Alpha-image reconstruction (AIR): A novel iterative image reconstruction algorithm with well-defined image quality metrics applied to clinical CT data

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Aims

- Increase convergence speed of the AIR[1] algorithm.
- Demonstrate that conventional image quality metrics can be applied to the AIR images.

[1]Hofmann, Sawall, Knaup, and Kachelrieß, "Alpha Image Reconstruction (AIR): A New Iterative CT Image Reconstruction Approach Using Voxel-Wise Alpha Blending", *Med. Phys. 41(6), p. 061914 (14 pages), 2014*

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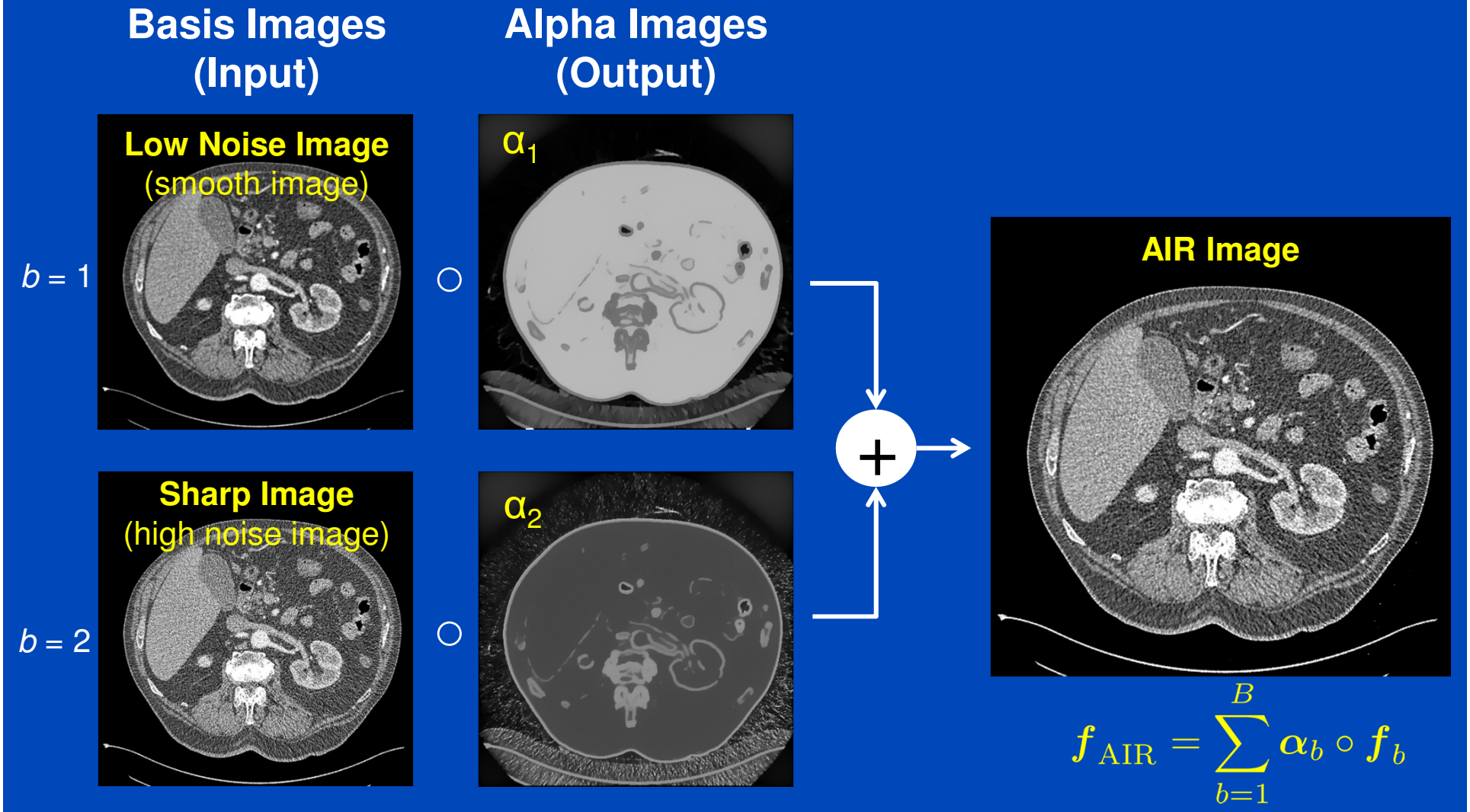
Alpha Image Reconstruction (AIR)[1]



$$f_{\mathrm{AIR}} = \sum_{b=1}^{B} \alpha_b \circ f_b$$

[1]Hofmann, Sawall, Knaup, and Kachelrieß, "Alpha Image Reconstruction (AIR): A New Iterative CT Image Reconstruction Approach Using Voxel-Wise Alpha Blending", *Med. Phys. 41(6), p. 061914 (14 pages), 2014*

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AIR

- **AIR minimizes a cost function:**

Rawdata Fidelity

Regularization

$$C(\boldsymbol{\alpha}) = \underbrace{||\mathbf{X}\left(\sum_{b=1}^{B}\boldsymbol{\alpha}_b \circ \boldsymbol{f}_b\right) - \boldsymbol{p}||^2_{\boldsymbol{W}}}_{\textbf{convex}} + \underbrace{\beta\sum_{b=1}^{B} TV(\boldsymbol{\alpha}_b)}_{\text{TV regularization, } \textbf{convex}} + \underbrace{\gamma\sum_{b=1}^{B}||\boldsymbol{\alpha}_b - \boldsymbol{d}_b||_2^2}_{\text{Penalizes deviations from default images } \mathbf{d}_b, \underline{\textbf{strictly convex}}.}$$

- **Gradient descent approach:**

$$\boldsymbol{\alpha}_b^{\nu+1} = \boldsymbol{\alpha}_b^{\nu} - \lambda\boldsymbol{\nabla}_{\alpha_b}\, C(\boldsymbol{\alpha}_b^{\nu})$$

$$\boldsymbol{\nabla}C(\boldsymbol{\alpha}_b) = \boldsymbol{f}_b \circ \left(\mathbf{x}^T\boldsymbol{W}\left(\mathbf{x}\left(\sum_{b=1}^{B}\boldsymbol{\alpha}_b \circ \boldsymbol{f}_b\right) - \boldsymbol{p}\right)\right) + \boldsymbol{\nabla}_{\alpha_b}\left(\beta\sum_{b=1}^{B} TV(\boldsymbol{\alpha}_b) + \gamma\sum_{b=1}^{B}||\boldsymbol{\alpha}_b - \boldsymbol{d}_b||_2^2\right)$$

- $\beta, \gamma = 0.01$

Improved AIR

- **Improved AIR separates optimization into two steps:**

Rawdata Fidelity | Regularization

$$C(\boldsymbol{\alpha}) = \|\mathbf{X}\left(\sum_{b=1}^{B} \boldsymbol{\alpha}_b \circ \boldsymbol{f}_b\right) - \boldsymbol{p}\|_{\boldsymbol{W}}^2 + \beta \sum_{b=1}^{B} TV(\boldsymbol{\alpha}_b) + \gamma \sum_{b=1}^{B} \|\boldsymbol{\alpha}_b - \boldsymbol{d}_b\|_2^2$$

One iteration =

1. Step: Optimization of rawdata fidelity with OS-SART

⇩

SART image $\boldsymbol{\alpha}_{SART}$

2. Step: Optimization of regularization terms with gradient descent

⇩

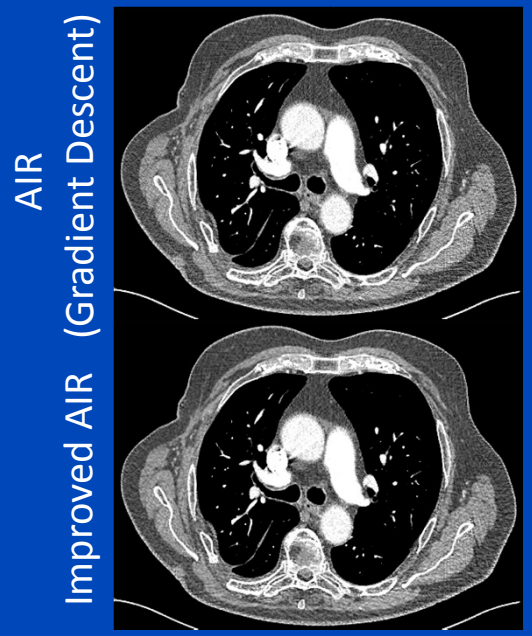
Regularized image $\boldsymbol{\alpha}_{Reg}$

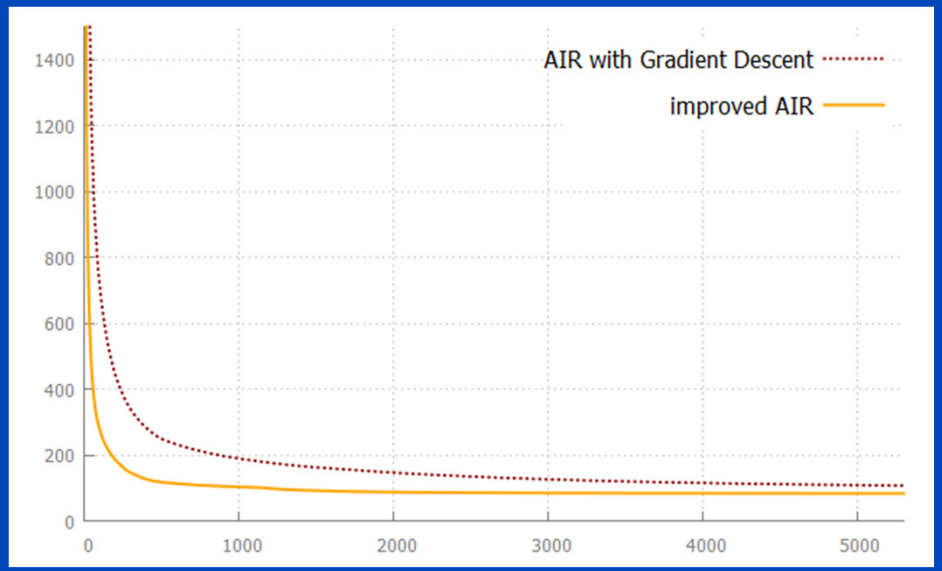
Linear Combination: $\boldsymbol{\alpha} = (1-\tau)\boldsymbol{\alpha}_{SART} + \tau\boldsymbol{\alpha}_{Reg}$

- $\beta, \gamma = 0.01$ (different weighting between the penalty terms is possible)

Performance

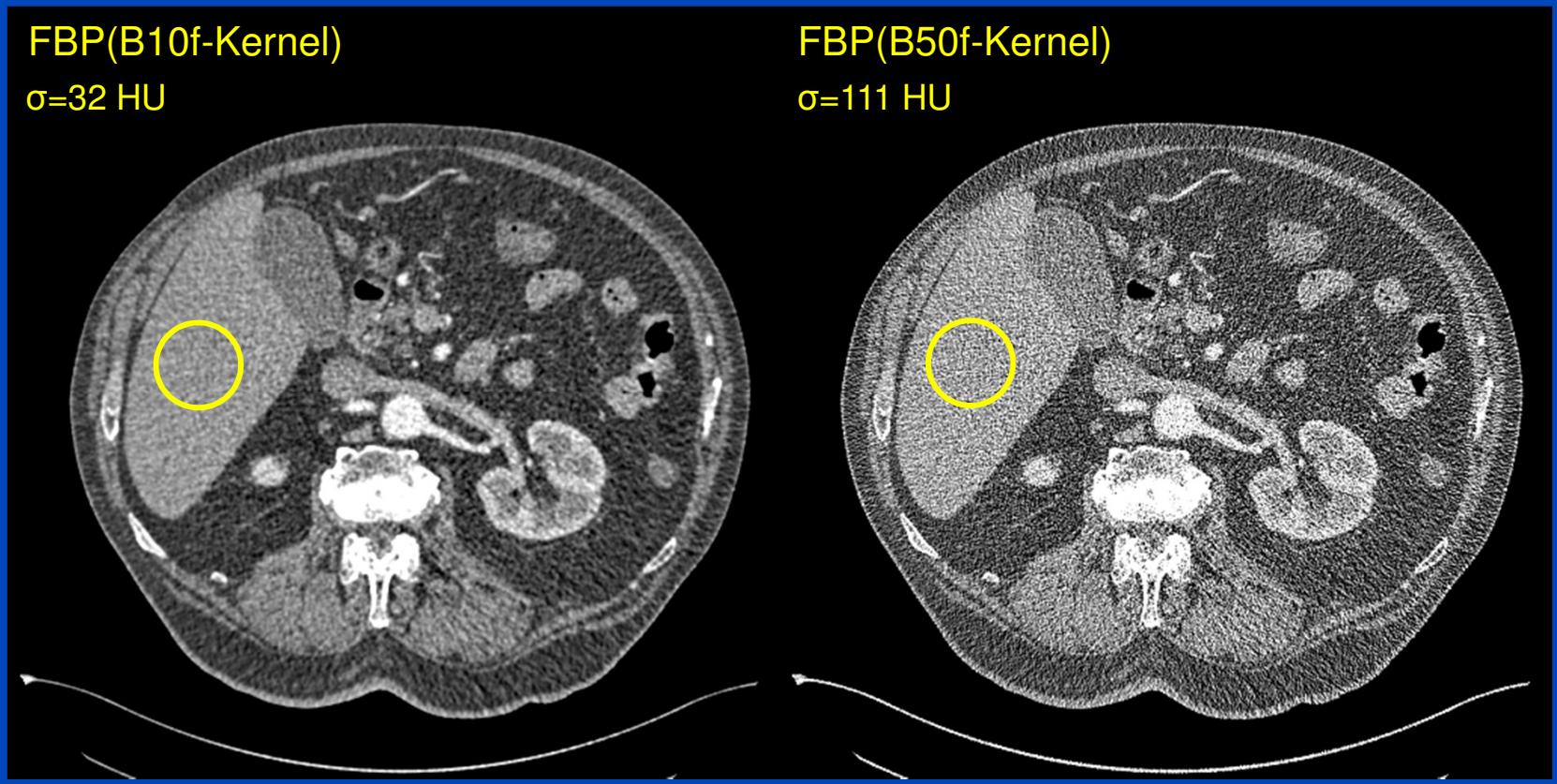
- **High quality images can be acquired after a couple 1000 iterations of the gradient descent implementation and after 200-300 iterations of the improved algorithm.**





Convergence plots of the rawdata fidelity

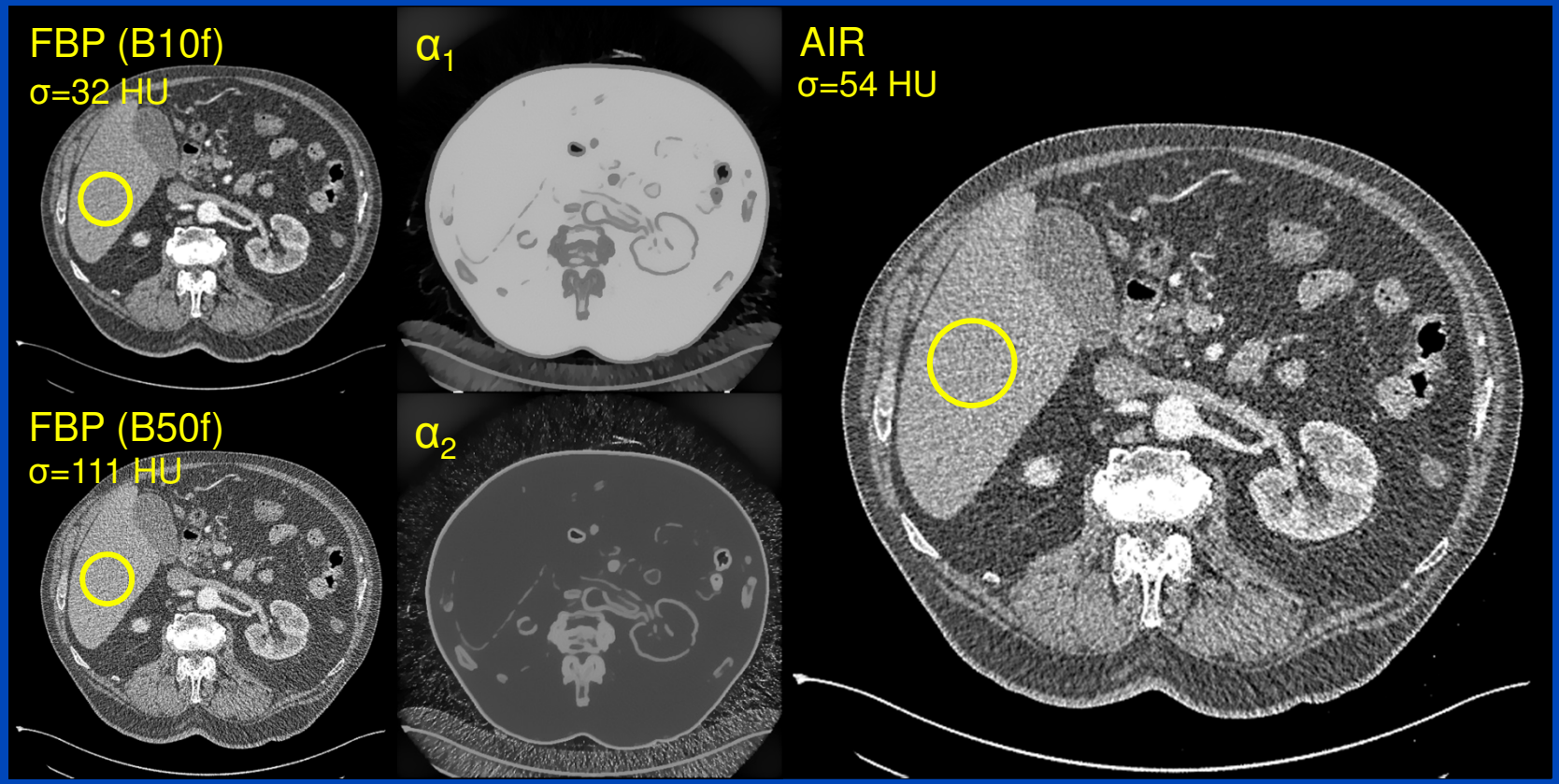
AIR Applied to Clinical Data



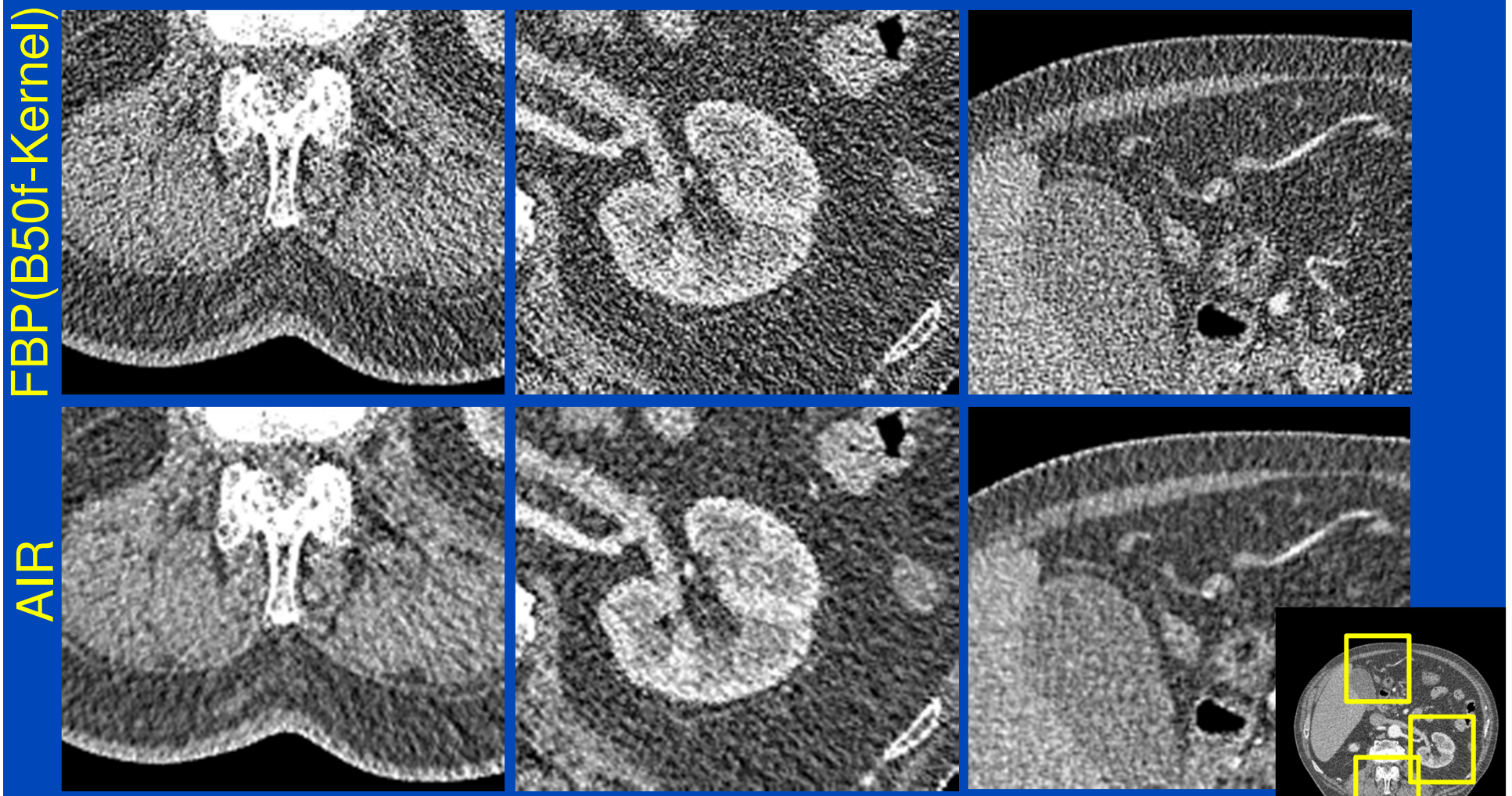
C/W = 0/500 HU

C/W = 0/500 HU

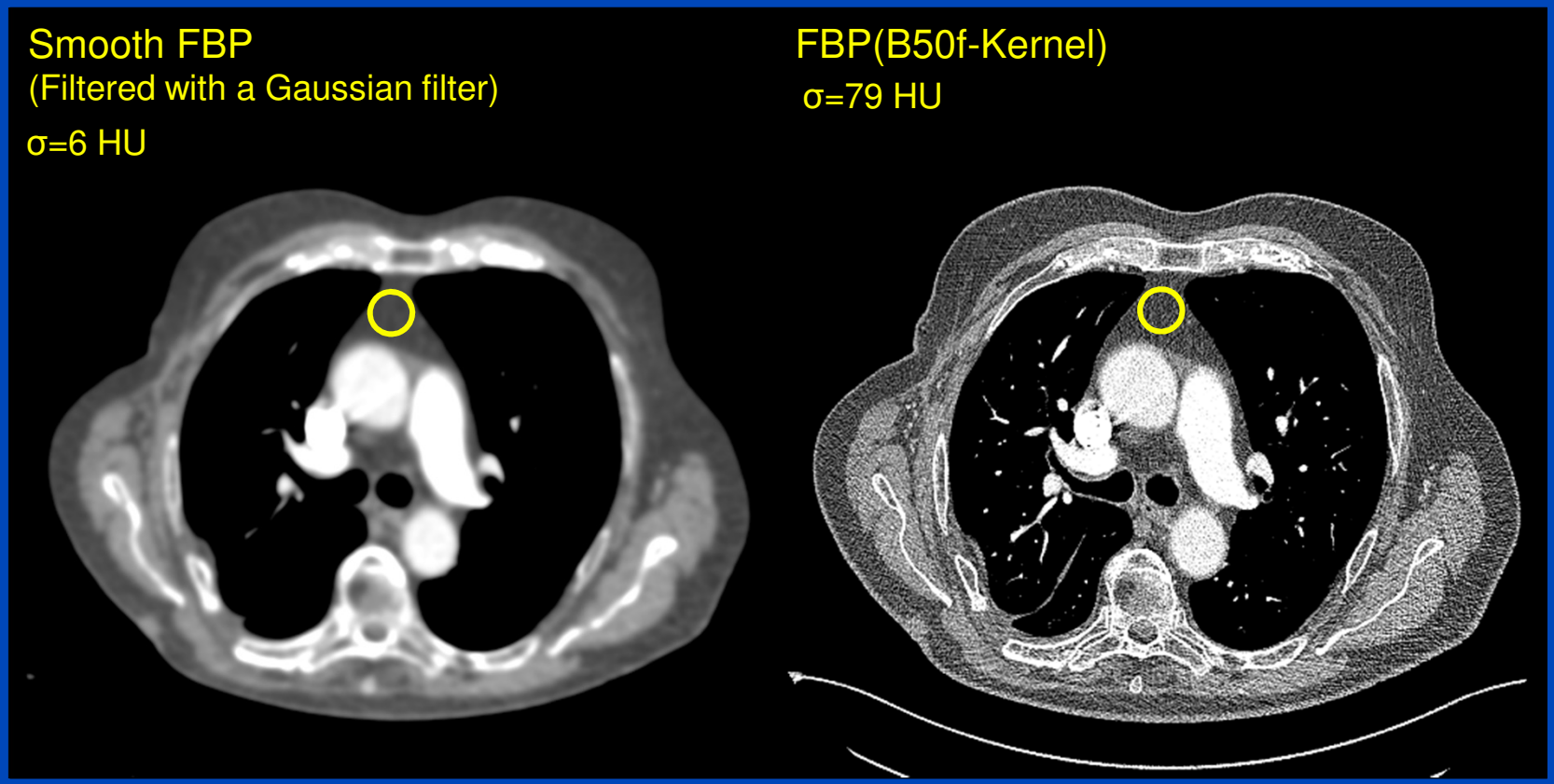
AIR Applied to Clinical Data



AIR Applied to Clinical Data

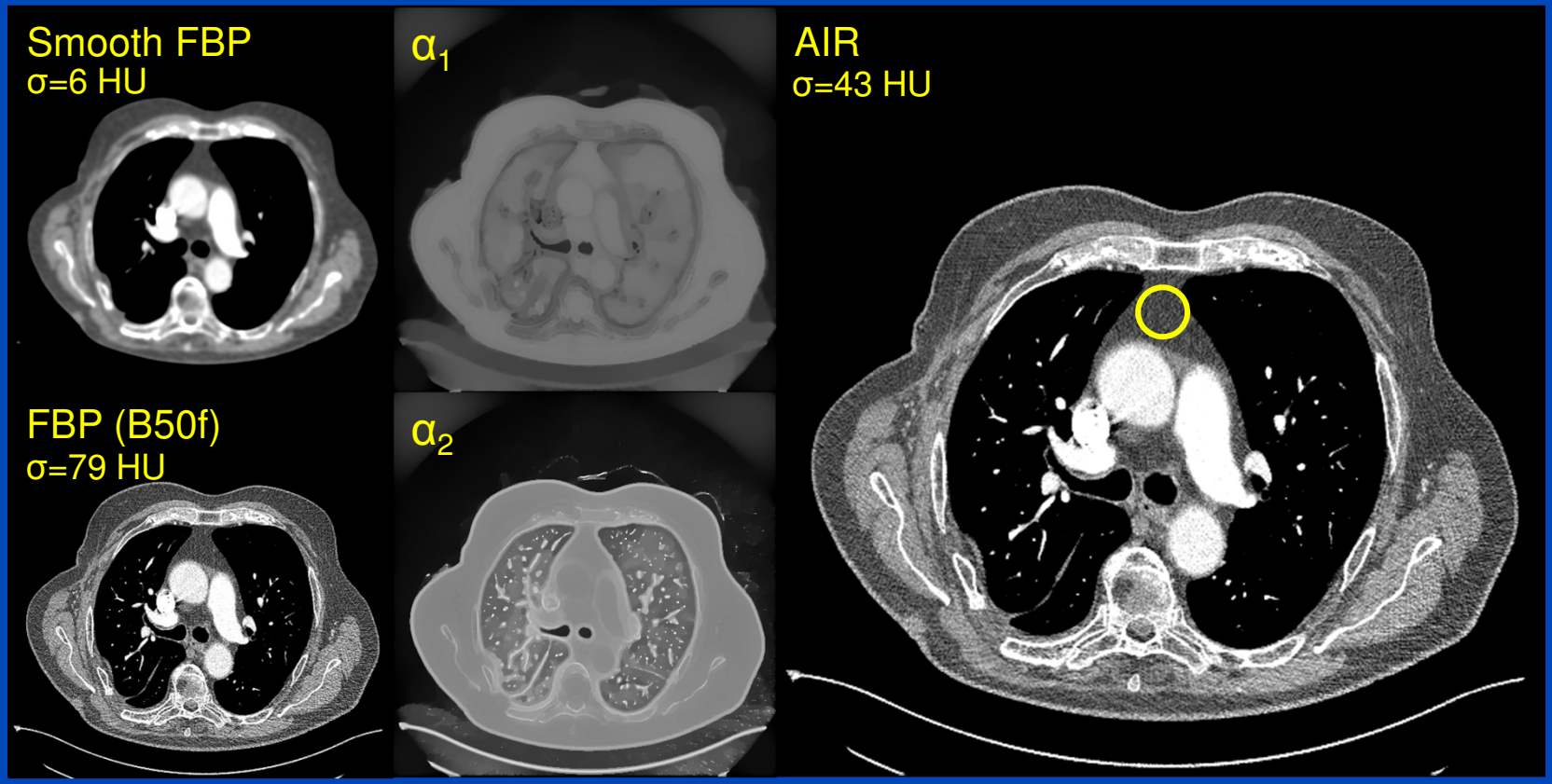


AIR Applied to Clinical Data

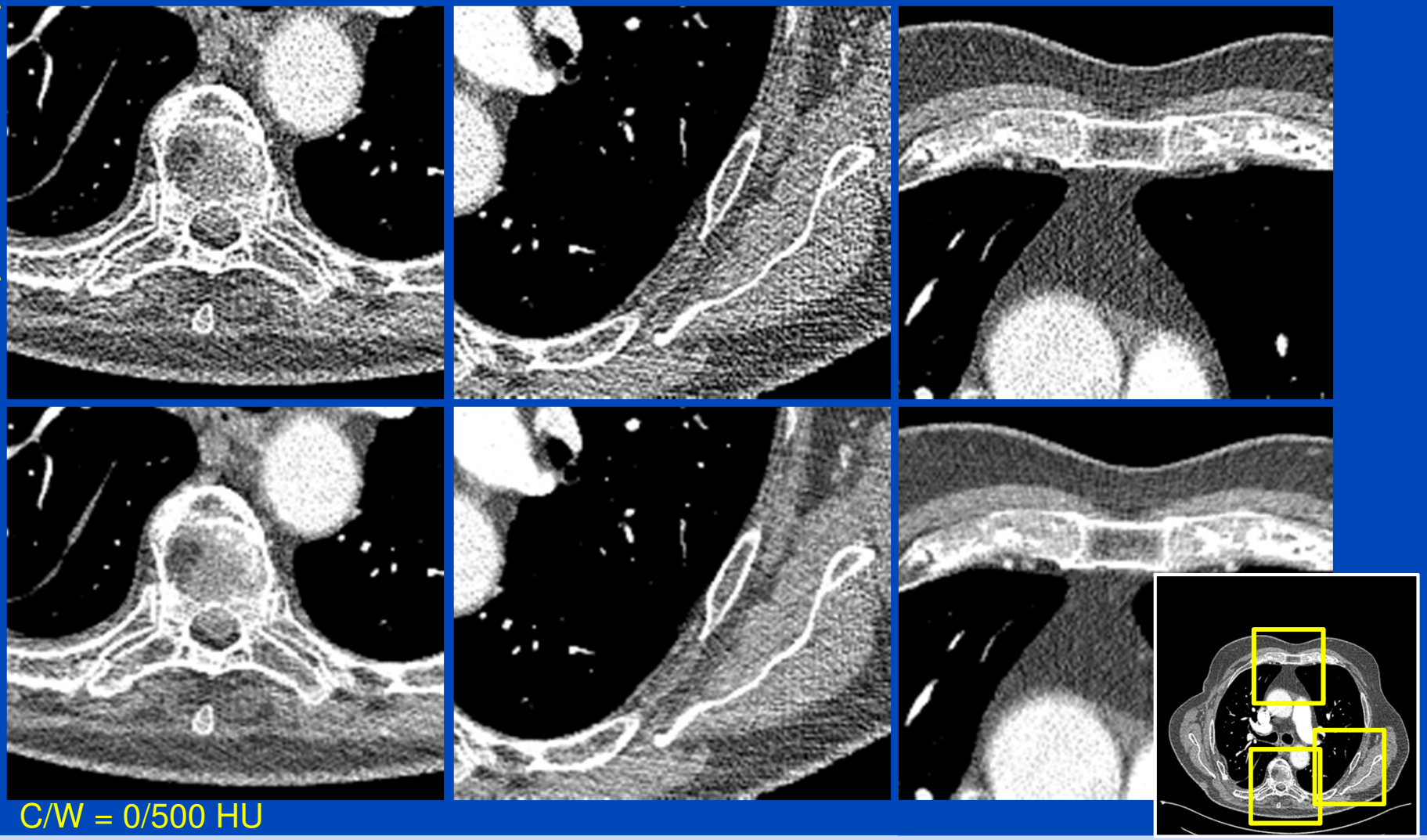


C/W = 0/500 HU C/W = 0.5/1 C/W = 0/500 HU

AIR Applied to Clinical Data



AIR Applied to Clinical Data



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Modulation Transfer Function

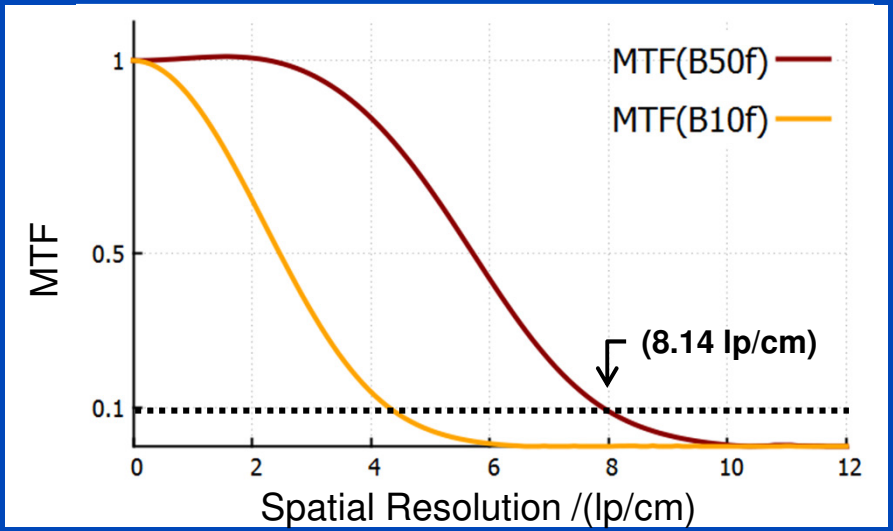
- **If an MTF or another image quality metric is defined for the basis images it can be estimated for every voxel of the AIR image.**
- **MTF of a B50f/B10f-Kernel was measured at a Definition Flash Scanner.**

$$\mathrm{MTF}(j,\rho) = \sum_{n}^{B} \alpha_b^j \, \mathrm{MTF}_b(\rho)$$

α_b^j = voxel j of weighting image b

B = number of basis images

MTF_b = MTF of the basis image b



Modulation Transfer Functions for the Basis Images

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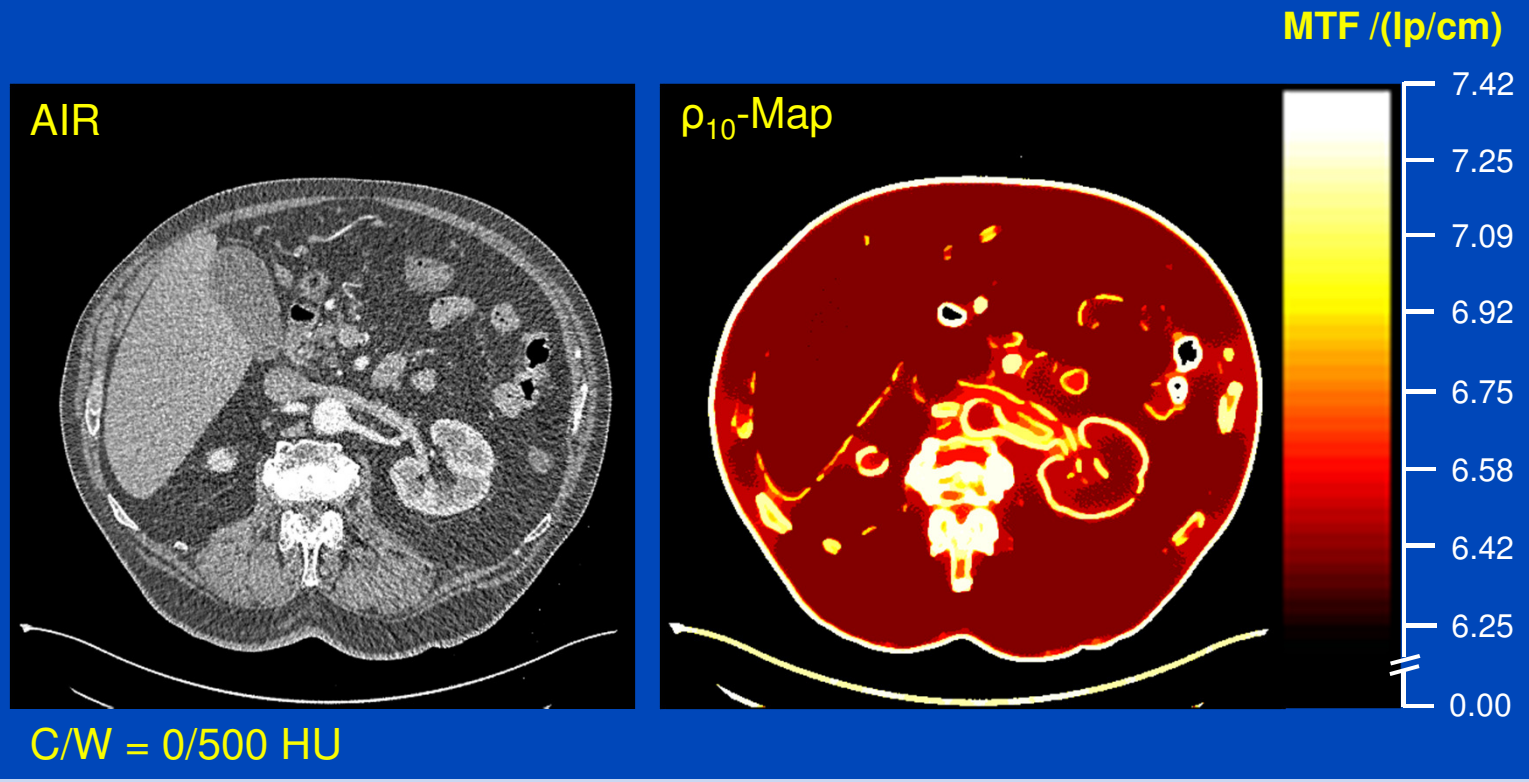
Modulation Transfer Function

- The MTF is computed for each voxel.
- The “10%-value“ of the MTF ρ_{10} for each voxel is displayed as a map.



Conclusion

- Optimized AIR algorithm improves performance by a factor of about 5-10.
- Noise can be significantly reduced while spatial resolution at edges is mostly maintained.
- Predictions for image quality metrics based on the basis images are possible.

Thank You!

The 4th International Conference on

Image Formation in X-Ray Computed Tomography

Conference Chair

Marc Kachelrieß, German Cancer Research Center (DKFZ), Heidelberg, Germany

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

Parts of the reconstruction software RayConStruct IR were provided by RayConStruct® GmbH, Nürnberg, Germany.