FreeCT_ICD: Free, Open-Source MBIR Reconstruction Software for Diagnostic CT

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Outline

1) Background
2) FreeCT_ICD
   - Approach
   - Software
3) Results
4) Conclusions

Background

- Needed large-scale imaging datasets for quantitative imaging research

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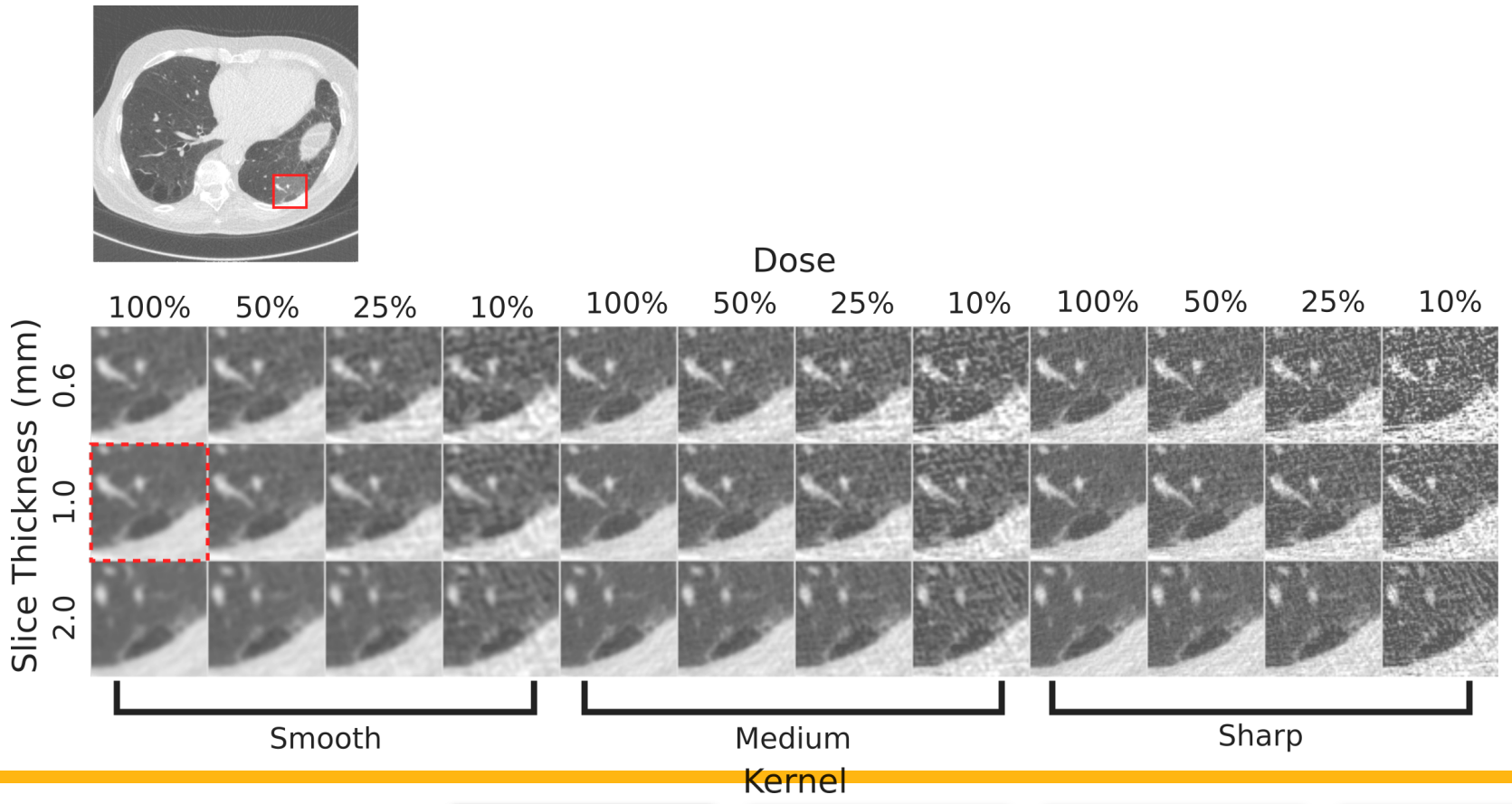
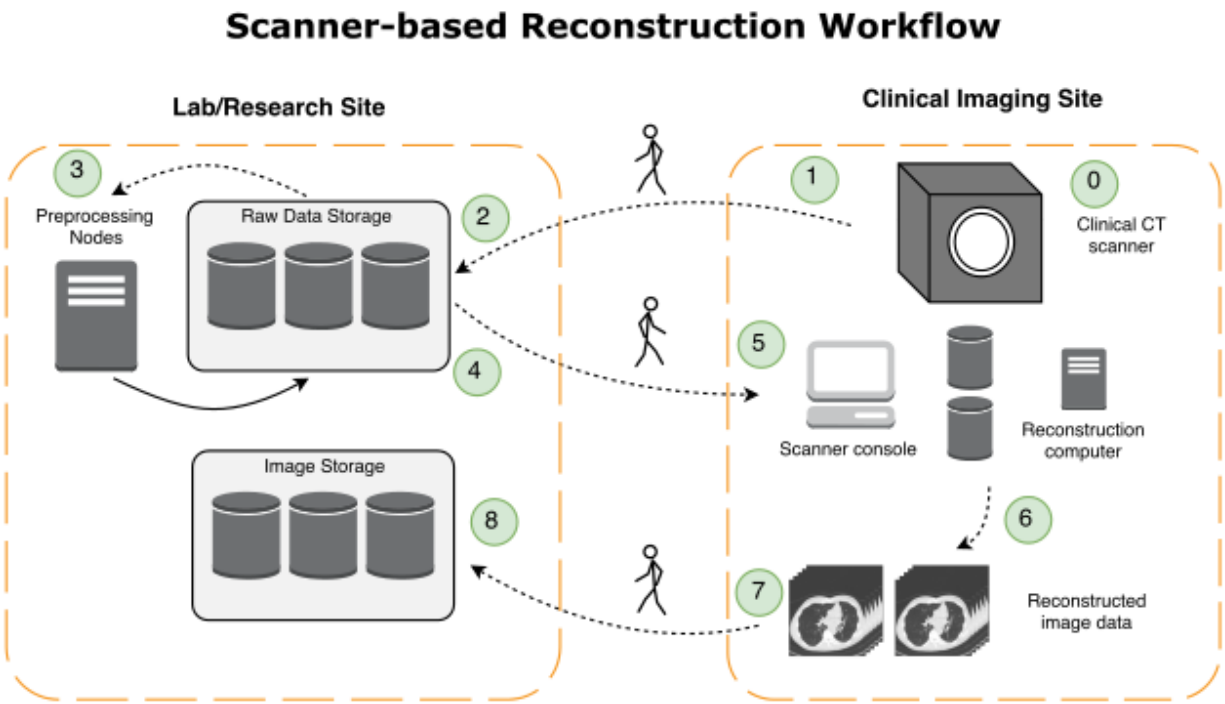


Background

- Needed large-scale imaging datasets for quantitative imaging research



Background

- Needed large-scale imaging datasets for quantitative imaging research

- Problematic:
  - Not-automatable, time-consuming
  - Easy to make mistakes
  - Not flexible

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- Needed large-scale imaging datasets for quantitative imaging research
- Problematic:
  - Not-automatable, time-consuming
  - Easy to make mistakes
  - Not flexible
- Existing “off-line” tools are not geared towards reconstruction of diagnostic data

Background

- FreeCT_wFBP (Hoffman et al. 2016)
  - Weighted filtered backprojection (Stierstorfer et al. 2004)
  - Support for reconstructing full diagnostic CT scans without needing access to the scanner
  - **Reduced time for large scale imaging dataset generation from weeks/months to <1 day**

J. Hoffman, S. Young, F. Noo, and M. McNitt-Gray, Technical Note: FreeCT_wFBP: A robust, efficient, open-source implementation of weighted filtered backprojection for helical, fan-beam CT, Med. Phys. **43**(3), 1411–1420 (2016).

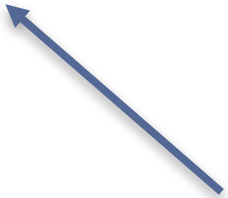
Background

- While wFBP is an important tool…

FreeCT

Background

- While wFBP is an important tool…
- "Where's iterative?"



(First question from reviewers!)

FreeCT

Today's Goal

- Introduce FreeCT_ICD software
  - Iterative "companion" to FreeCT_wFBP
  - Briefly touch on algorithmic/implementation details
  - Software details

FreeCT

Algorithm Details

- System Geometry
  - 3rd generation helical CT (most clinical diagnostic scanners)
  - Support for flying focal spots
    - In-plane available, Z & Z+in-plane under development
  - Little things:
    - Quarter detector offset

Algorithm Details

- Implemented the approach of Thibault et al. 2007

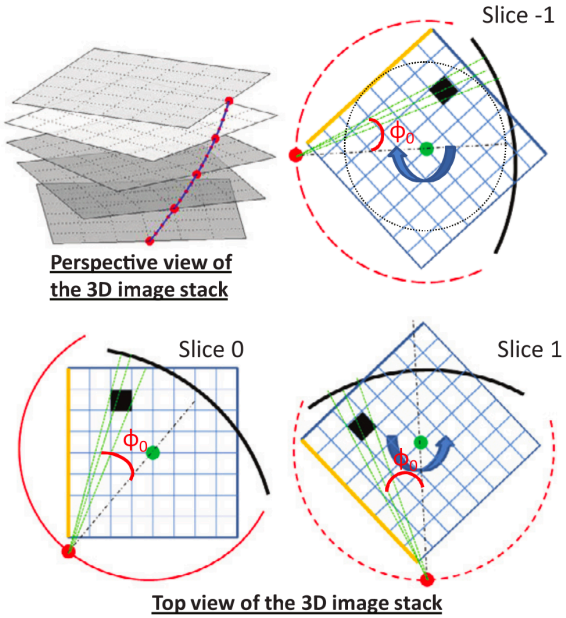
$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \left\{ \frac{1}{2}(\mathbf{y} - \mathbf{A}\mathbf{x})^T \mathbf{D}(\mathbf{y} - \mathbf{A}\mathbf{x}) + U(\mathbf{x}) \right\},$$

- Optimize with iterative coordinate descent (ICD)
  - Good convergence properties (few iterations)

J.-B. Thibault, K.D. Sauer, C. a Bouman, and J. Hsieh, A three-dimensional statistical approach to improved image quality for multislice helical CT., Med. Phys. **34**(2007), 4526–4544 (2007).

Algorithm Details

- Utilizes a **stored system matrix** approach
  - Exploit symmetry using **rotating slices**



$$\Delta\theta = \frac{2\pi l}{N_{2\pi}}$$

$$d = \frac{lh}{N_{2\pi}}$$

Source: Xu & Tsui 2012

J. Xu and B.M.W. Tsui, Iterative image reconstruction in helical cone-beam x-ray CT using a stored system matrix approach., Phys. Med. Biol. **57**(11), 3477–97 (2012).

Algorithm Details

- System Matrix
  - Joseph's method … *
  - (*) Adapted in our particular case w/ an extra interpolation step that further reduces matrix size
    - No observed loss in image quality
  - Typical matrix sizes are ~10 GB for a Siemens Definition AS 64

Algorithm Details

- Penalties
  - 2D support at present (w/ plans for 3D)
  - Quadratic penalty

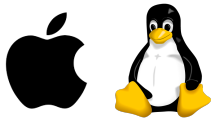
$$\psi(t) = \frac{1}{2}t^2$$

  - Edge-preserving (Fair potential)

$$\psi(t;\delta) = \delta^2\left(\left|\frac{t}{\delta}\right| - \log\left(1 + \left|\frac{t}{\delta}\right|\right)\right)$$

Software Details

- Implemented in C++
- Minimal external dependencies (Easy to compile)
  - Boost (https://www.boost.org/)
  - Yaml-cpp (https://github.com/jbeder/yaml-cpp)
  - OpenMP (https://www.openmp.org/)
- Platform independent
  - Tested on Linux and MacOS
  - Windows should be supported, not tested



- GNU GPL v2.0
  - “Free to do whatever you want with the code as long as you share your changes”

Software Details

- Key features
  - Modularity
    - Easily-modified penalty functions (code structure)
    - “Swappable” system matrices
  - Supports scans from clinical scanners
    - Also does simulated data
  - Ability to initialize with FreeCT_wFBP
    - Non-trivial when using clinical data and rotating slice geometry
    - Automatically configured based on inputs to FreeCT_ICD

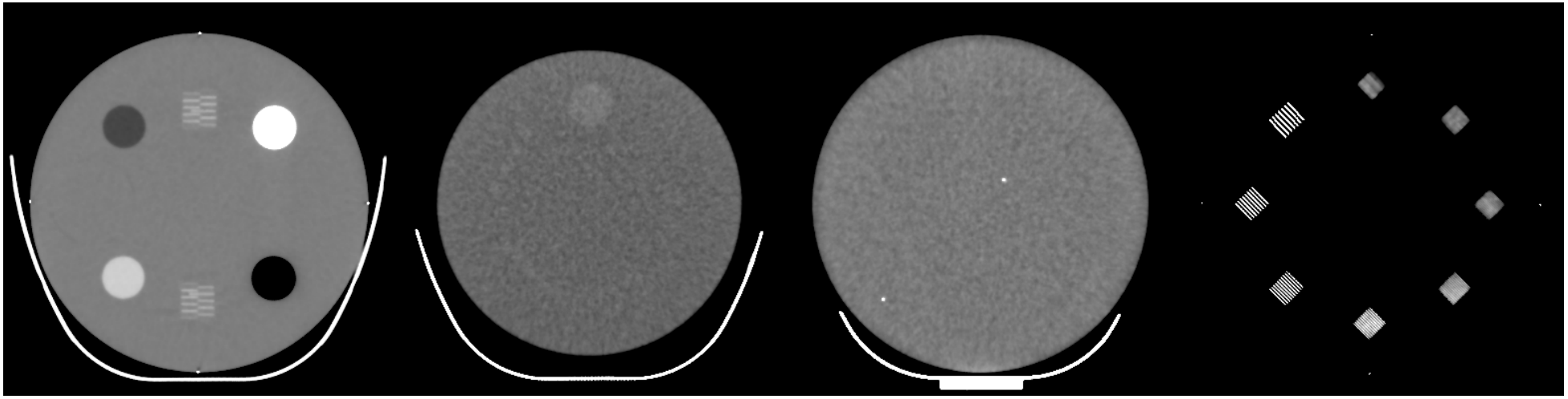
Some images… finally!

Results

- ACR Phantom Reconstructions

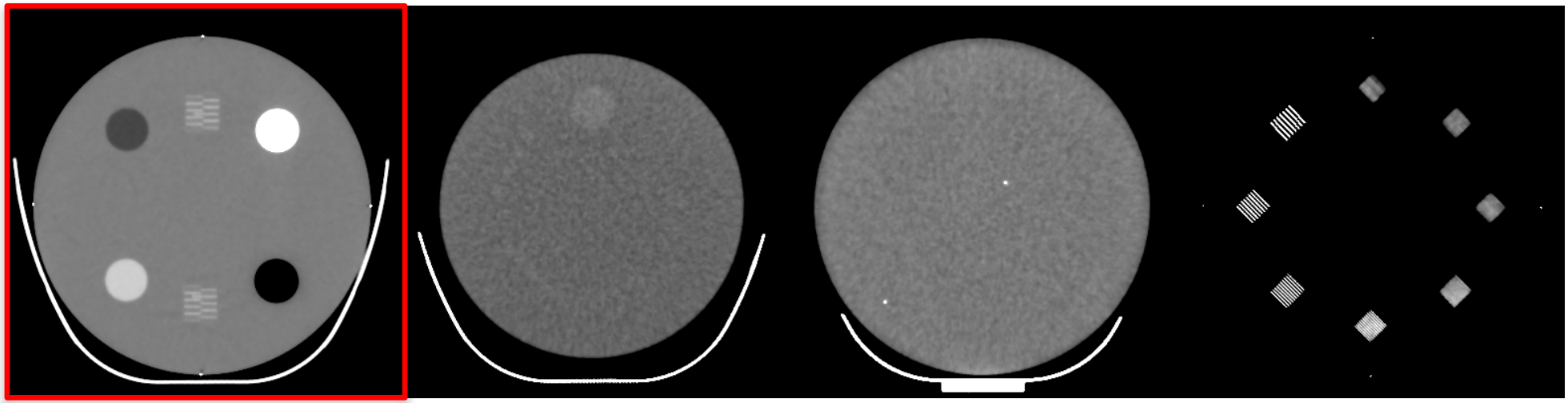
Scan	ACR Phantom
Acquisition Parameters	
Collimation	16 x 1.2mm
Pitch	1.0
Flying focal spot	Off
Rotation time [s]	0.33
Reconstruction Parameters	
wFBP initialization	yes
Voxel grid Dimensions	512 x 512 x 132
Voxel size [mm]	0.58 x 0.58 x 1.5
FOV radius [mm]	300
Edge-preserving parameter	0.005
Penalty term parameter	0.1
Iterations	50
Matrix size [GB]	8.5

Results



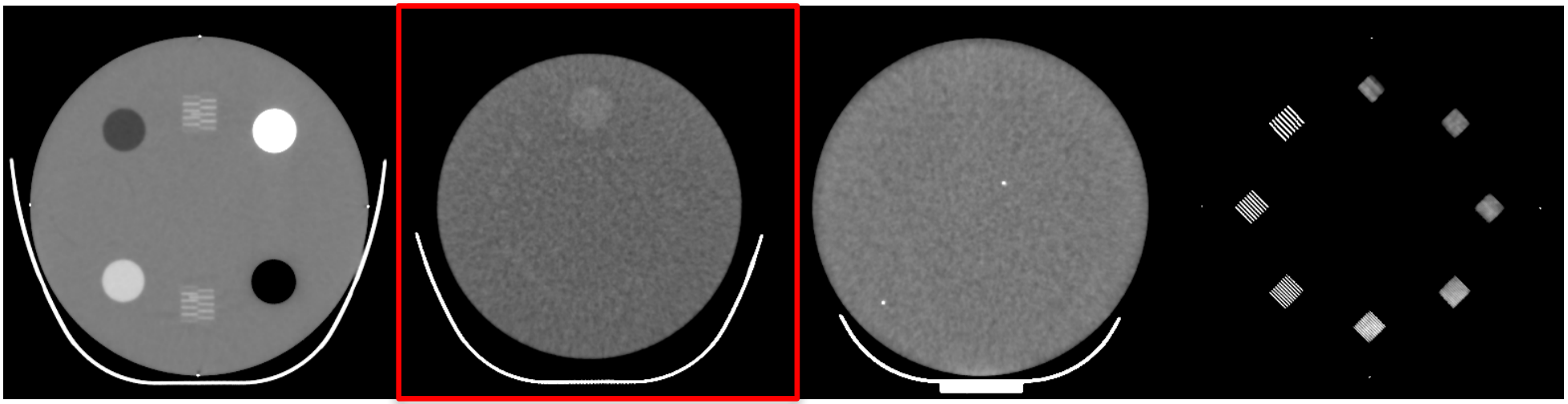
ACR CT Accreditation Phantom/Protocols

Results



Material	Acceptable range [HU]	FreeCT_ICD [HU]
Polyethylene	-107 to -84	-89
Bone	850 to 970	864
Water	-7 to 7	-2
Acrylic	110 to 135	123
Air	-1005 to -970	-988

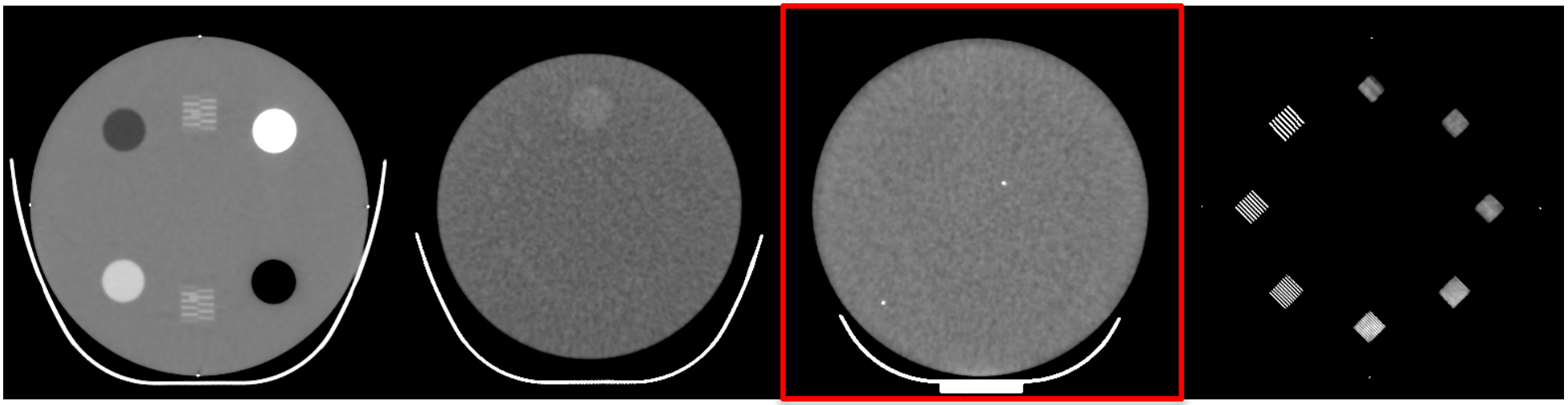
Results



CNR: 3.83 (> 1.0 req.)

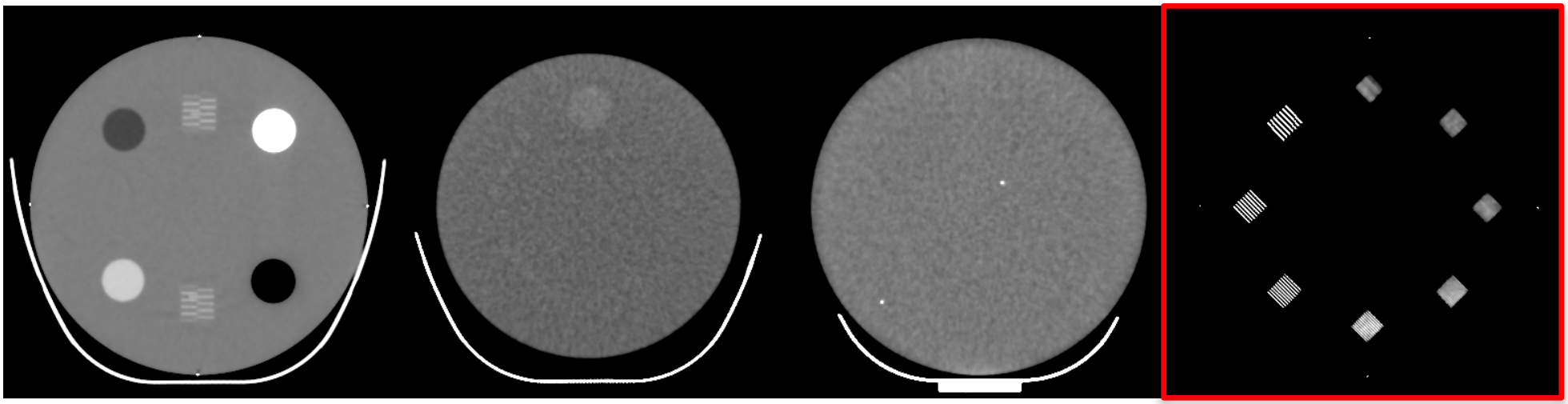
wFBP: 2.21

Results



Uniformity: 0.9HU (< 5.0HU req.)

Results



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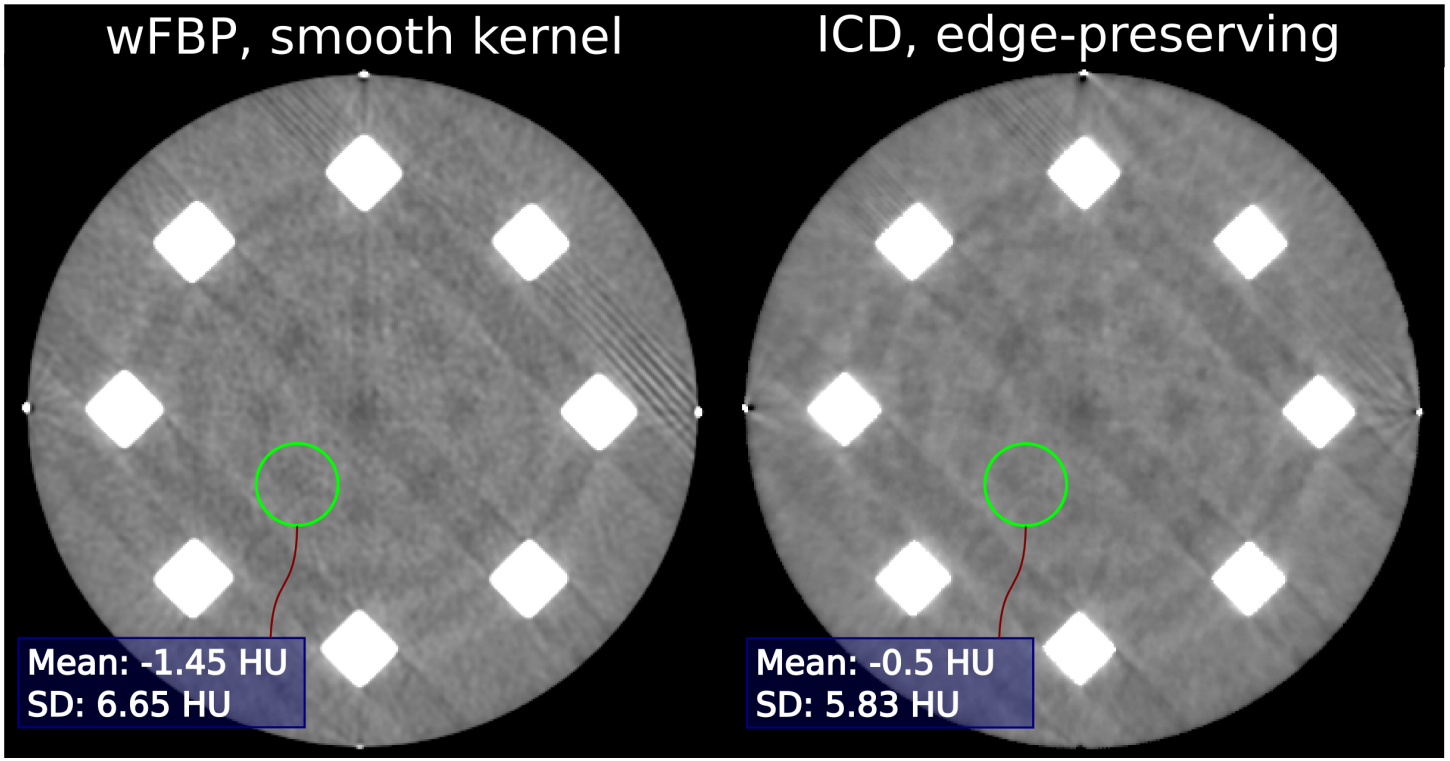
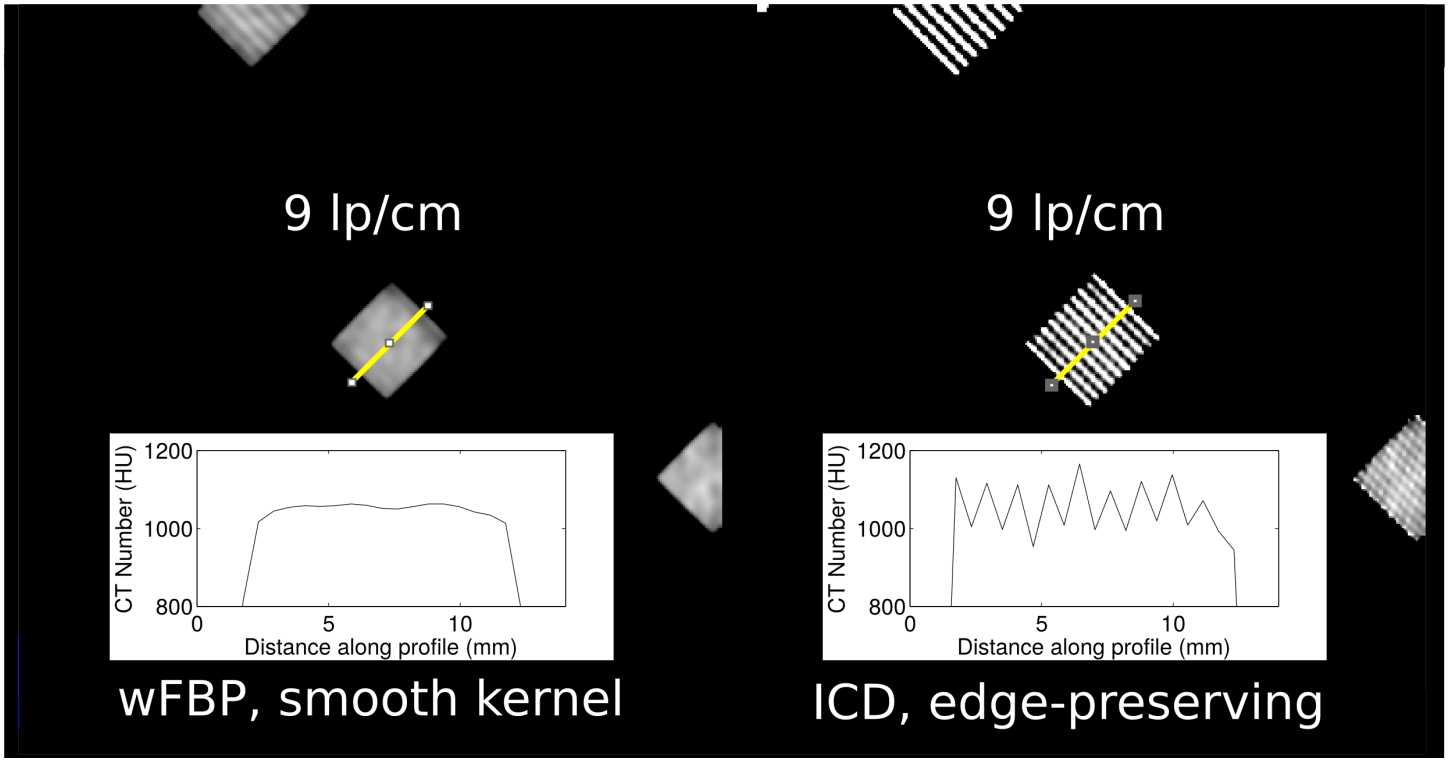


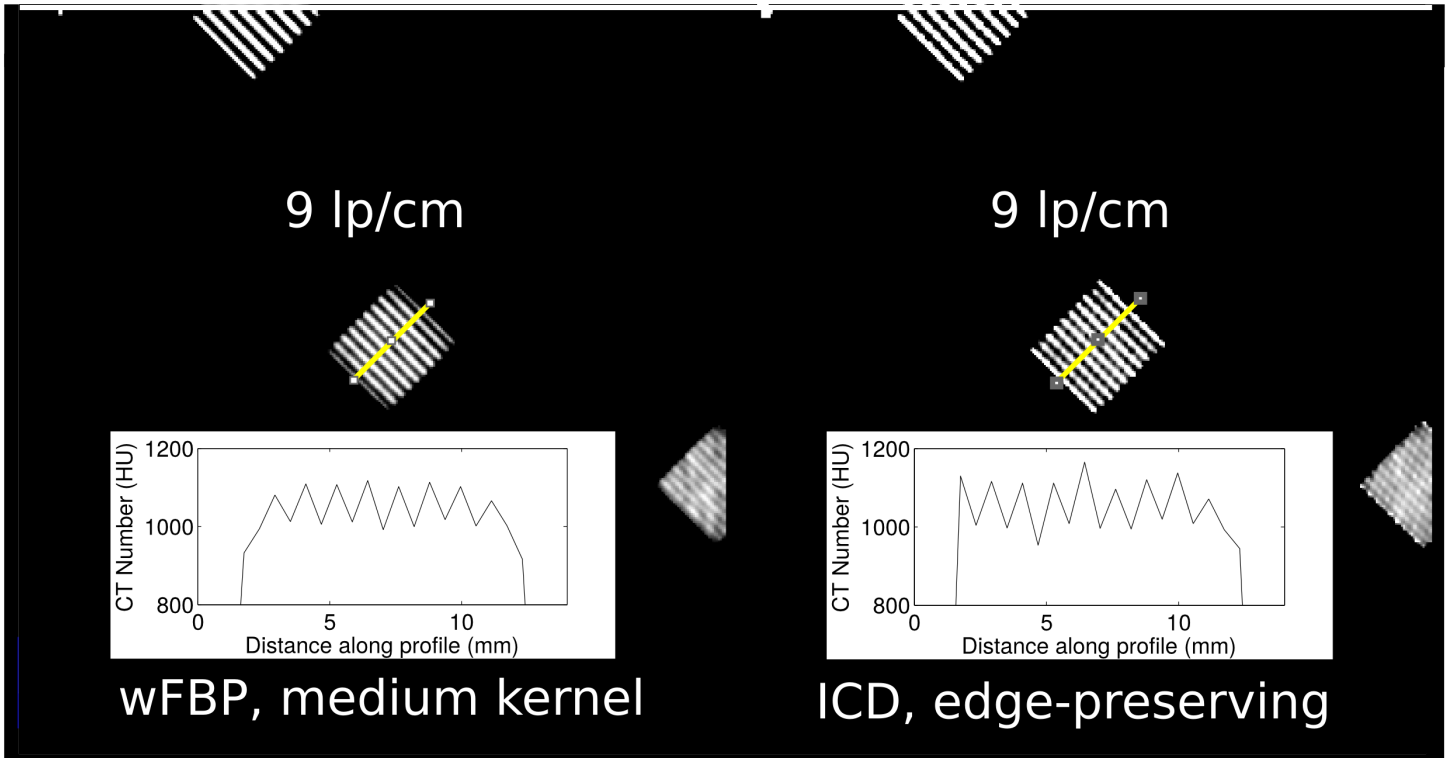
W/L: 200/0 HU

Results



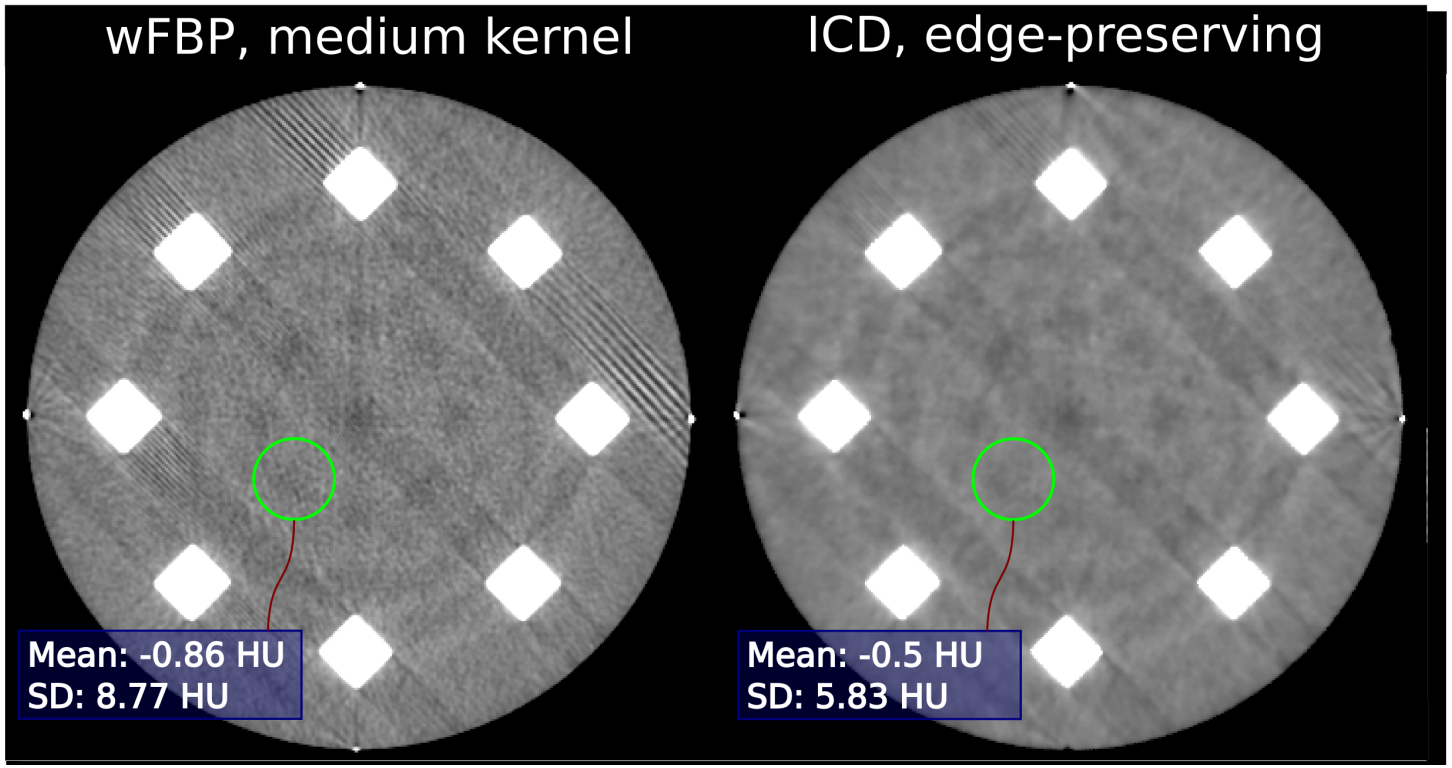
W/L: 100/1050 HU

Results



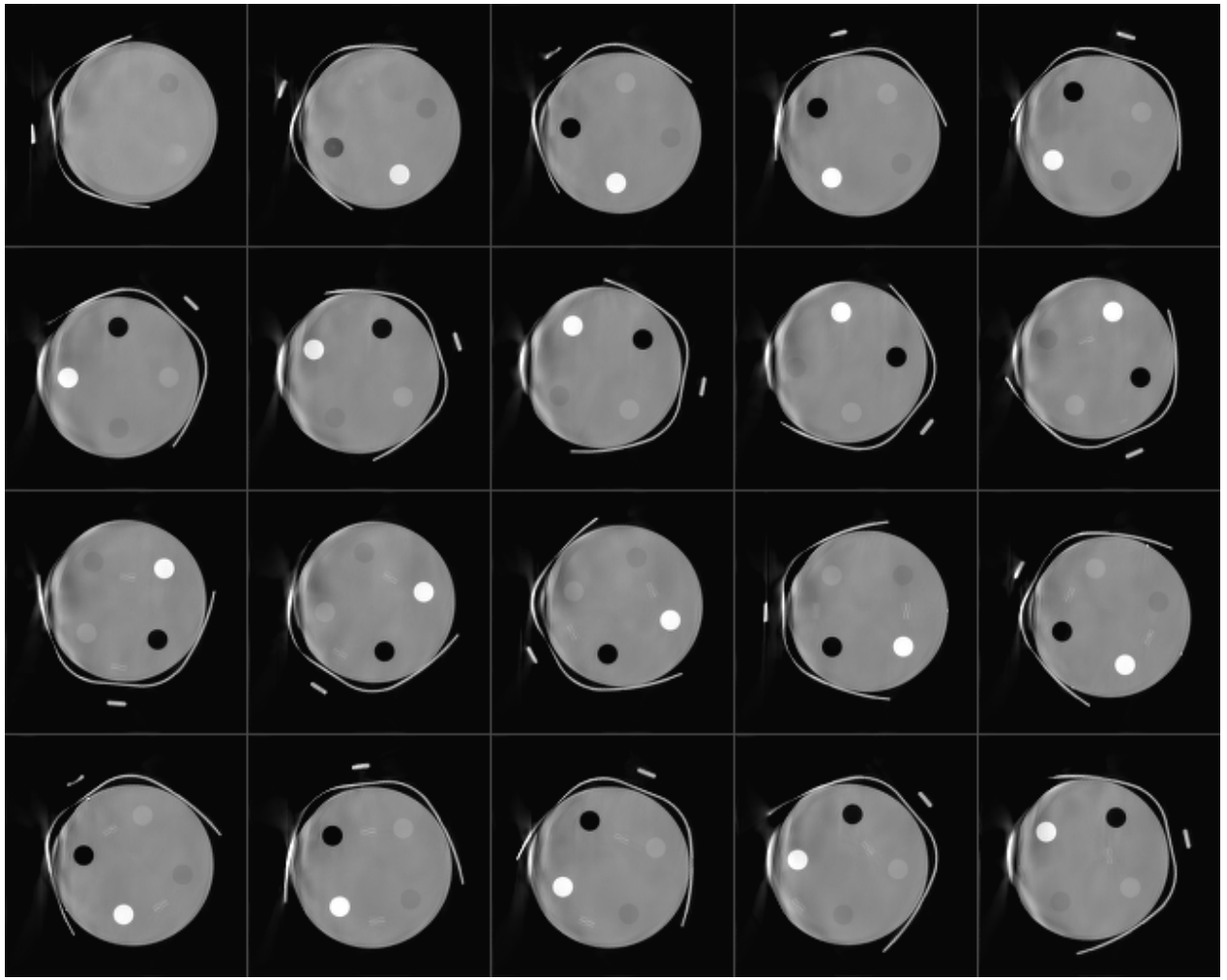
W/L: 100/1050 HU

Results



W/L: 200/0 HU

Results

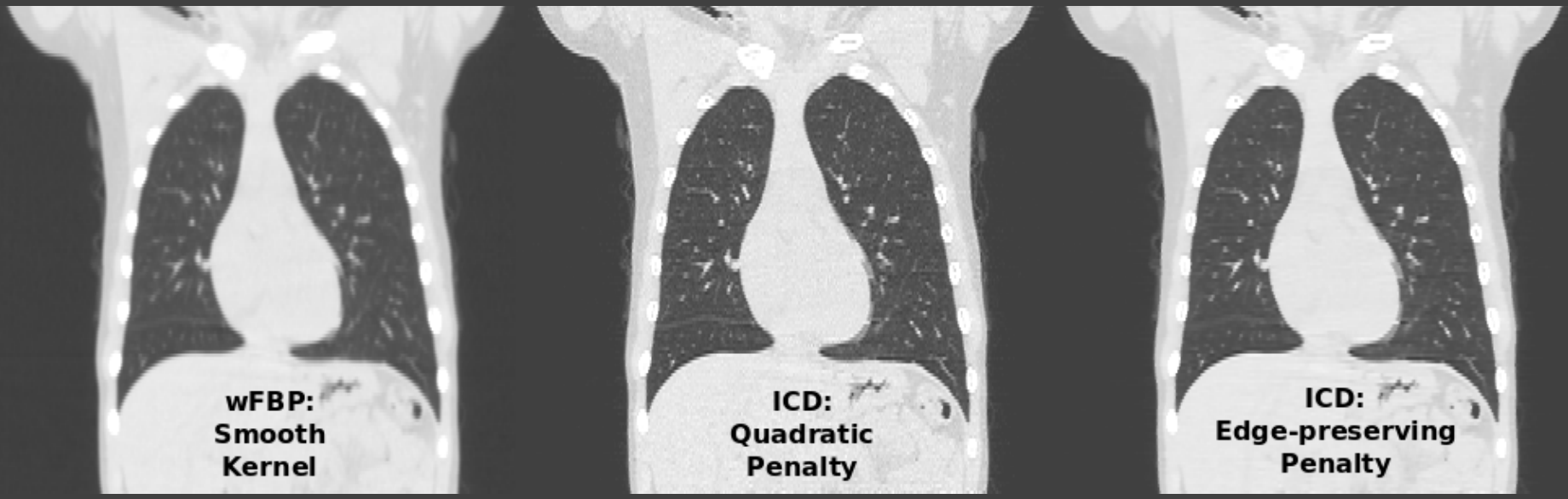


Results

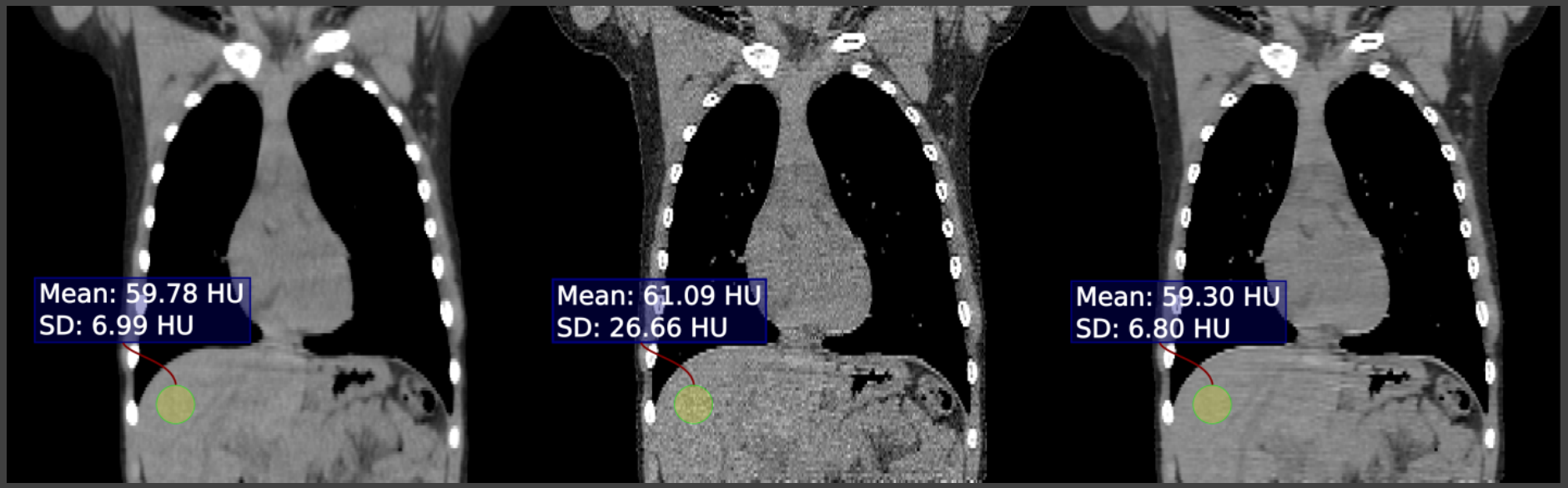
- Pediatric chest

Scan	Pediatric Chest
Acquisition Parameters	
Collimation	16 x 1.2mm
Pitch	1.0
Flying focal spot	Off
Rotation time [s]	0.33
Reconstruction Parameters	
wFBP initialization	yes
Voxel grid Dimensions	512 x 512 x 163
Voxel size [mm]	0.98 x 0.98 x1.5
FOV radius [mm]	500
Edge-preserving parameter	0.005
Penalty term parameter	0.1
Iterations	50
Matrix size [GB]	14.6

Results


wFBP:
Smooth
Kernel
ICD:
Quadratic
Penalty
ICD:
Edge-preserving
Penalty

Results

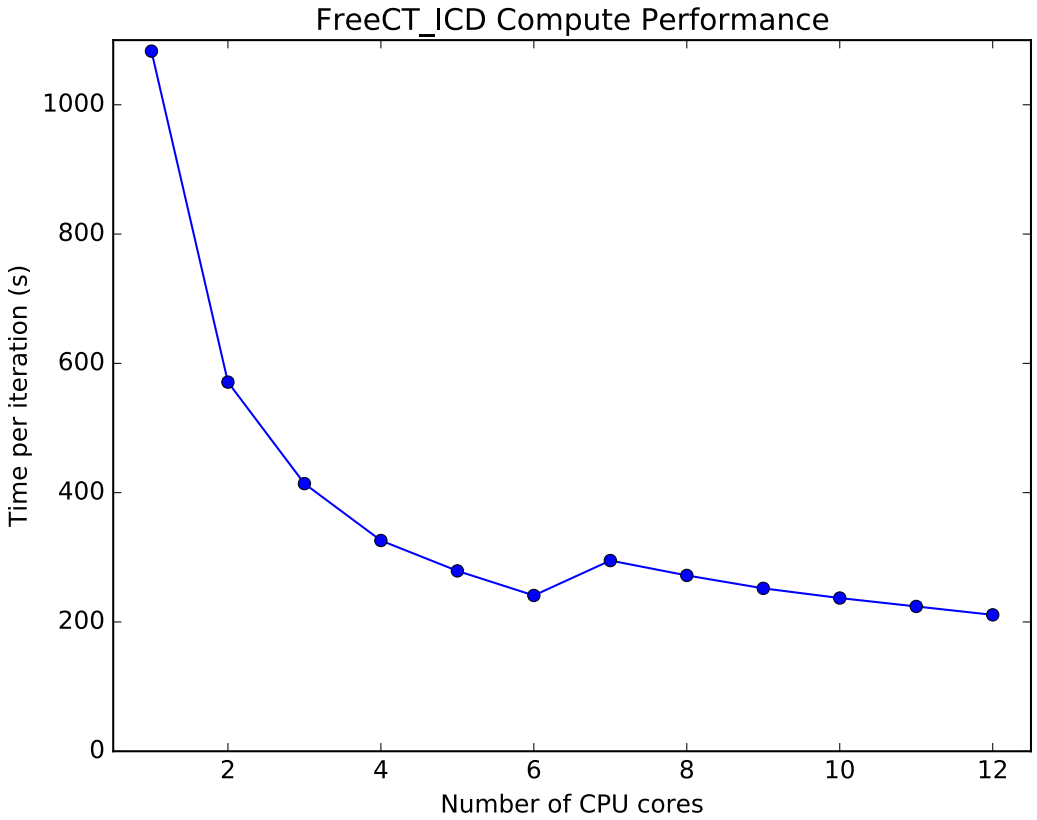

Mean: 59.78 HU
SD: 6.99 HU
Mean: 61.09 HU
SD: 26.66 HU
Mean: 59.30 HU
SD: 6.80 HU

Results

- Execution time/speed
  - ACR Dataset (512x512x120, 16x1.2mm, 11 cores)
    - ~20 minutes per iteration
    - With wFBP initializer, ~2-3 hours per reconstruction

Results

- Execution time/speed



Limitations and Future Work

- 2D Regularizer/Penalty
  - Working on an extension to 3D, math for rotation between slices
- A little slow
  - Working on a GPU version, theoretically ~1 min/iteration
- Raw data availability
- Documentation (incoming)

Conclusions

- Free, open-source MBIR reconstruction software
  - GNU GPL v2.0
- Focus on modularity, low-dependency design
- Reconstructs clinical data

Final Thoughts

- Available today!
  - https://github.com/FreeCT/FreeCT_ICD
- Feedback helps make it better, let us know if you're using it or have any thoughts, contributions
  - jmhoffman@mednet.ucla.edu
  - freect.project@gmail.com

Acknowledgements

- Stefano Young
- Frédéric Noo
- Scott Hsieh

Thank you! Questions?

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