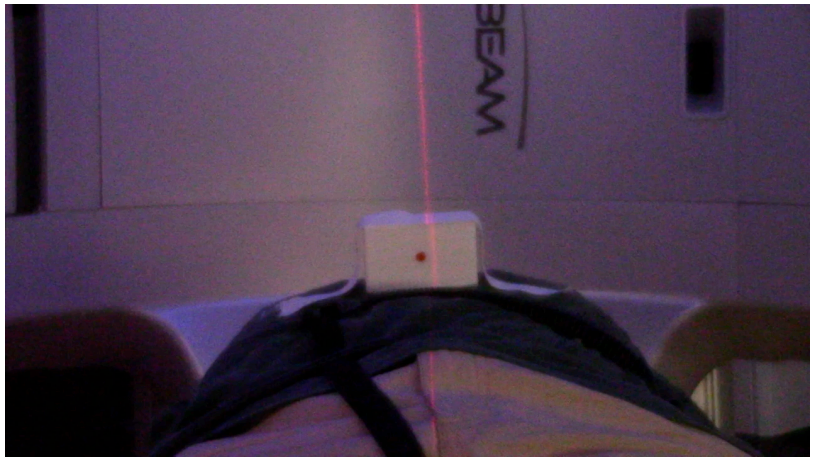


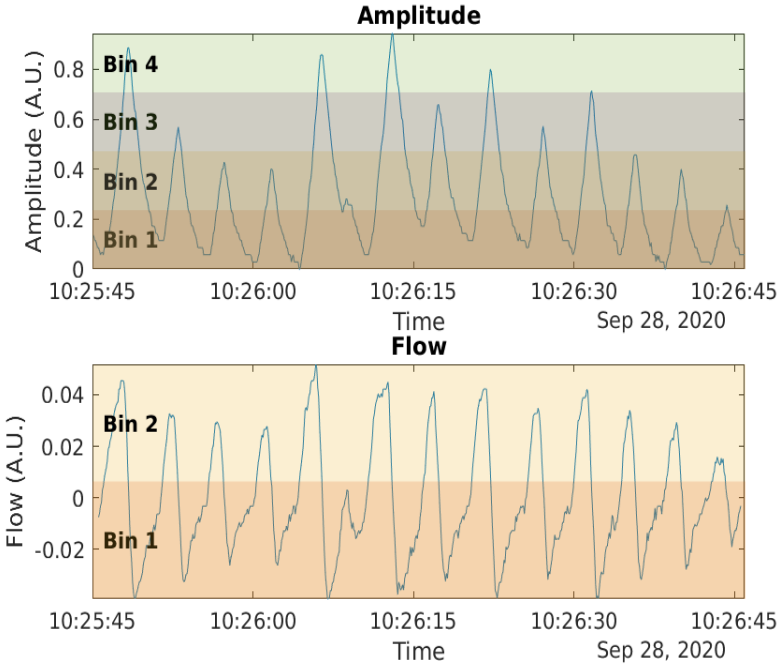


Adapting Workflow for Prospective Patient Data

Need good breathing trace which captures patient drift

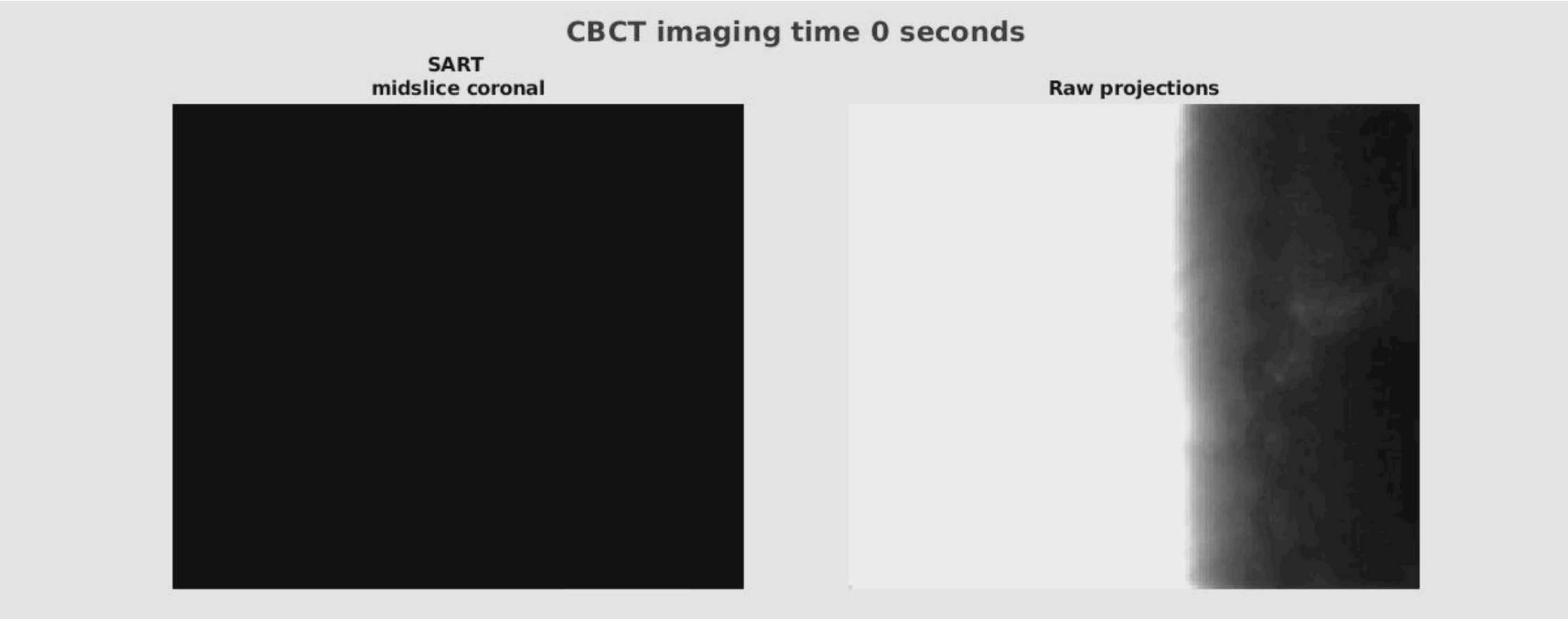






Adapting Workflow for Prospective Patient Data

Need to adapt framework for half fan projections



Implementation of mcSART

MATLAB

Higher level scripting/processes

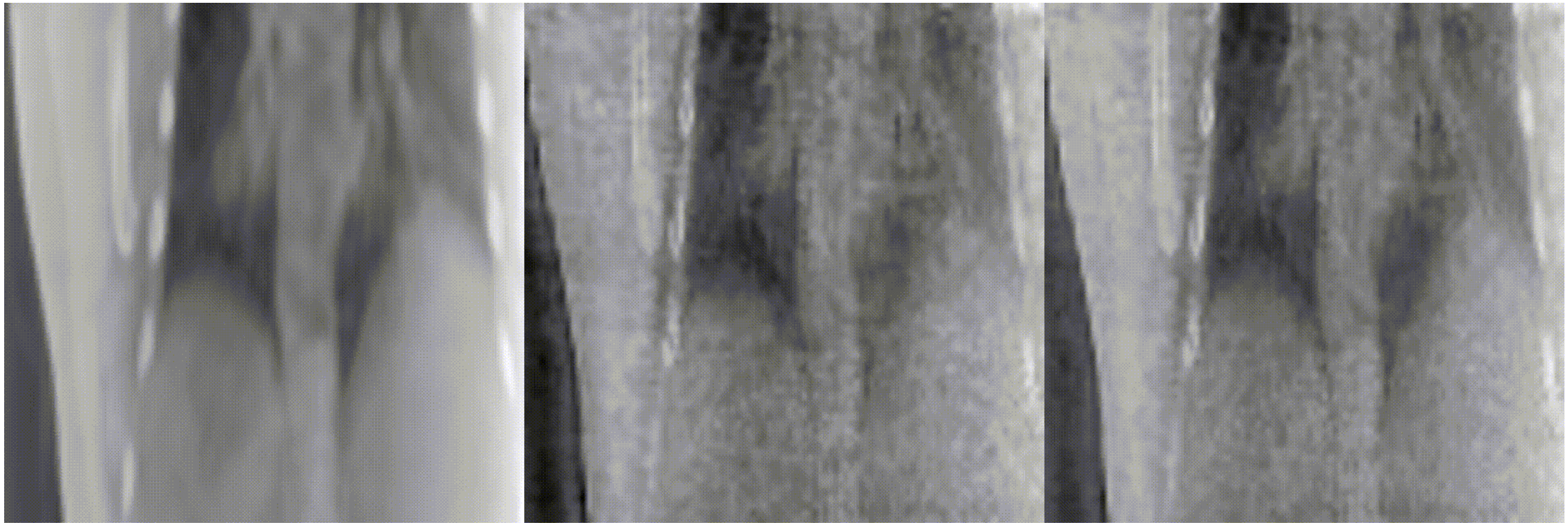
ITK/RTK

Forward/back projectors, SART/FDK reconstruction tools etc.

Sample Reconstructions

Test patient – Lung cancer, pre-treatment imaging on Novalis Tx

3D FDK | 4D SART | mcSART



Tissue SNR Evaluation

4 patients – Lung cancer, pre-treatment imaging on Novalis Tx

Mean Lung SNR					
Method	Patient 1	Patient 2	Patient 3	Patient 4	**Global**
FDK	3.5	3.3	3.4	3.2	**3.4**
4D-SART	3.2	5.2	1.3	2.1	**3**
mcSART	5.1	3.9	5.2	3	**4.3**
Mean Soft Tissue SNR					
Method	Patient 1	Patient 2	Patient 3	Patient 4	**Global**
FDK	5.8	6.7	3.8	3.8	**5**
4D-SART	6.2	11.6	12.7	10.4	**10.2**
mcSART	13.2	11.1	8.6	19.1	**13**

The soft tissue and lung SNR measurements for mcSART images were

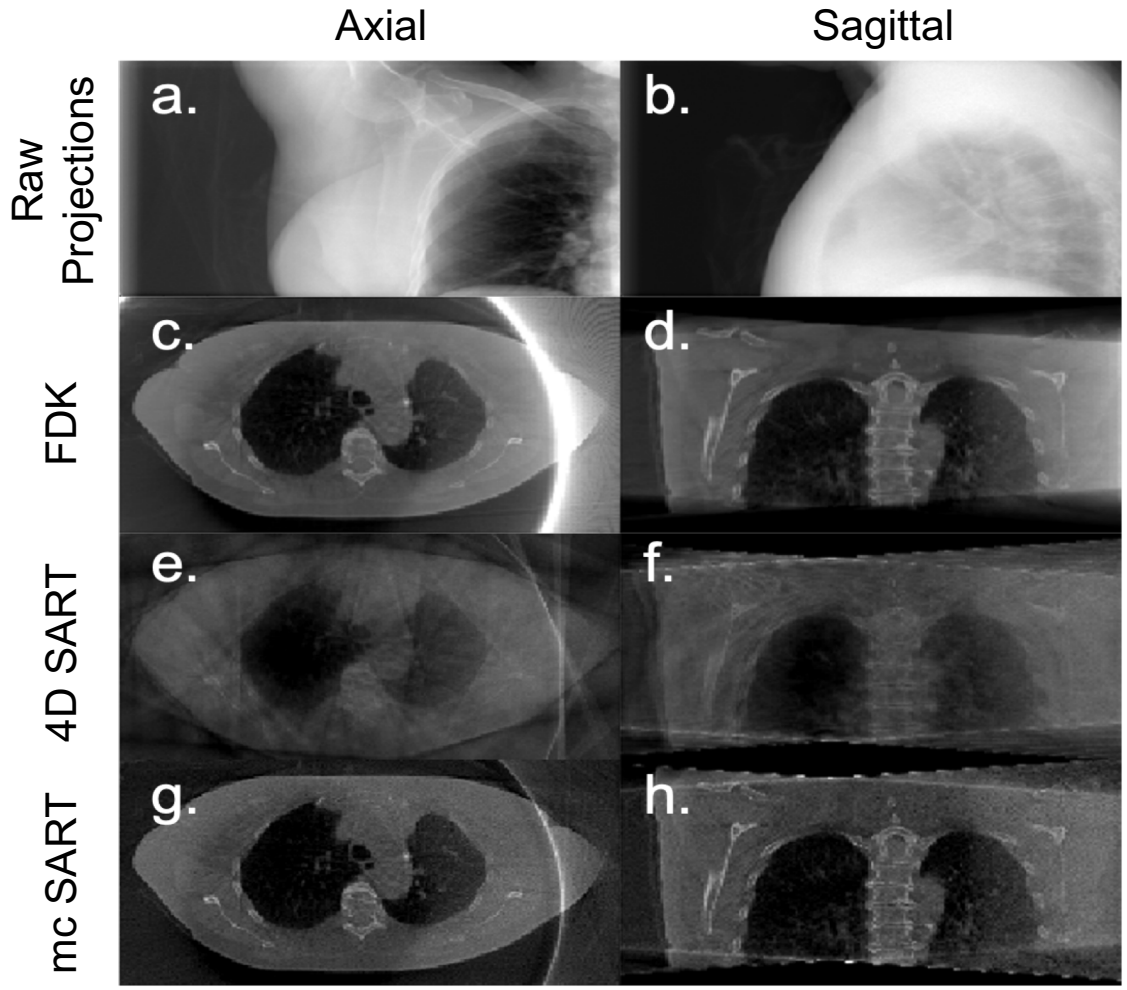
- 160% and 28% greater than FDK-reconstructed image
- 26% and 43% greater than 4D-SART reconstructed images.

Conclusions and Future Work

Conclusions: We have developed a method to create a high-quality motion-compensated reference image and motion model with real patient data using mcSART.

Next Steps:

- Evaluate image quality metrics in larger cohort of patients.
- Test reconstruction of abdominal mcSART CBCT images.
- Quantitatively compare ITV volumes from 5DCT simulation to 5D mcSART.



Thank you.

Acknowledgements

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