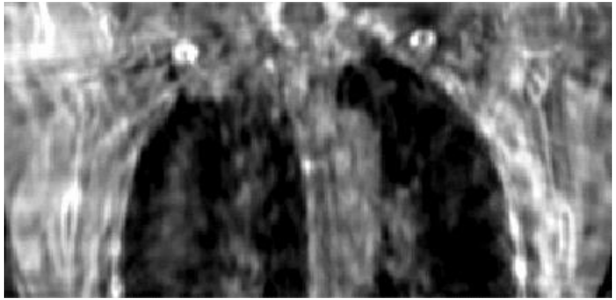
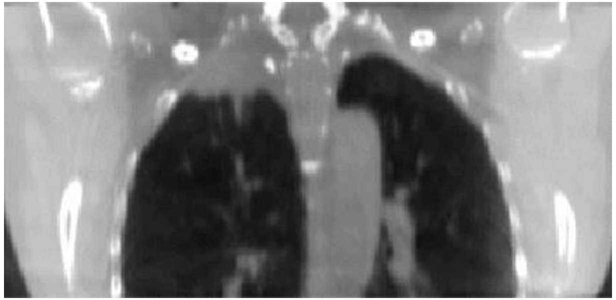
AAPM Grand Challenge: SPARE

Sparse-view Reconstruction Challenge for 4D Cone-beam CT

Chun-Chien Shieh

Xun Jia, Bin Li, Yesenia Gonzalez, Simon Rit, Paul Keall





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AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

AUSTRALIAN CANCER RESEARCH FOUNDATION

ACRF IMAGE X INSTITUTE

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By the end of this talk

- Aim of the SPARE challenge
- How the challenge datasets were generated
- How image quality was quantified
- The top 4 performing teams
- Access to the full datasets

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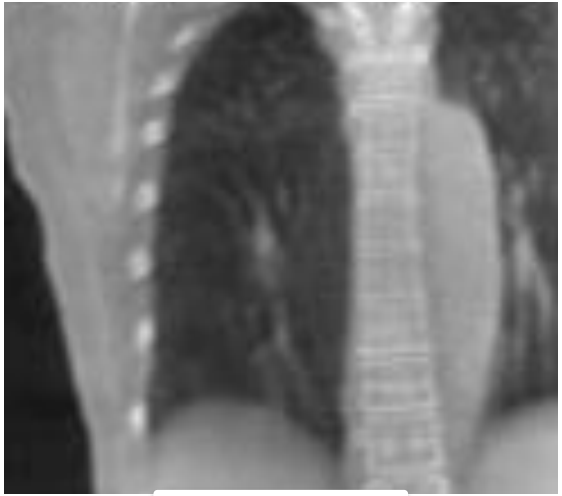
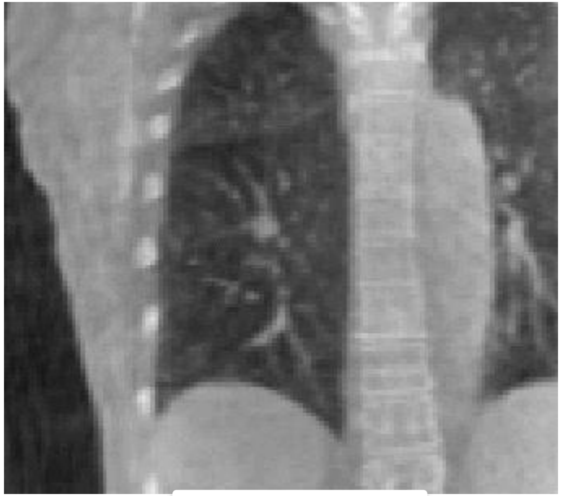
4D cone-beam CT



3D-CBCT

- 1 minute scan
- Motion blur



4D-CBCT

- 2-4 minutes
- Undersampling artifacts

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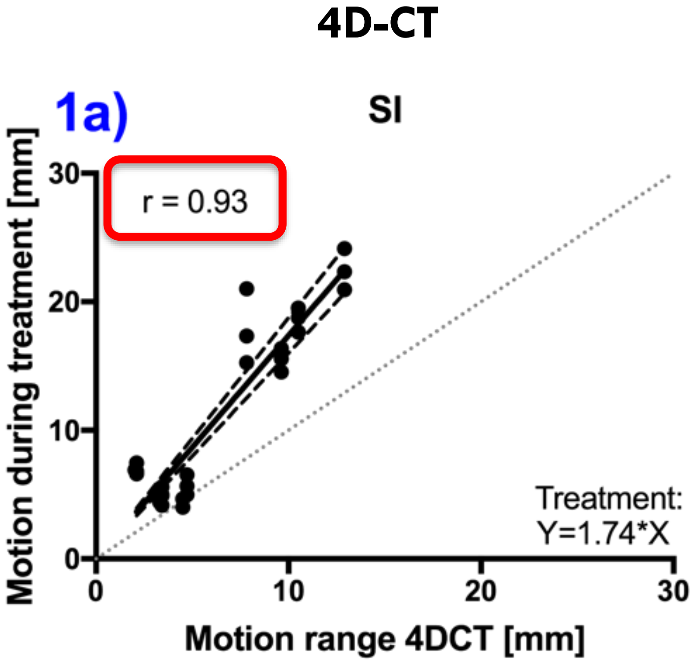
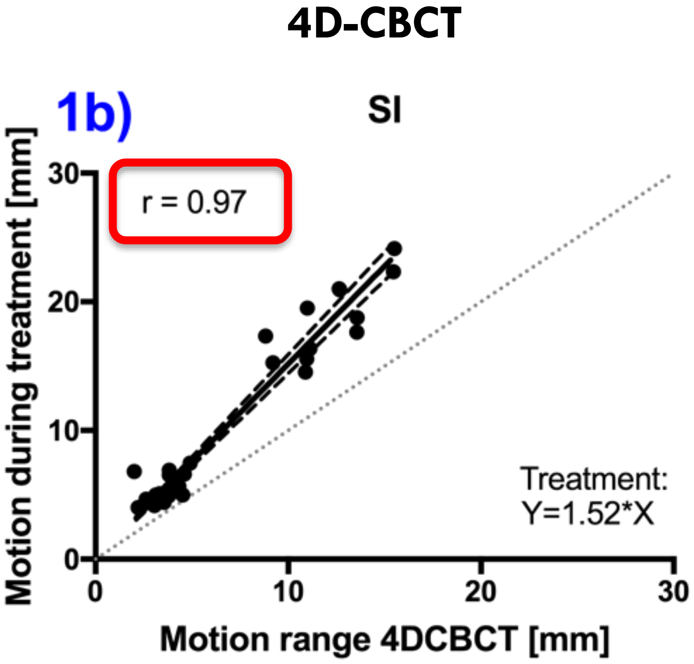
4D-CBCT better predicts intrafraction motion range than 4DCT





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Steiner et al., WE-HI-KDBRB1-10, 1:45-3:45 pm

4DCBCT-based model for intrafraction motion monitoring

IOP Publishing | Institute of Physics and Engineering in Medicine Physics in Medicine & Biology

Phys. Med. Biol. 60 (2015) 3807–3824 doi:10.1088/0031-9155/60/9/3807

3D fluoroscopic image estimation using patient-specific 4DCBCT-based motion models

S Dhou[1], M Hurwitz[1], P Mishra[2], W Cai[1], J Rottmann[1], R Li[3], C Williams[1], M Wagar[1], R Berbeco[1], D Ionascu[4] and J H Lewis[1]

[1] Department of Radiation Oncology, Brigham and Women's Hospital, Dana-Farber Cancer Institute, and Harvard Medical School, Boston, MA, USA
[2] Varian Medical Systems, Palo Alto, CA, USA
[3] Department of Radiation Oncology, Stanford University, Stanford, CA, USA
[4] Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, MI, USA

IOP Publishing | Institute of Physics and Engineering in Medicine Physics in Medicine & Biology

Phys. Med. Biol. 62 (2017) 3065–3080 https://doi.org/10.1088/1361-6560/aa6393

A Bayesian approach for three-dimensional markerless tumor tracking using kV imaging during lung radiotherapy

Chun-Chien Shieh[1], Vincent Caillet[1,2], Michelle Dunbar[1], Paul J Keall[1], Jeremy T Booth[2,3], Nicholas Hardcastle[2,4], Carol Haddad[2], Thomas Eade[1,2] and Ilana Feain[1]

[1] Sydney Medical School, The University of Sydney, NSW 2006, Australia
[2] Northern Sydney Cancer Centre, Royal North Shore Hospital, NSW 2065, Australia
[3] School of Physics, The University of Sydney, NSW 2006, Australia
[4] Centre for Medical Radiation Physics, University of Wollongong, NSW 2522, Australia

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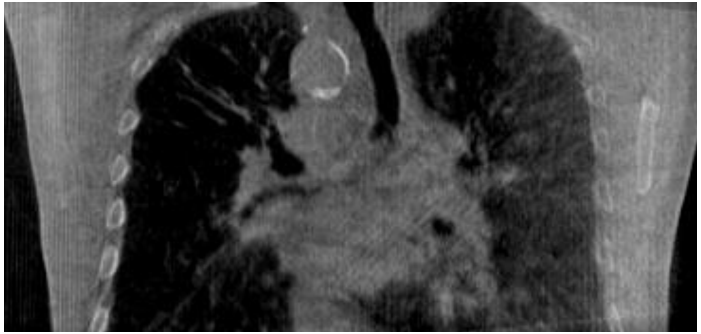
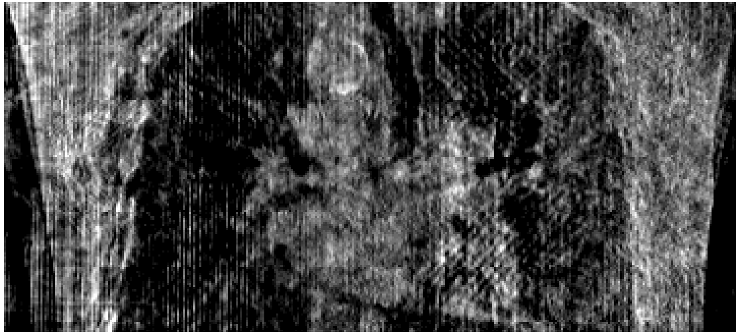
High quality 4D-CBCT from a standard one-minute scan?

- Shorter scan time
- Lower dose
- High quality 4D-CBCT on every system

Standard 3D reconstruction



Conventional 4D reconstruction



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Algorithms for reconstructing undersampled 4D-CBCT data

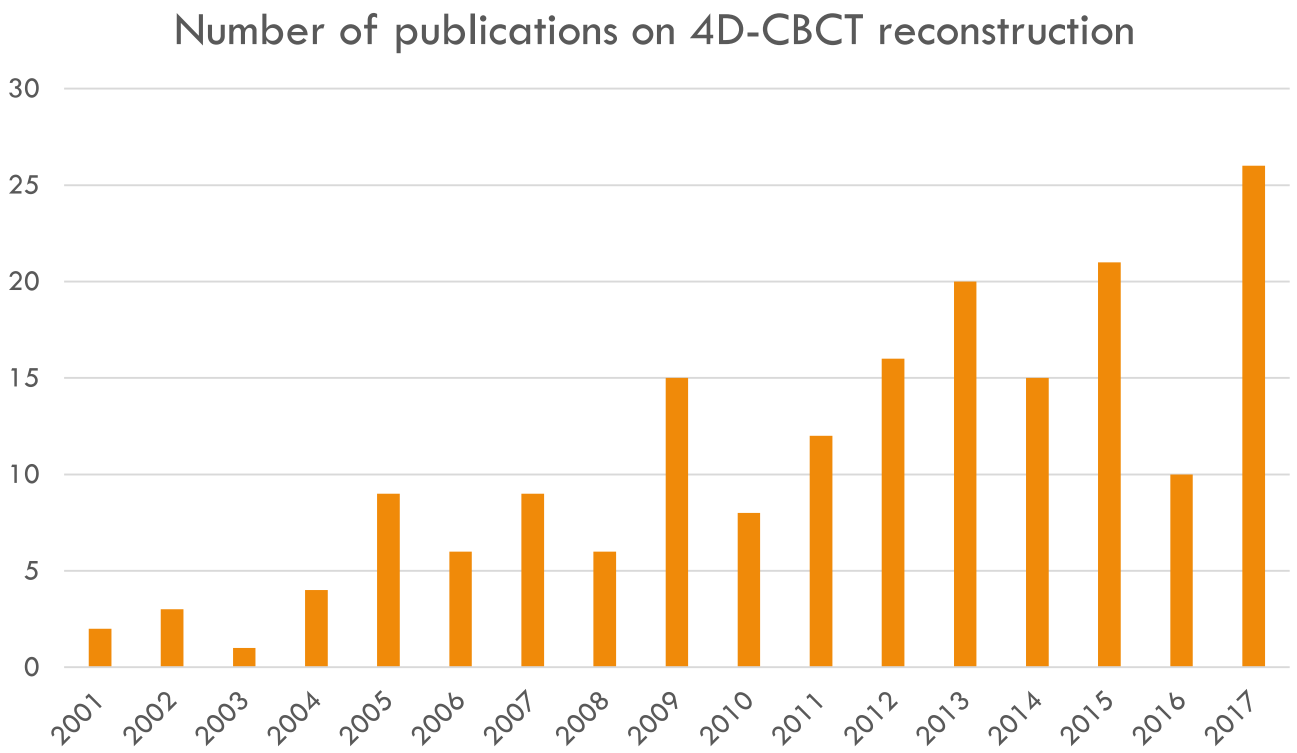

IMAGE X INSTITUTE

Algorithms for reconstructing undersampled 4D-CBCT data

- Iterative
  - Total-variation
  - PICCS
- Motion compensation
  - Projection space
  - Image space
- Prior deformed
- Hybrid

Image reconstruction in circular cone-beam computed tomography by constrained, total-variation minimization

Emil Y Sidky and Xiaochuan Pan

High temporal resolution and streak-free four-dimensional cone-beam computed tomography

Shuai Leng[1], Jie Tang[1], Joseph Zambelli[1], Brian Nett[1], Ranjini Tolakanahalli[3] and Guang-Hong Chen[1,2,3,4]

On-the-fly motion-compensated cone-beam CT using an *a priori* model of the respiratory motion

Simon Rit, Jochem W. H. Wolthaus, Marcel van Herk, and Jan-Jakob Sonke[a)]
Department of Radiation Oncology, The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands

A novel digital tomosynthesis (DTS) reconstruction method using a deformation field map

Lei Ren[a)]

Simultaneous motion estimation and image reconstruction (SMEIR) for 4D cone-beam CT

Jing Wang[a)] and Xuejun Gu
Department of Radiation Oncology, The University of Texas Southwestern Medical Center, Dallas, Texas 75235-8808

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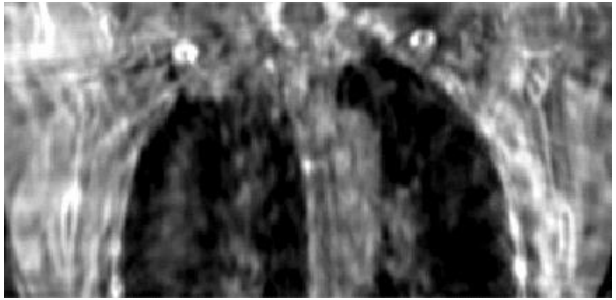
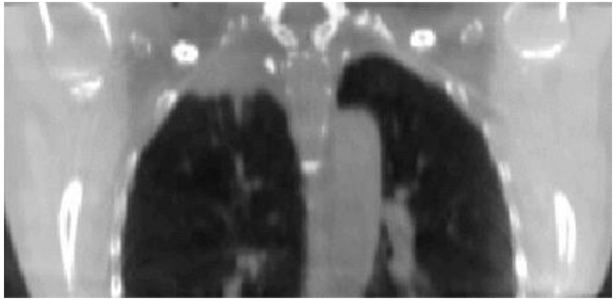
SPARE Challenge

Sparse-view Reconstruction Challenge for 4D Cone-beam CT





Spare scan time
Spare dose

Aims

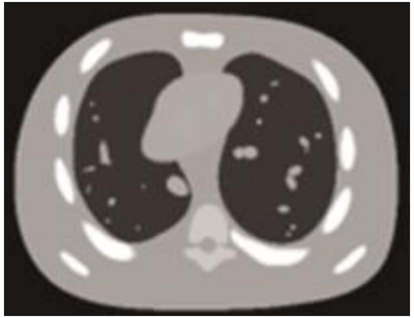
- To systematically investigate the efficacy of various algorithms for 4D-CBCT reconstruction from a one minute scan.

- Provide a common dataset for future 4D-CBCT reconstruction studies.

IMAGE X INSTITUTE

The challenges of hosting a 4D-CBCT challenge

- Ground truth
- Realistic images
  - Patient images
  - Poisson noise
  - Scatter

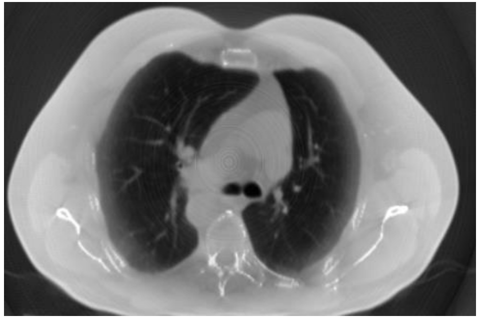


NCAT phantom

XCAT phantom

- Monte Carlo simulation of real patient CTs

Patient – no scatter



Patient – scatter

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Data – source volumes for simulation

THE CANCER IMAGING ARCHIVE

4D-Lung dataset

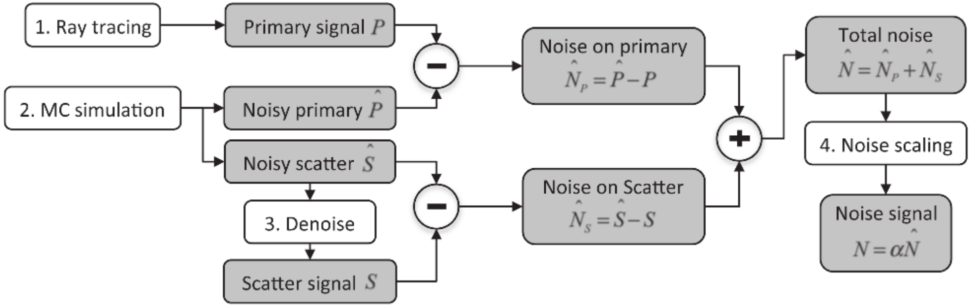
- 20 locally-advanced NSCLC patients
- Patients had multiple 4D-CTs
- Respiratory signal
- 12 patients had at least two 4D-CTs with acceptable quality
- 32 scans in total

Prof Geoff Hugo gdhugo@wustl.edu
https://wiki.cancerimagingarchive.net/display/Public/4D-Lung

Data – Monte Carlo simulation

A GPU Tool for Efficient, Accurate, and Realistic Simulation of Cone Beam CT Projections

Xun Jia[1], Hao Yan[1], Laura Cerviño[1], Michael Folkerts[1,2], and Steve B. Jiang[1]



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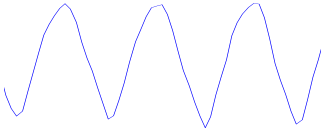
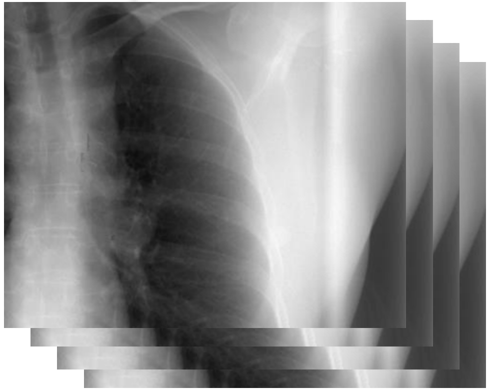
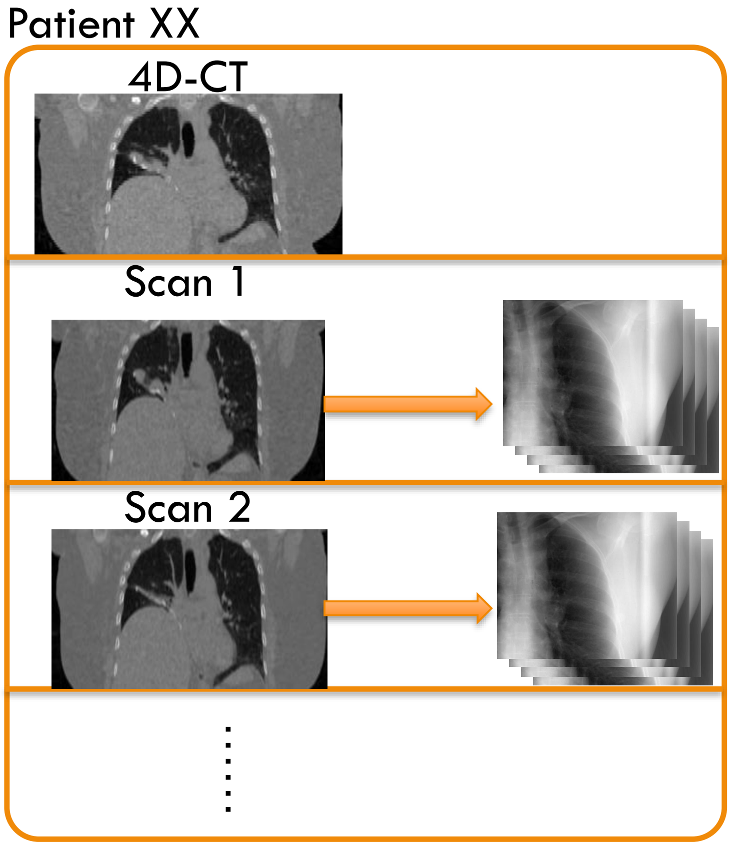


Respiratory signal

Monte Carlo simulation



Data – Monte Carlo Datasets



- Half-fan scan
- 680 projections over 360 degrees
- **No scatter**
  - 40 mA; 20 ms
  - Poisson noise
- **With scatter**
  - 40 mA; 20 ms
  - Poisson noise + scatter
- **Low dose & with scatter**
  - 20 mA; 20 ms
  - Poisson noise + scatter

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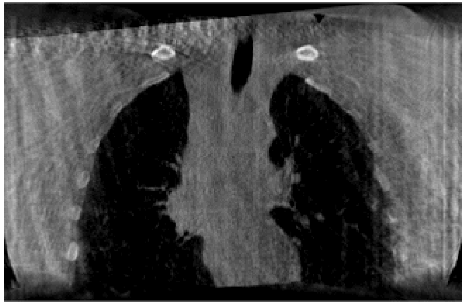
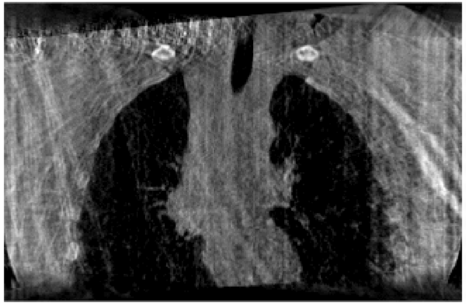
Data - Clinical scans

Clinical Varian Dataset





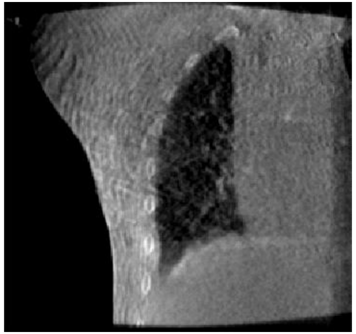
Fully-sampled   Down-sampled

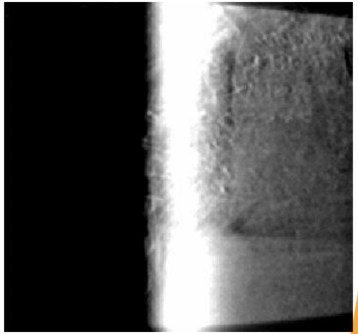
- CBCT scans from the 4D-Lung dataset
- 4 minutes, 2400 half-fan projections
- Down-sample to 680 projections
- Respiratory signal: RPM
- 5 patients. 30 scans.

IMAGE X INSTITUTE

Prof Geoff Hugo

Clinical Elekta Dataset





Fully-sampled   Down-sampled

- Regular 4D-CBCT on an Elekta Versa HD
- 3 minutes, 1000 full-fan projections
- Down-sample to 340 projections
- Respiratory signal: Amsterdam Shroud
- 5 patients. 20 scans.

Dr Simon Rit

Data - overview

Datasets

Monte Carlo

9 patients, 29 scans
3 training scans

Clinical Varian

5 patients, 25 scans
5 training scans

Clinical Elekta

5 patients, 15 scans
5 training scans

Provided to participants

For each patient

4D-CT

PTV contour

For each CBCT scan

CBCT projections

Respiratory signal

Blinded from participants

Ground truth/ Reference volumes

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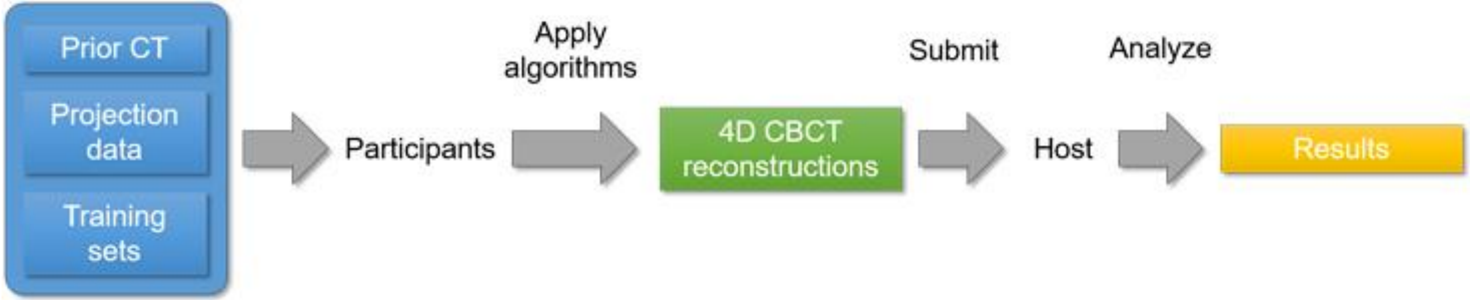
How the challenge was conducted

1. Registration (Dec 2017-15 Jan 2018)
2. Datasets and instructions sent to participants (31 Jan 2018)
3. The fun began!
4. Deadline: 30 April 2018
5. Analysis completed and summarized to the participants in May
6. Results sent to AAPM



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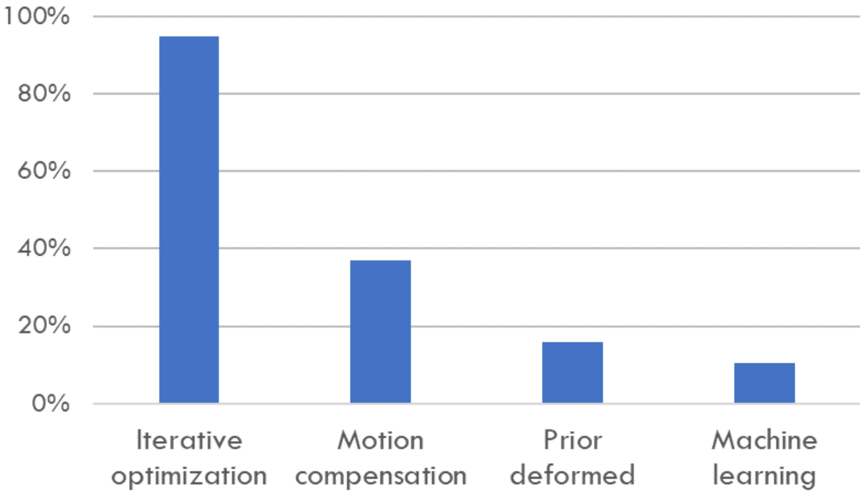
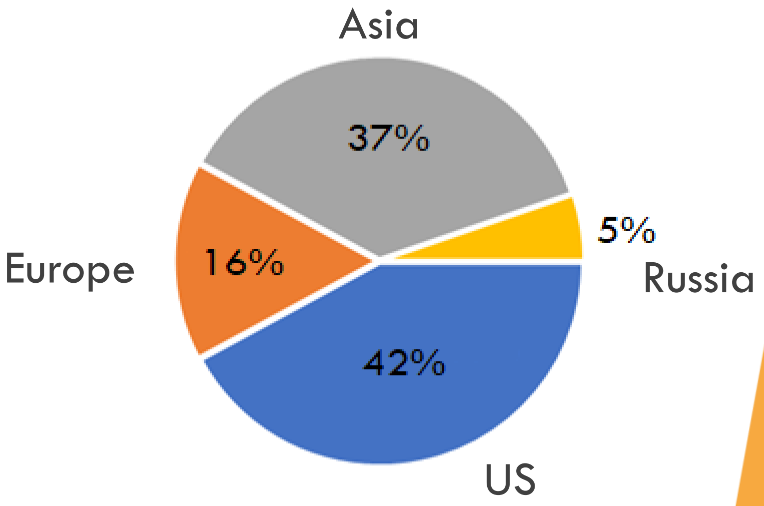
Participant demographics

19 participating teams





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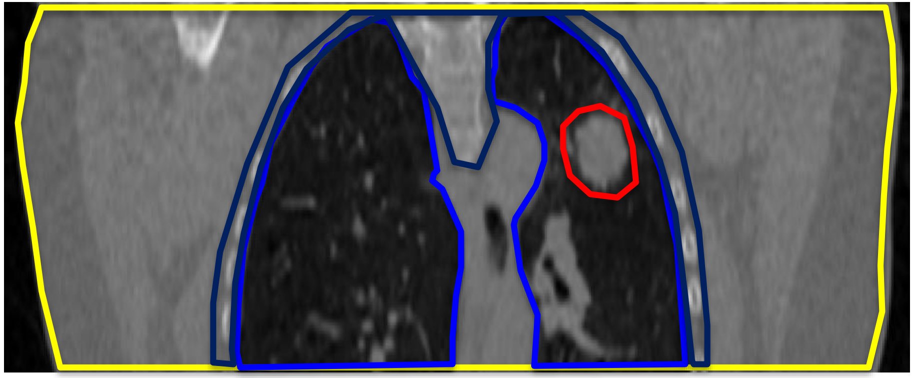
Evaluation metrics

Image similarity

- Structural similarity (SSIM)

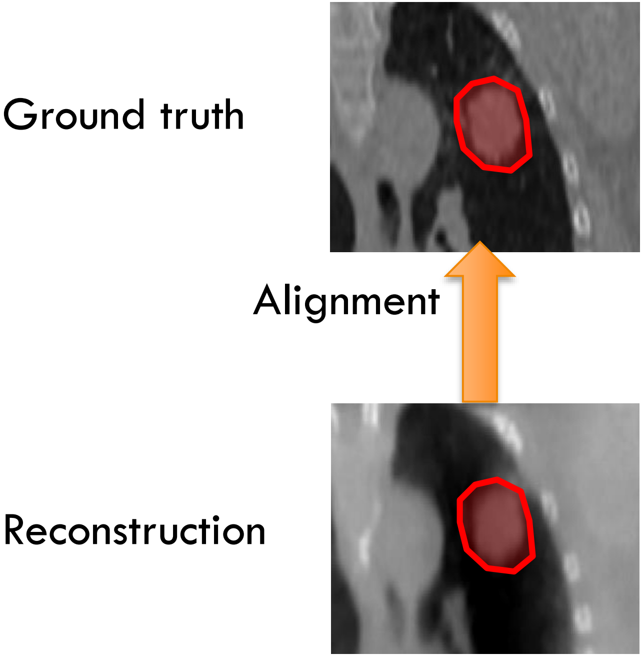


Body PTV

Lungs Bony anatomy

Target localization accuracy

- Alignment of PTV



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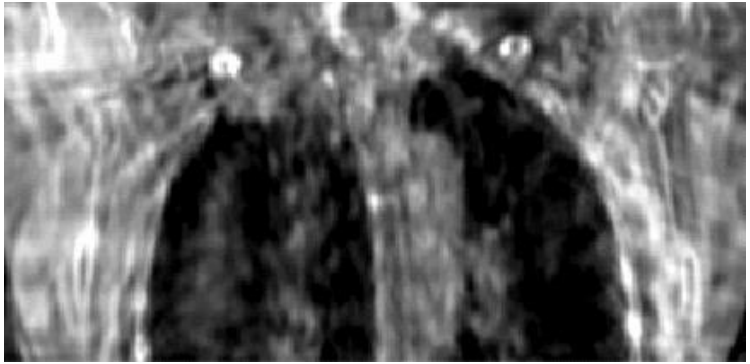
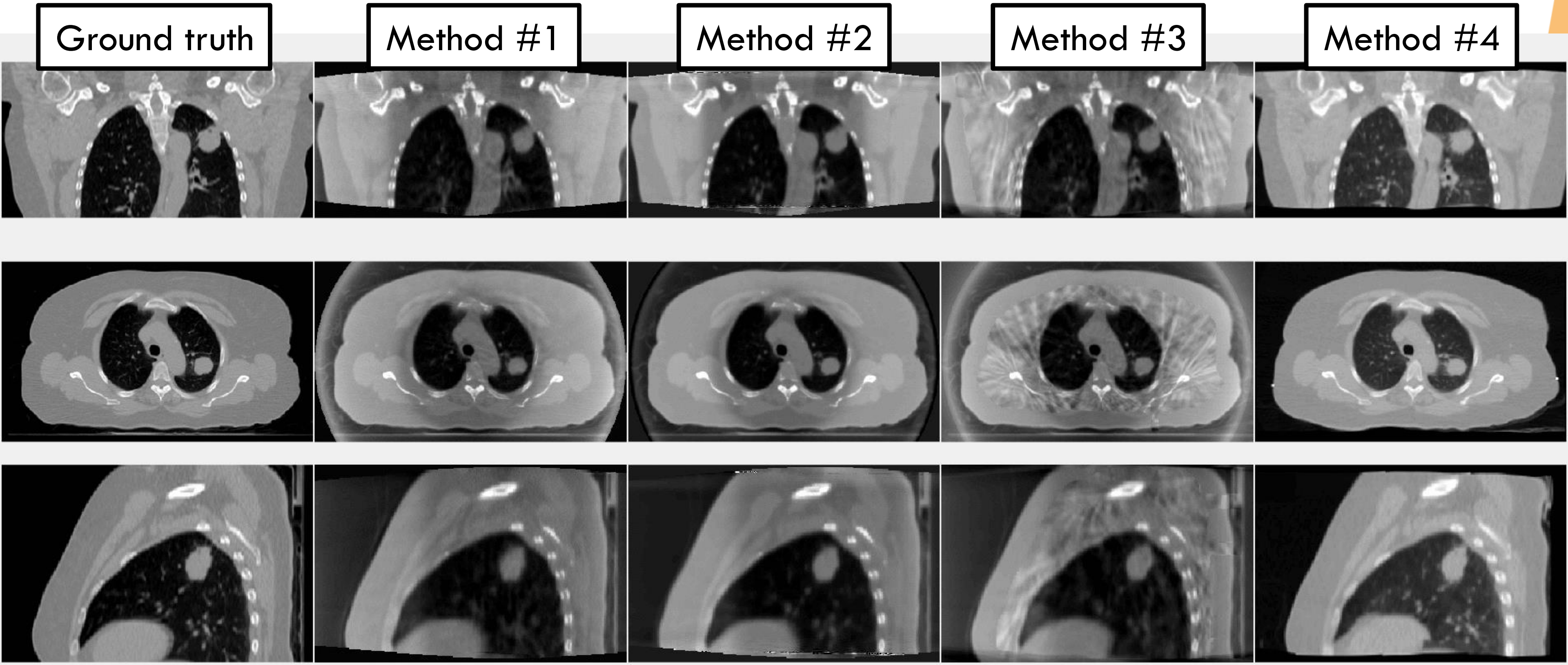
Results

- 19 participating teams
- 4 teams completed the entire challenge
  - with really impressive results



Let's remind ourselves this is what can be achieved with conventional FDK reconstruction…

Top 4 performing methods – Monte Carlo case#1



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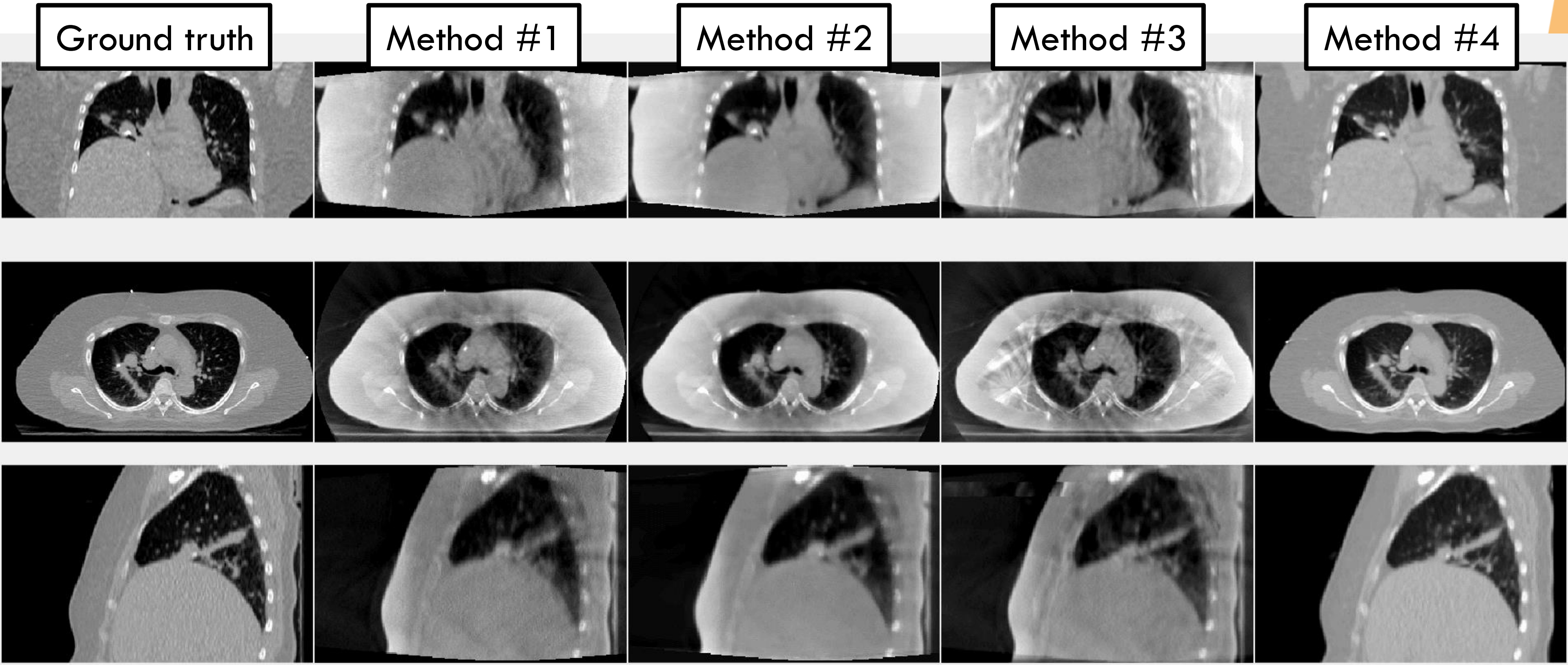
Top 4 performing methods – Monte Carlo case#2



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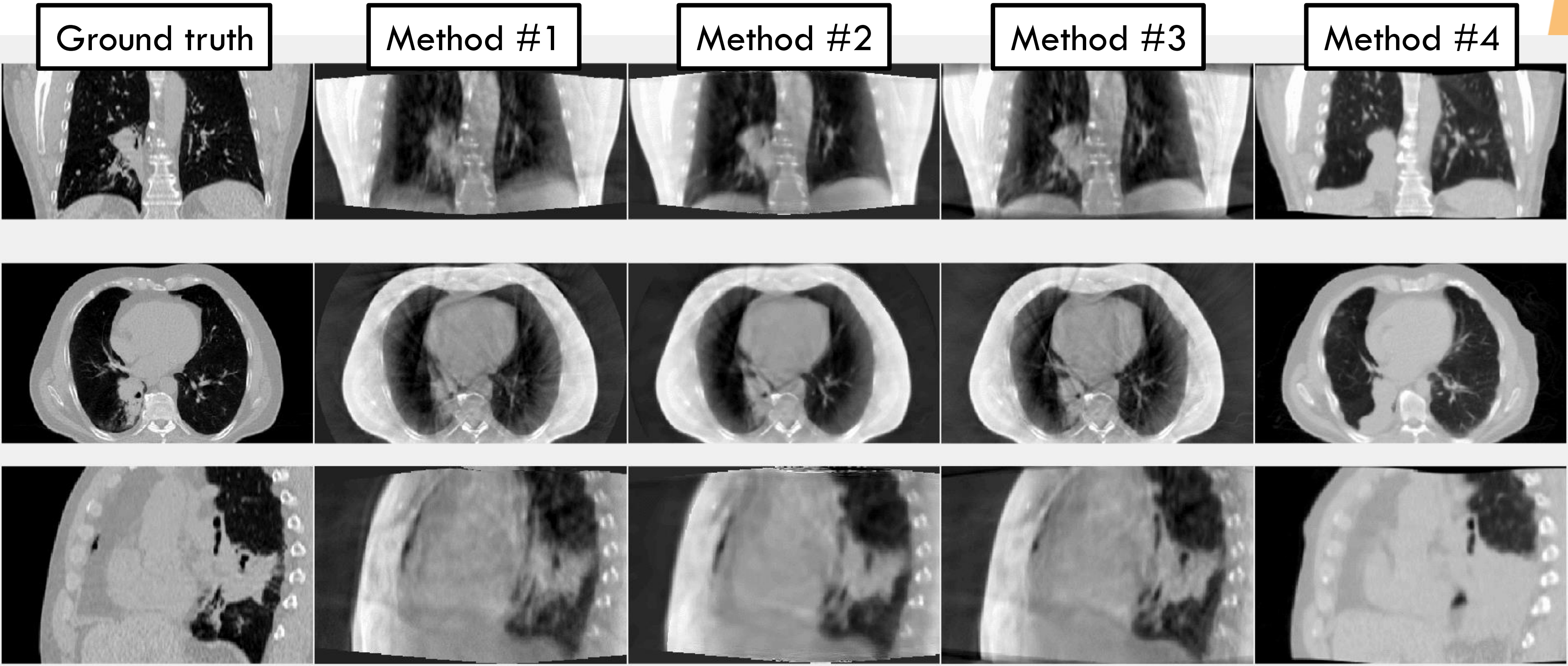
Top 4 performing methods – Monte Carlo case#3



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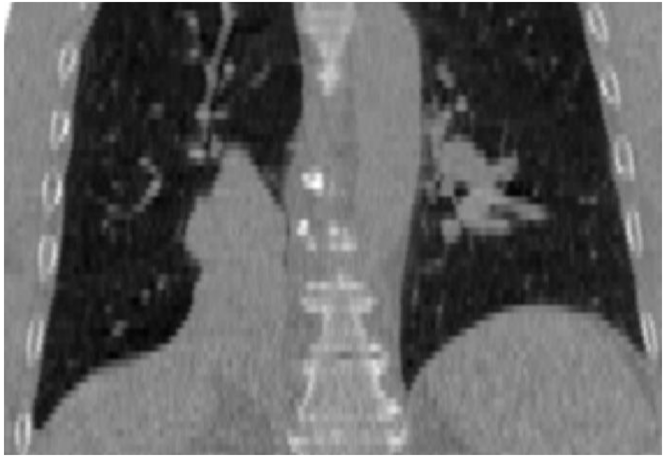
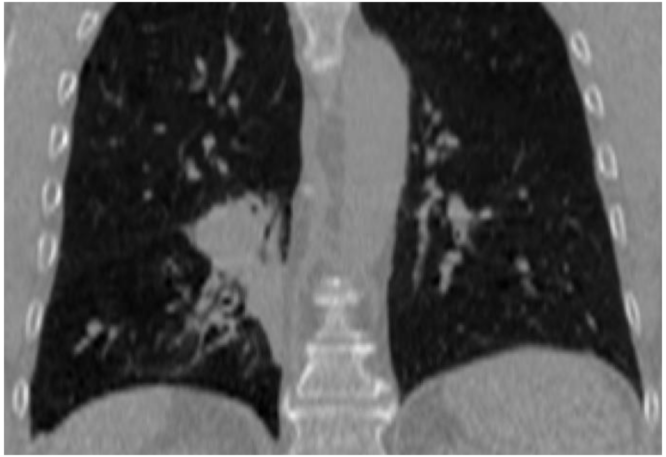
Monte Carlo case#3 – Large CT-CBCT difference

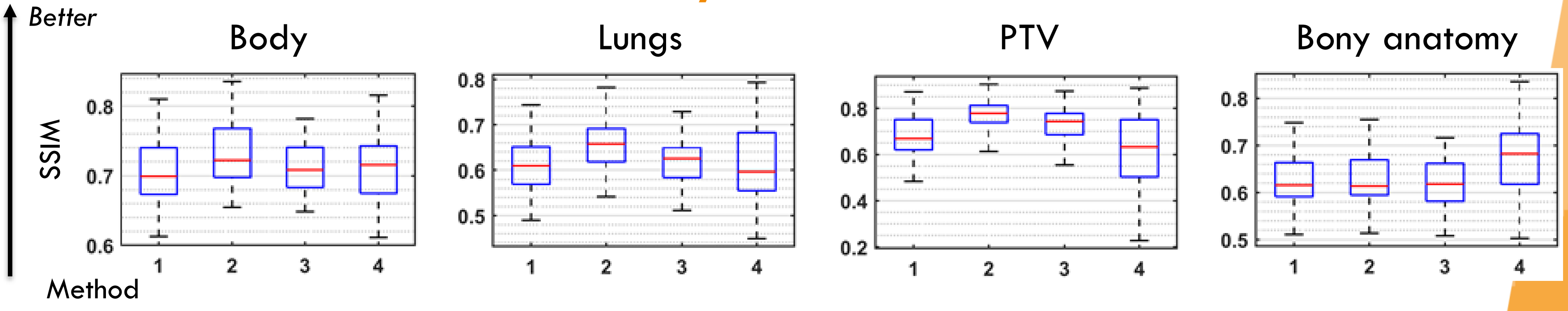


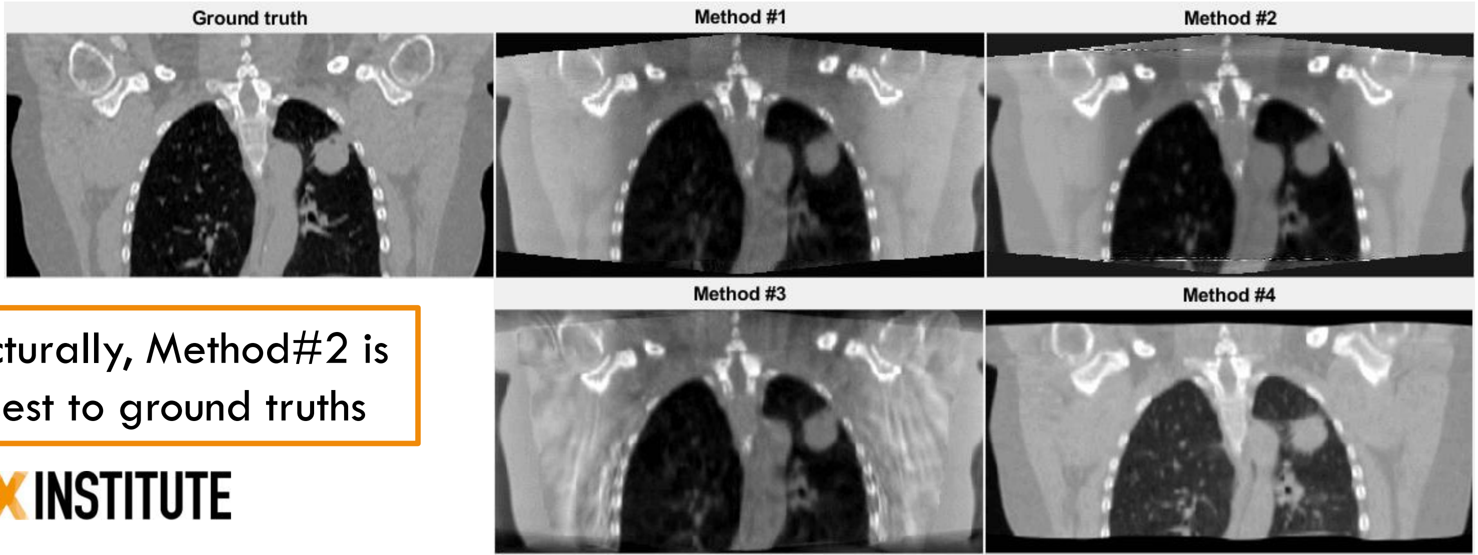
CT



CBCT

Results – Structural similarity





Structurally, Method#2 is closest to ground truths

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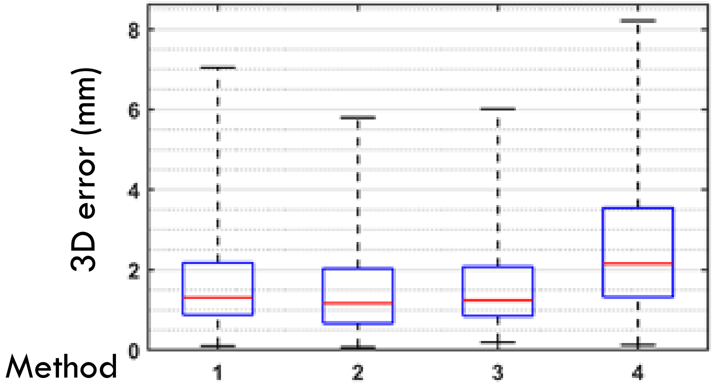
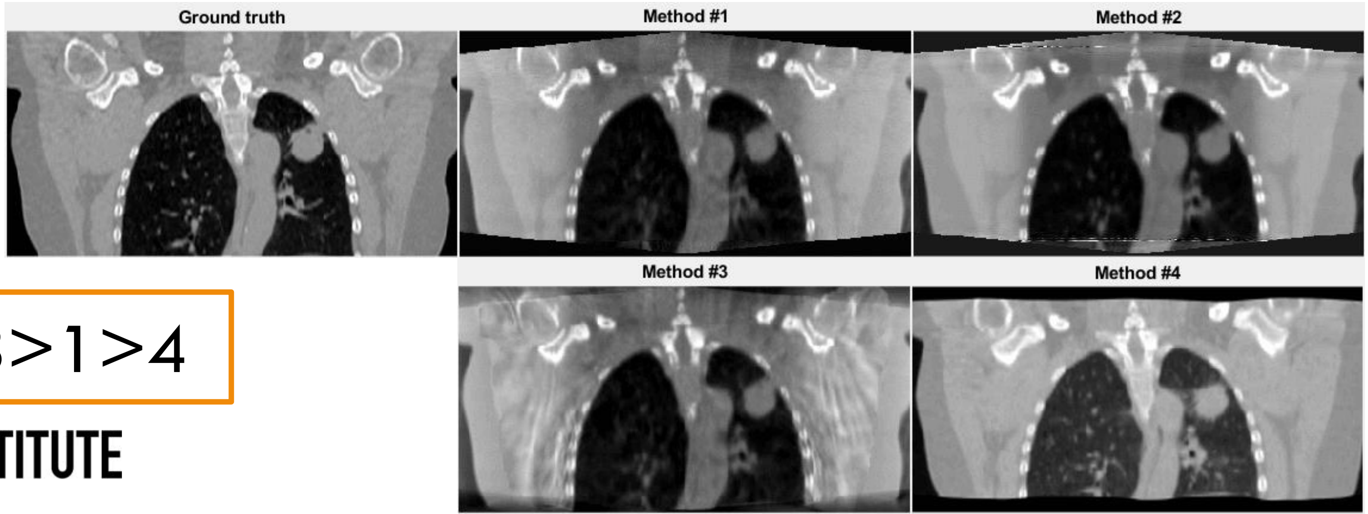
Results – Target localization accuracy





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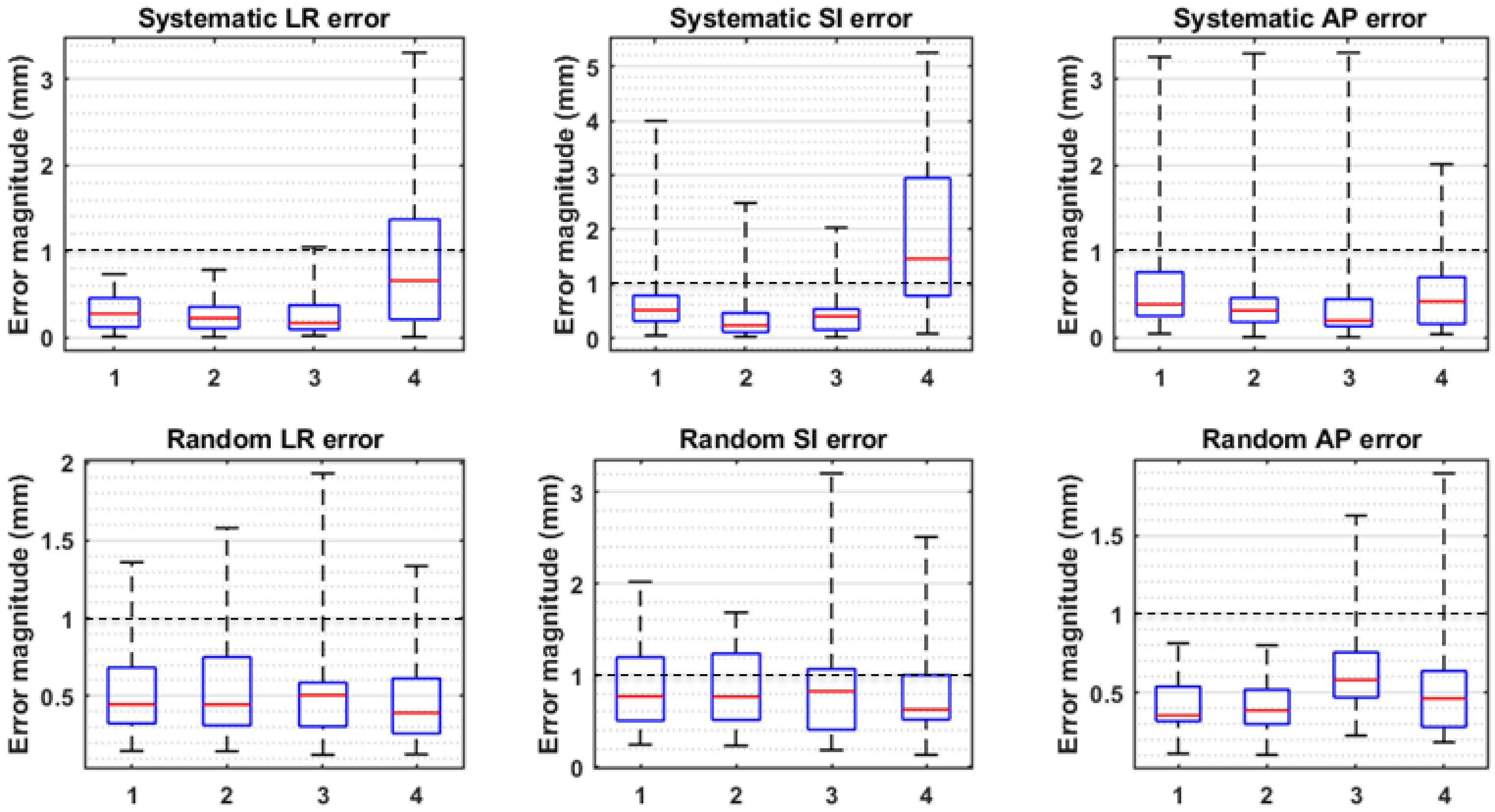
Results – target localization accuracy



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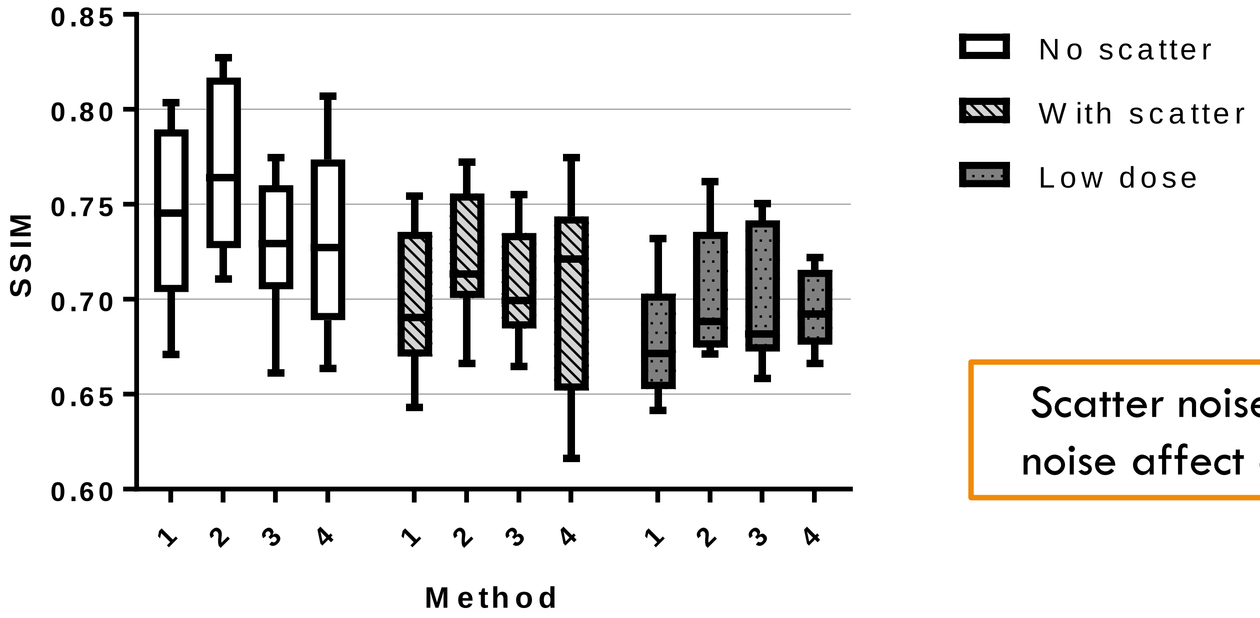
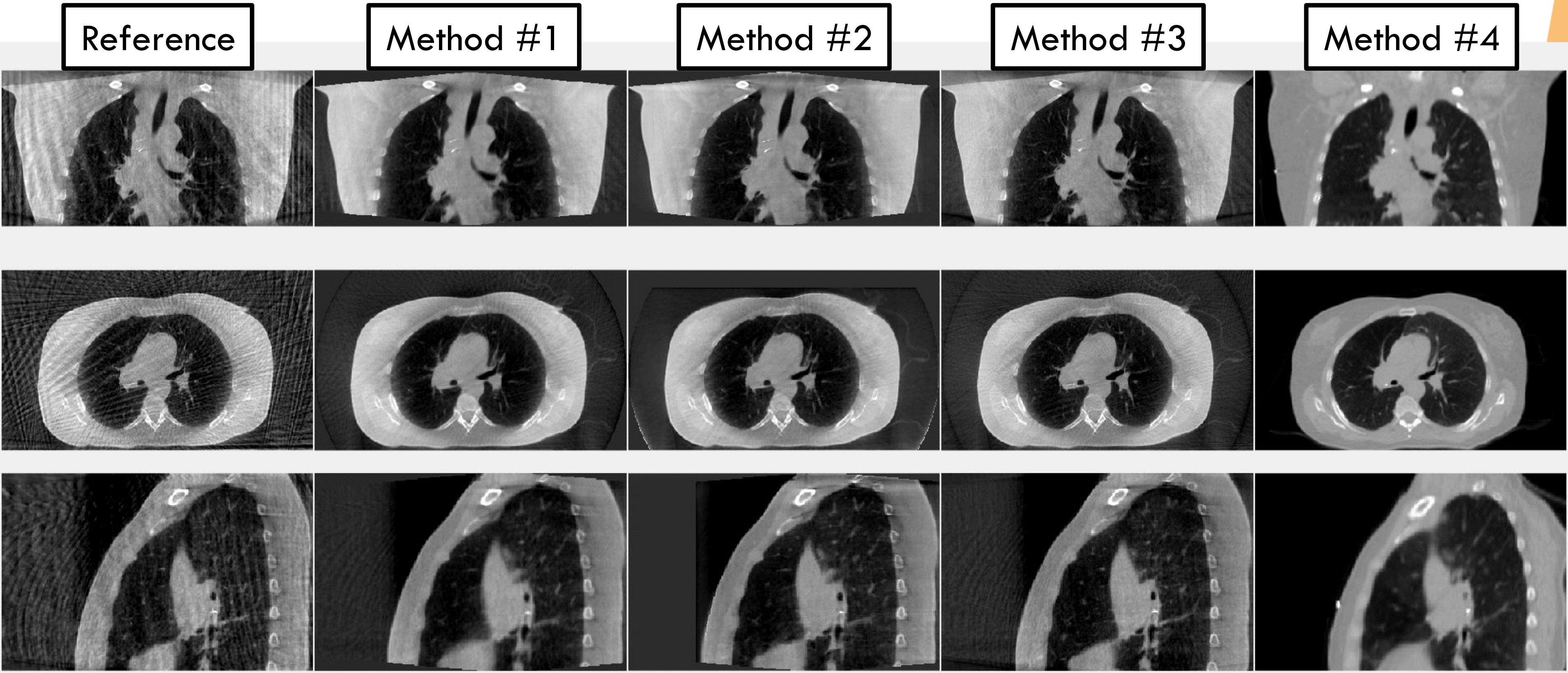
Results – scatter noise and imaging dose



Scatter noise and Poisson noise affect all algorithms

IMAGE X INSTITUTE

Results – Clinical Varian Datasets



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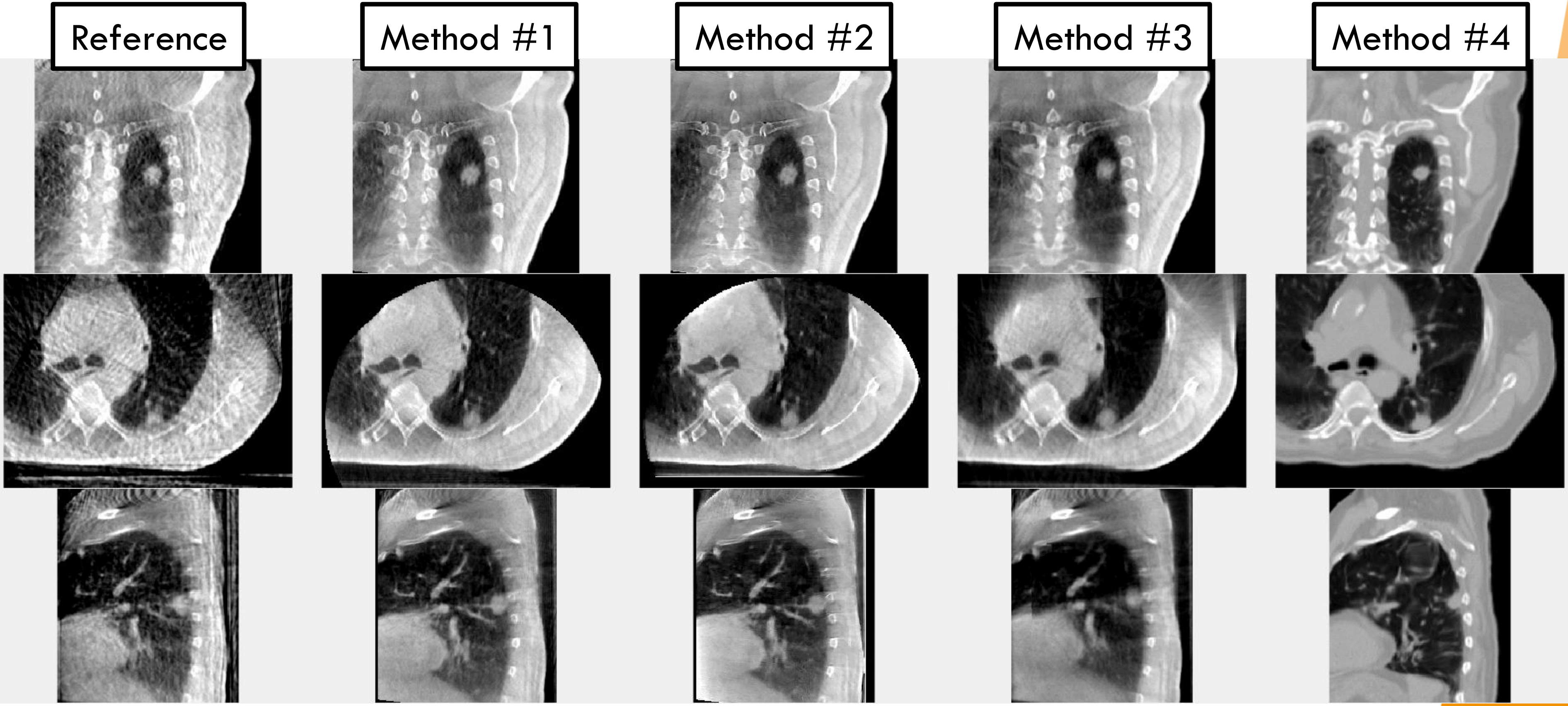
Results – Clinical Elekta Datasets



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Results – top performing teams

2nd

Simon Rit
(CREATIS)

4DCT-based motion-compensation

1st

Cyril Mory
(CREATIS)

Motion-aware temporal regularization (MA-ROOSTER)

3rd

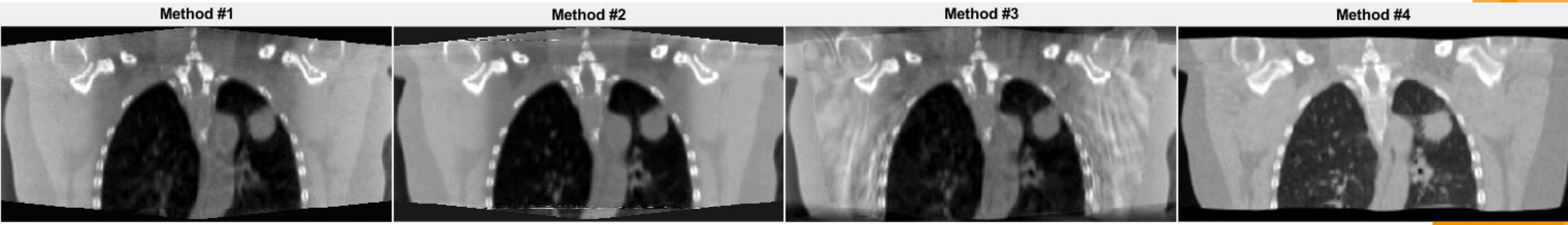
Matthew Riblett
(VCU)
Geoffrey Hugo
(Washington University)

Data-driven motion-compensation

4th

Yawei Zhang
Zhuoran Jiang
Xiaoning Liu
Lei Ren
(Duke University)

Prior deformed



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Results – top performing teams

2nd

- Good quality and accuracy
- Residual blur
- Clinically used

4DCT-based motion-compensation

1st

- Best overall quality and accuracy
- Occasional minor artifacts

Motion-aware temporal regularization (MA-ROOSTER)

3rd

- Data driven
- Good accuracy
- Motion can be "visually" unnatural

Data-driven motion-compensation

4th

- Best visual quality and details
- "CT-like"
- Sensitive to CT-CBCT difference

Prior deformed

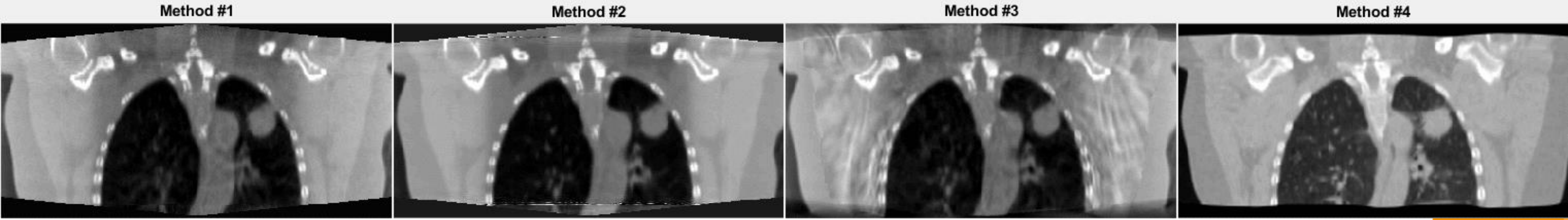
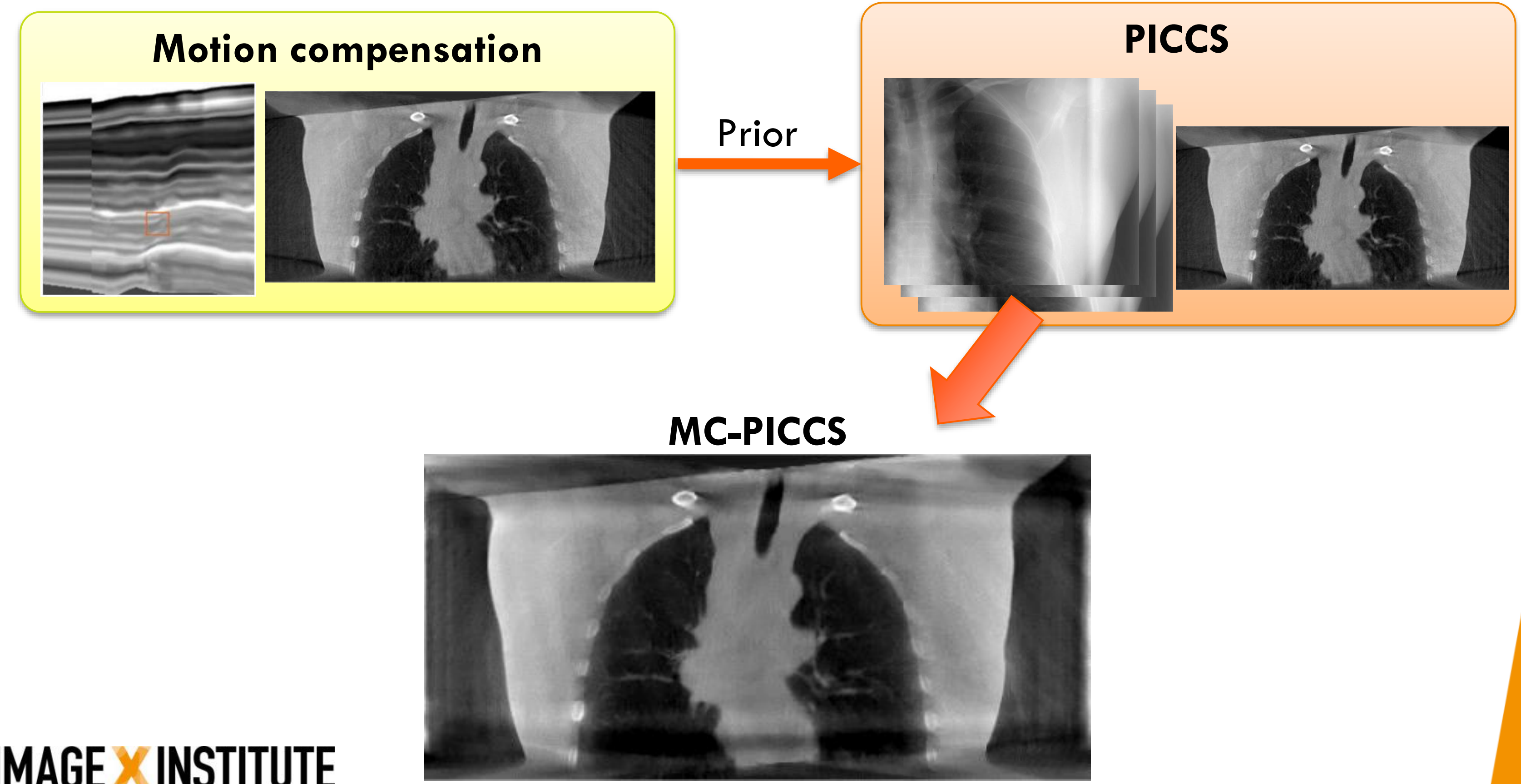


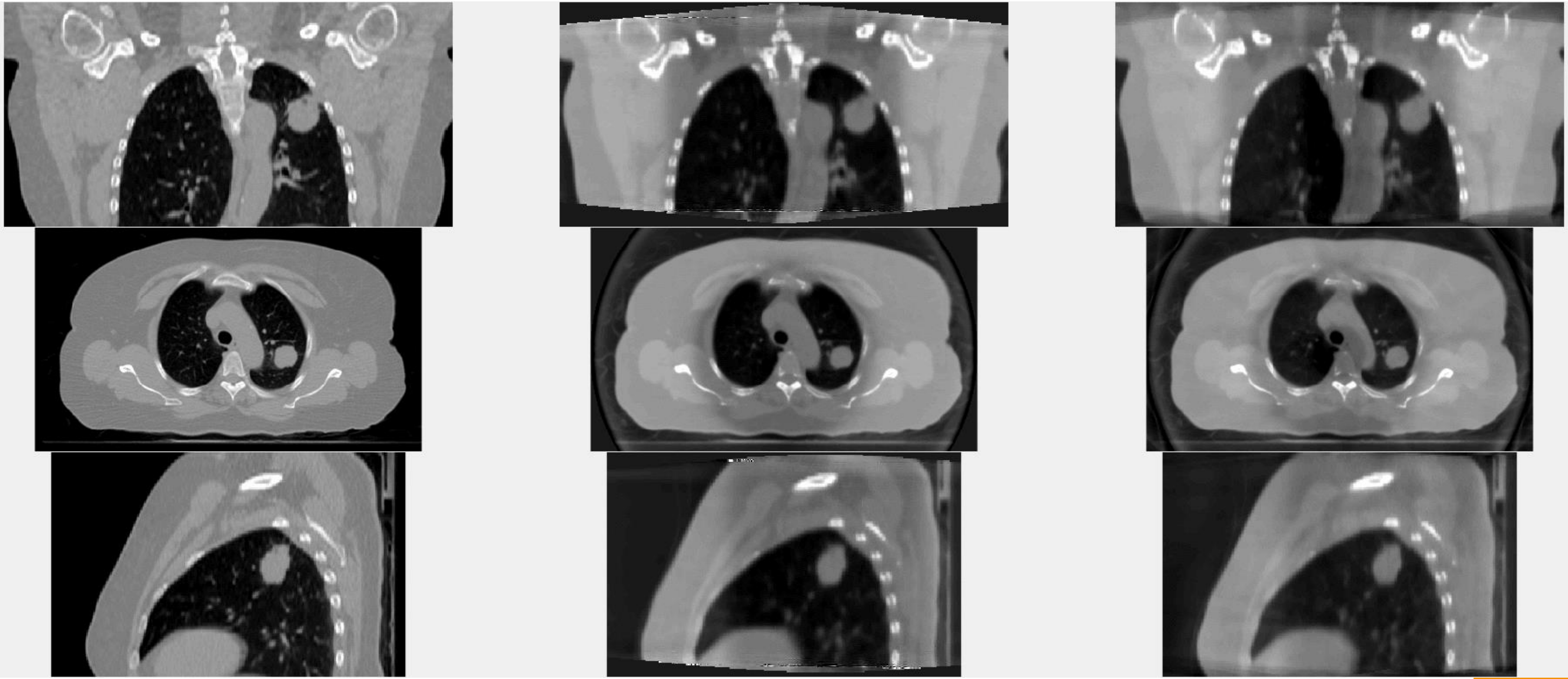
IMAGE X INSTITUTE

MC-PICCS

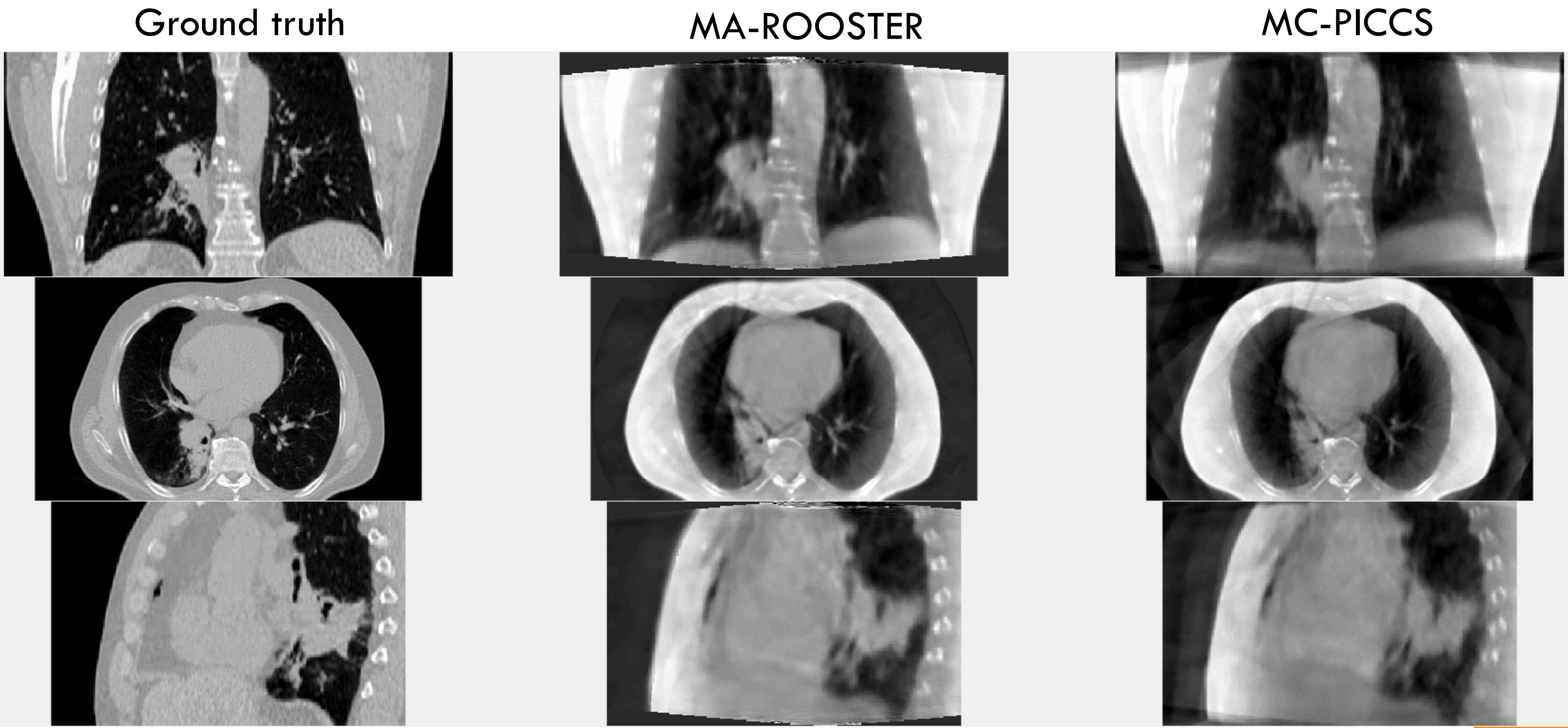


MA-ROOSTER vs MC-PICCS

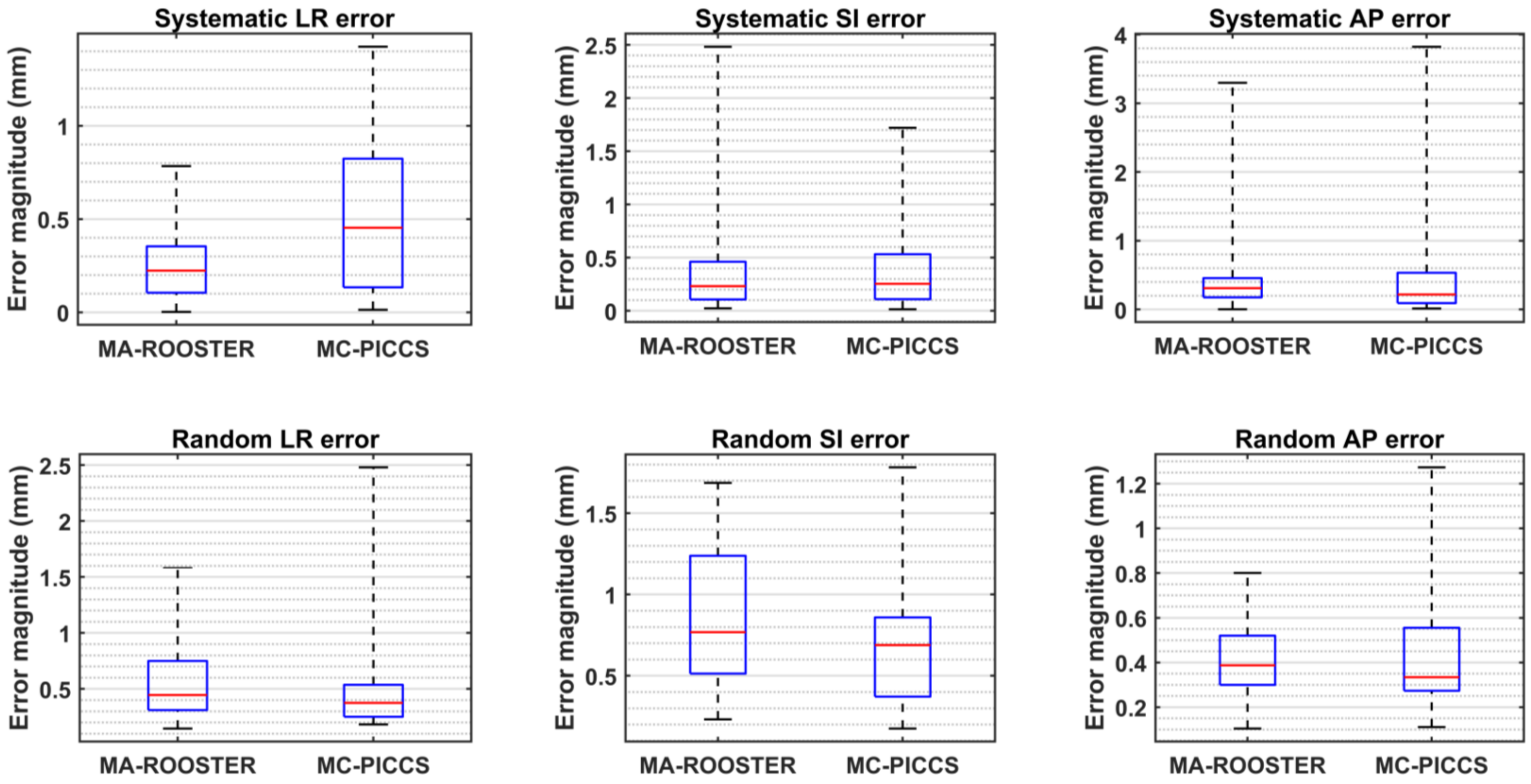
Ground truth | MA-ROOSTER | MC-PICCS



MA-ROOSTER vs MC-PICCS



MA-ROOSTER vs MC-PICCS



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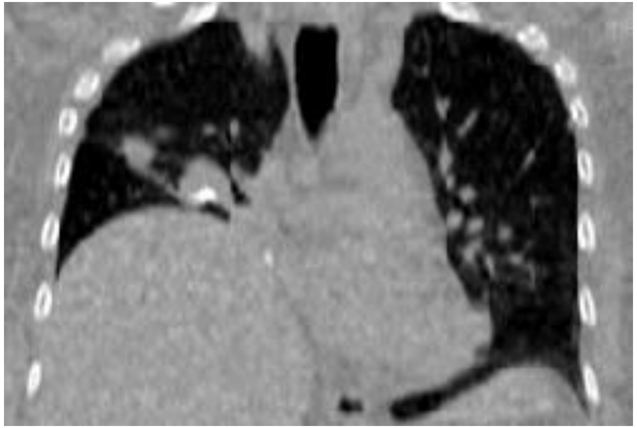
Room for improvements

- Noise and artifacts in the ground truth volumes
- Lack of beam information for projection calibration and scatter correction
- CT-CBCT alignment was not provided
- Better ways to under-sample the clinical datasets

Ahmad 2012 *Med Phys*



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Access to the full dataset

- All the data provided to the participants
- All the ground truth & reference reconstructions
- MATLAB scripts to automatically compute evaluation metrics
- A common dataset for future 4D-CBCT reconstruction studies

- Available from Aug-Sep 2018

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- AAPM
- ACRF Image X Website
  http://sydney.edu.au/medicine/image-x/
- Contact Dr Andy Shieh
  andy.shieh@sydney.edu.au

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Summary

- Accurate and high quality 4D-CBCT from a one-minute scan is challenging, but possible
- The use of motion model is critical
- Each method has its own advantages
- Overall, the combination of motion compensation and iterative regularization gives the best results
- The SPARE Challenge datasets will be publicly available for future studies

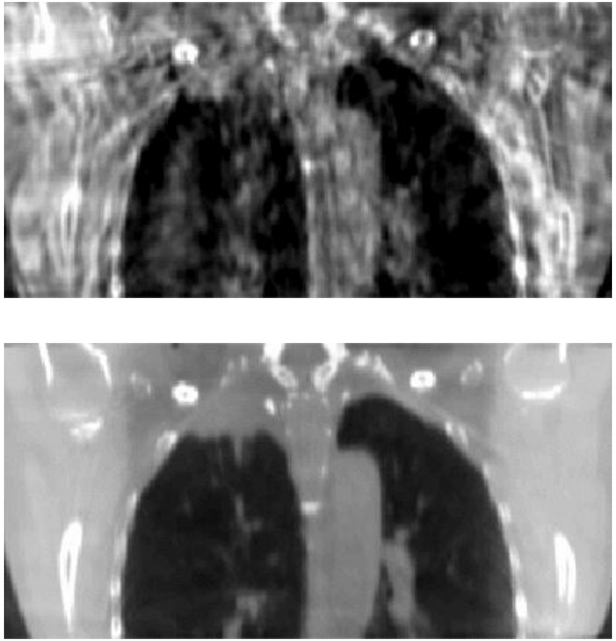

IMAGE X INSTITUTE UTSouthwestern Medical Center CREATIS AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE