Simple Image Domain Denoising with an Adaptive Bilateral Filter Drastically Improves Robustness of Quantitative Emphysema Scoring to Changes in Dose, Reconstruction Kernel, and Slice Thickness

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Purpose and Significance

- Purpose:
  - Evaluate the feasibility of post-reconstruction adaptive denoising to minimize/mitigate the impacts of parameter selection on emphysema scoring
- Significance:
  - Image post-processing is one possible method to improve reliability (Gallardo-Estrella 2016/2017, Schilham 2006, Tylen 2001)
  - If successful
    - Simple, easily available alternative to strict protocol standardization
    - Allow for reduced-dose scans combined with smoothing for quantitative emphysema scoring
    - Could allow for more widespread utilization of quantitative emphysema scoring

Robustness of QI for Emphysema Scoring

- Changes in CT parameters can introduce changes in emphysema scores:
  - **Reconstruction kernel:** Trotta et al. 2006, Boedeker et al. 2007, Gierada et al. 2010
  - **Slice thickness:** Genevois et al. 1996, Trotta et al. 2006, Gierada 2010
  - **Dose reduction:** Trotta et al. 2006, Gierada et al. 2007, Choo et al. 2014, Nishio et al. 2012 & 2016
  - **Reconstruction algorithm:** Mets et al. 2012, Choo et al. 2014, Nishio et al. 2012 & 2016
  - **Multivariate:** Gierada et al. 2010 (slice thickness, reconstruction kernel)
- Image post-processing may be one means to mitigate the effects of parameters selection

Methods

- Bilateral filtering

$$I_{filtered}(\vec{x}) = \frac{1}{W_p} \sum_{\vec{x}_i \in \Omega_i} I(\vec{x}_i) e^{-\frac{\|\vec{x}_i - \vec{x}\|}{2\sigma_d^2}} e^{-\frac{\|I(\vec{x}_i) - I(\vec{x})\|}{2\sigma_r^2}}$$

Gaussian filter

"Range" filter

- Small differences in intensity, likely noise, get smoothed away (i.e. higher weight in the range filter)
- Big differences, likely to be actual edges, are preserved (i.e. lower weight in the range filter)

Methods

- Bilateral filtering
  - Adapted to dose and slice thickness according to:

$$\sigma_r(d_{test}, s_{test}) = \sqrt{2}^{\left(\frac{d_{ref}}{d_{test}}\right)*\left(\frac{s_{ref}}{s_{test}}\right)-1}$$

TABLE 4-1 VALUES FOR THE STANDARD DEVIATION OF THE RANGE FILTER (σ_r) AS A FUNCTION OF DOSE AND SLICE THICKNESS.

		Dose (%)			
		100	50	25	10
Slice Thickness (mm)	2.0	0.841	1.000	1.414	4.000
	1.0	1.000	1.414	2.828	22.627
	0.6	1.260	2.245	7.127	228.070

Effectively Gaussian

Methods

- Cohort
  - 142 subjects scanned with the **lung screening protocol** at our site (MP 200, Def. AS 64)
    - 120 kV, tube current modulation, 25-40 quality reference mAs (~2 mGy CTDIvol), 64x0.6mm collimation

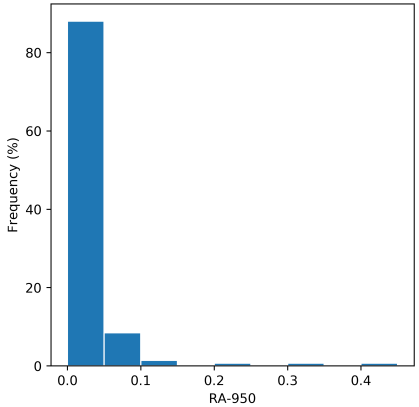


Figure: Histogram of RA-950 scores at reference

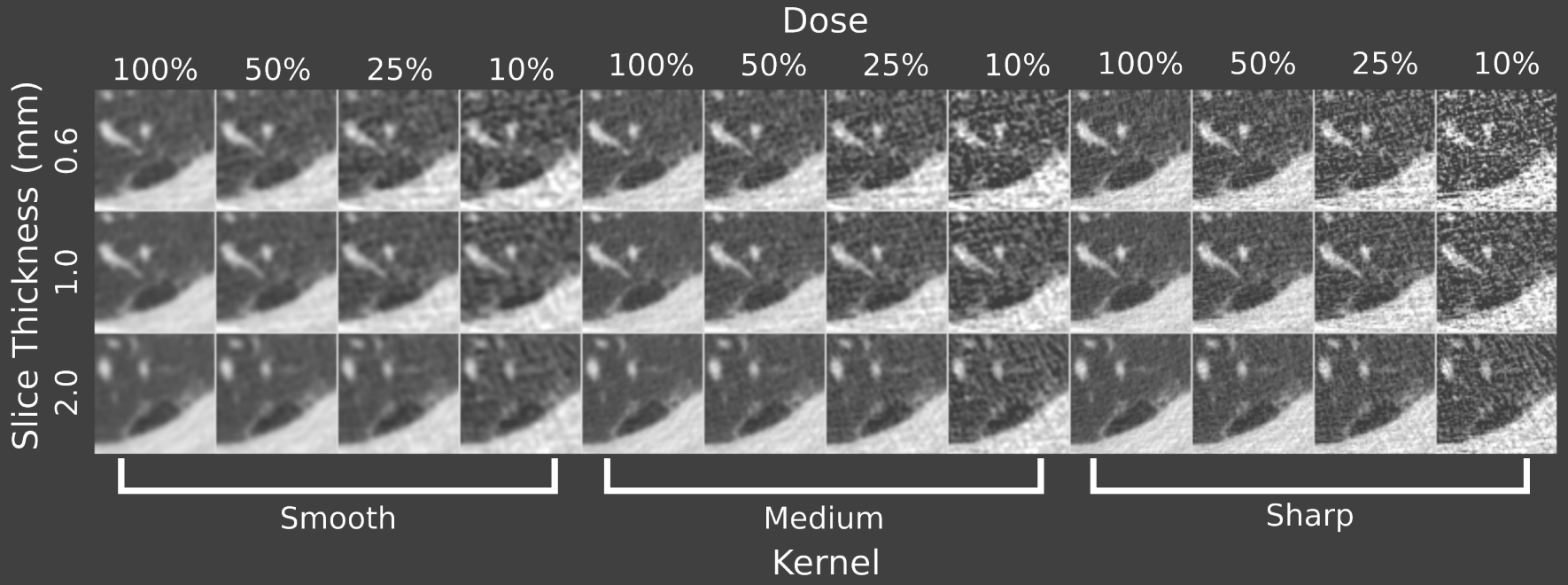
SA-2

Methods

- Reconstructions
  - **72 configurations per subject**
  - 4 simulated doses: 100%, 50%, 25%, 10% (approx. 2.0, 1.0, 0.5, and 0.2mGy CTDIvol)
  - 3 kernels: Smooth, Medium, Sharp
  - 3 slice thicknesses: 0.6mm, 1.0mm, 2.0mm
  - 2 algorithms: FreeCT_wFBP, Siemens SAFIRE

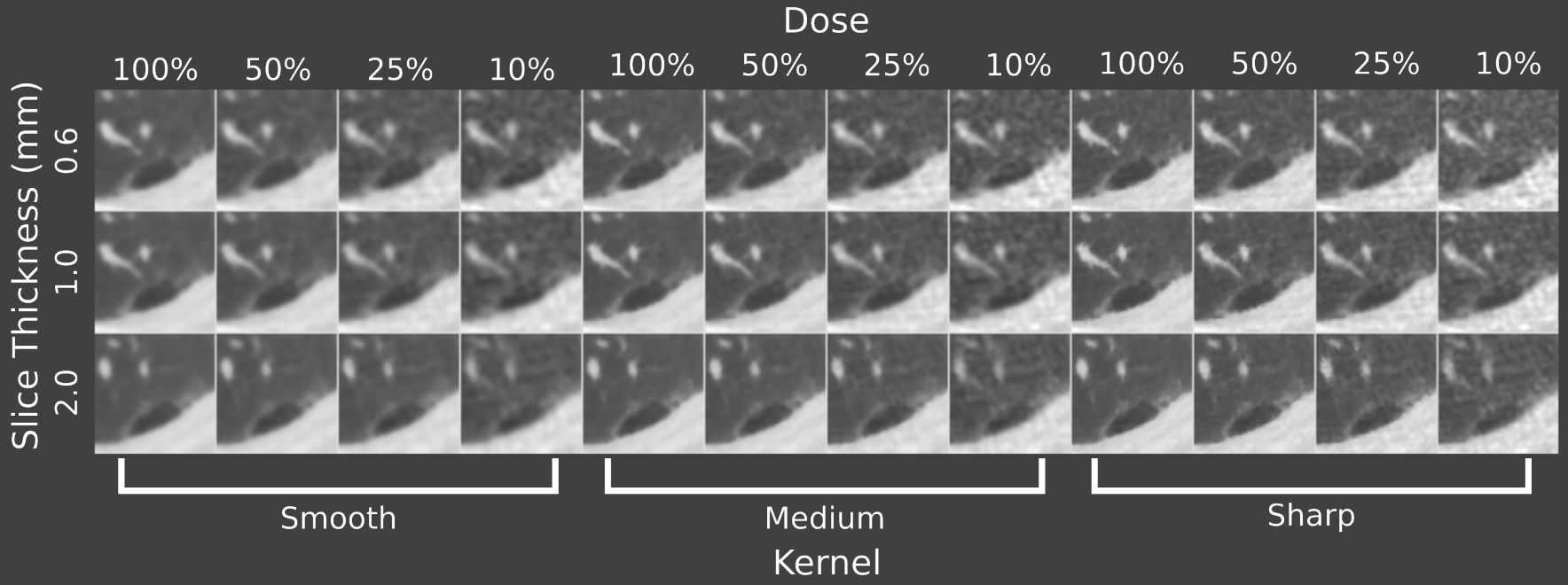
Specific Aim 3

Sample Images: wFBP



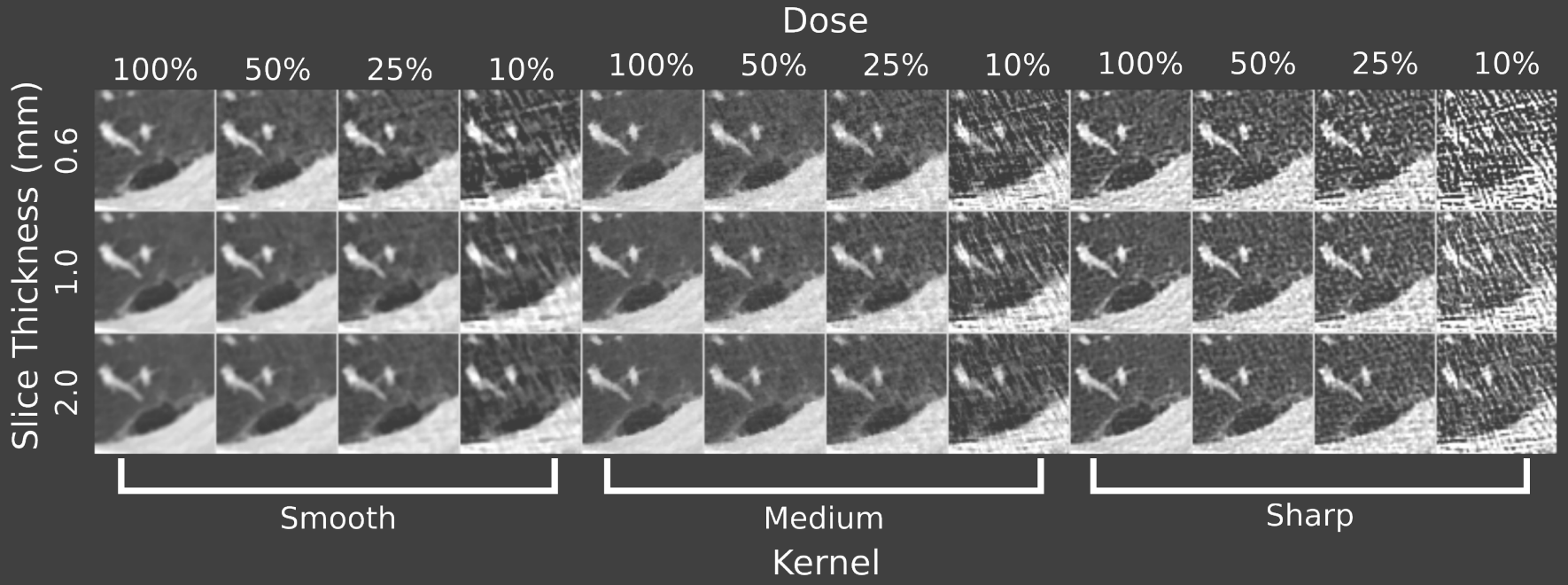
Specific Aim 3

Sample Images: wFBP + denoising



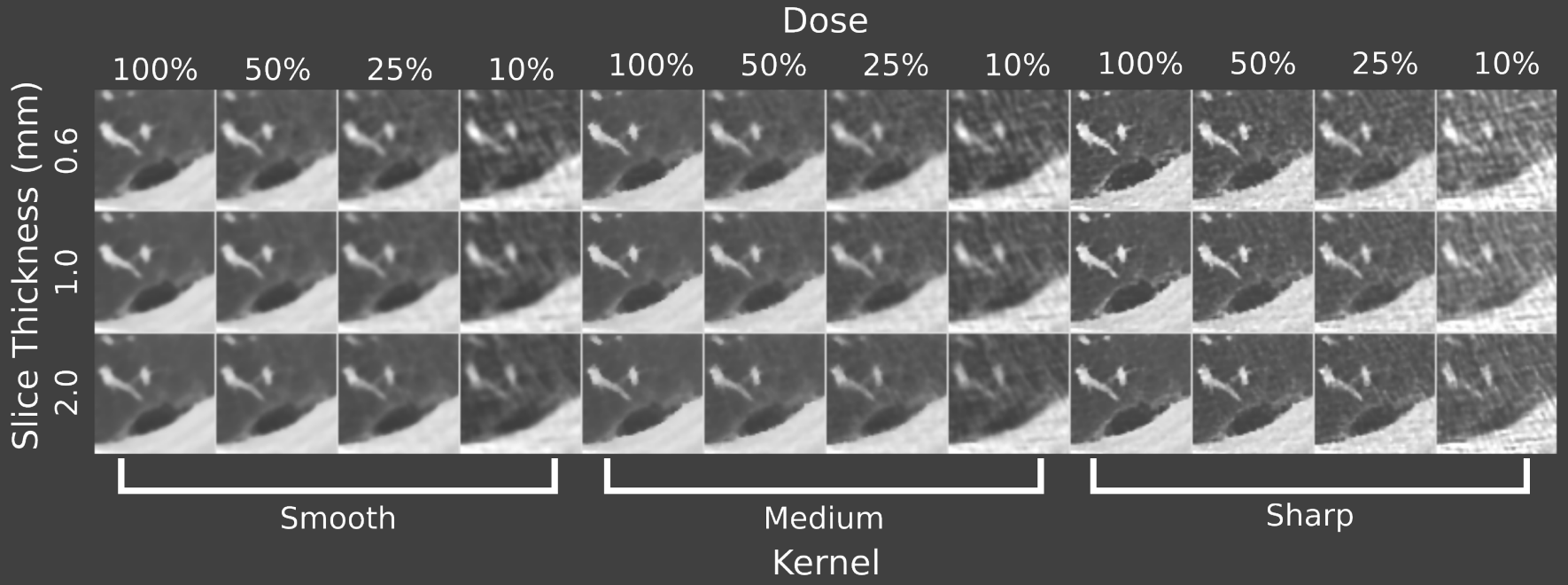
Specific Aim 3

Sample Images: SAFIRE



Specific Aim 3

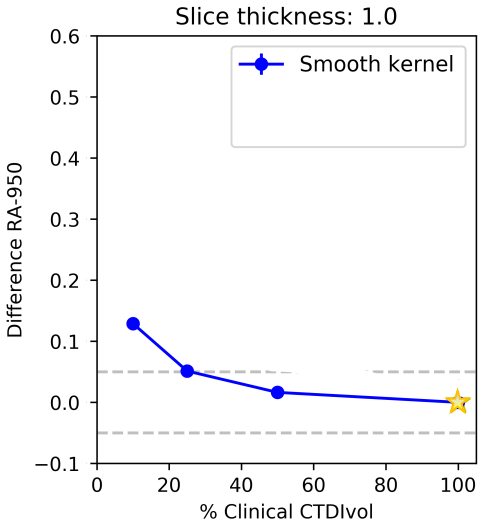
Sample Images: SAFIRE + denoising



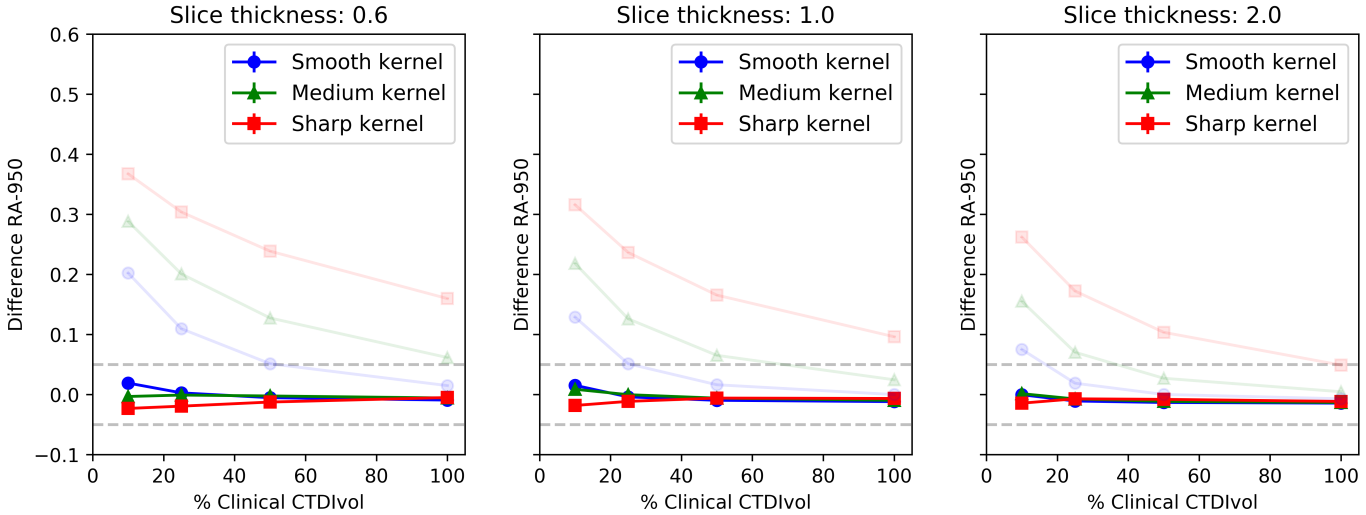
Specific Aim 3

Results:

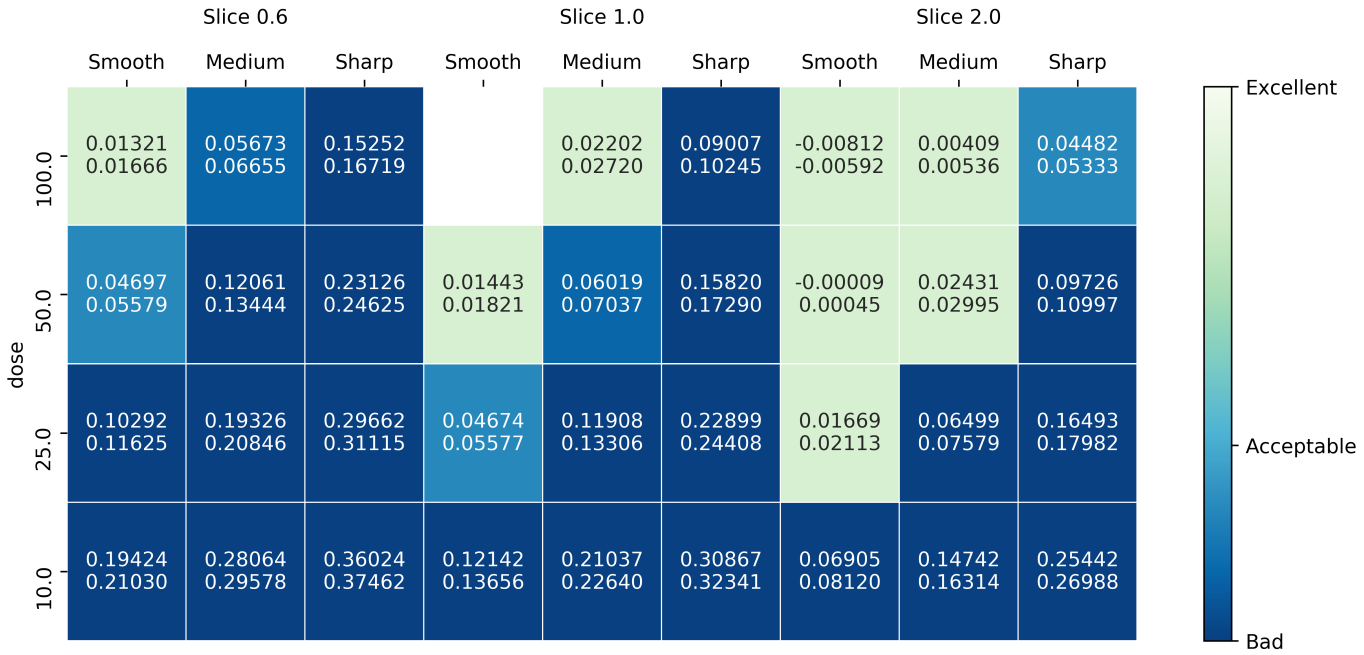
Results: wFBP *(without denoising)*



Results: wFBP + bilateral filtering



Results: wFBP (reminder)

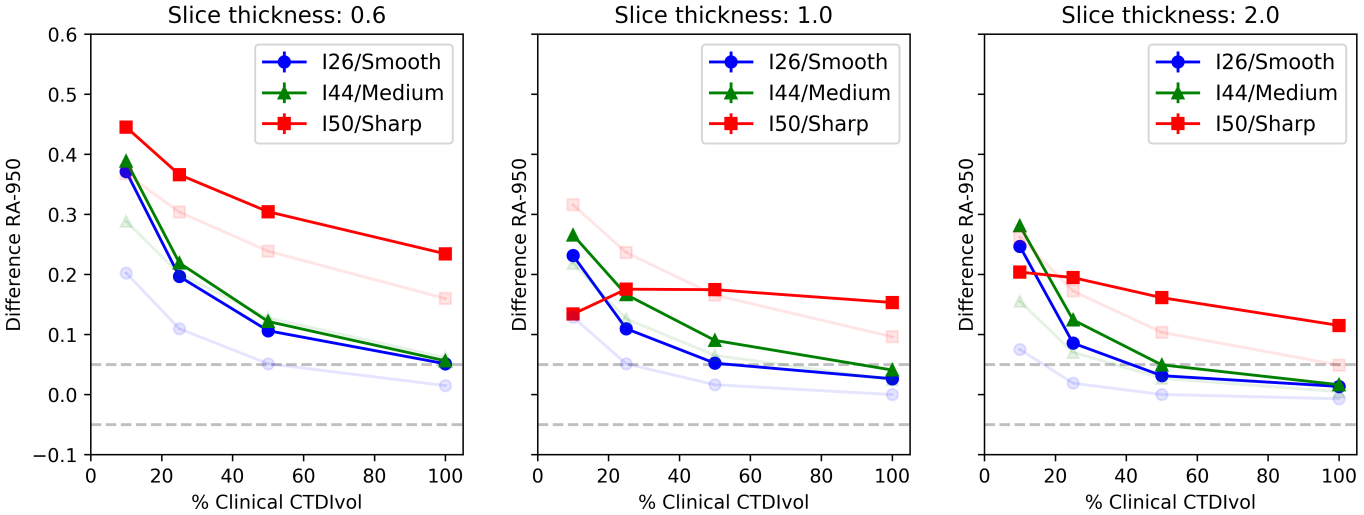


Results: wFBP + bilateral filtering

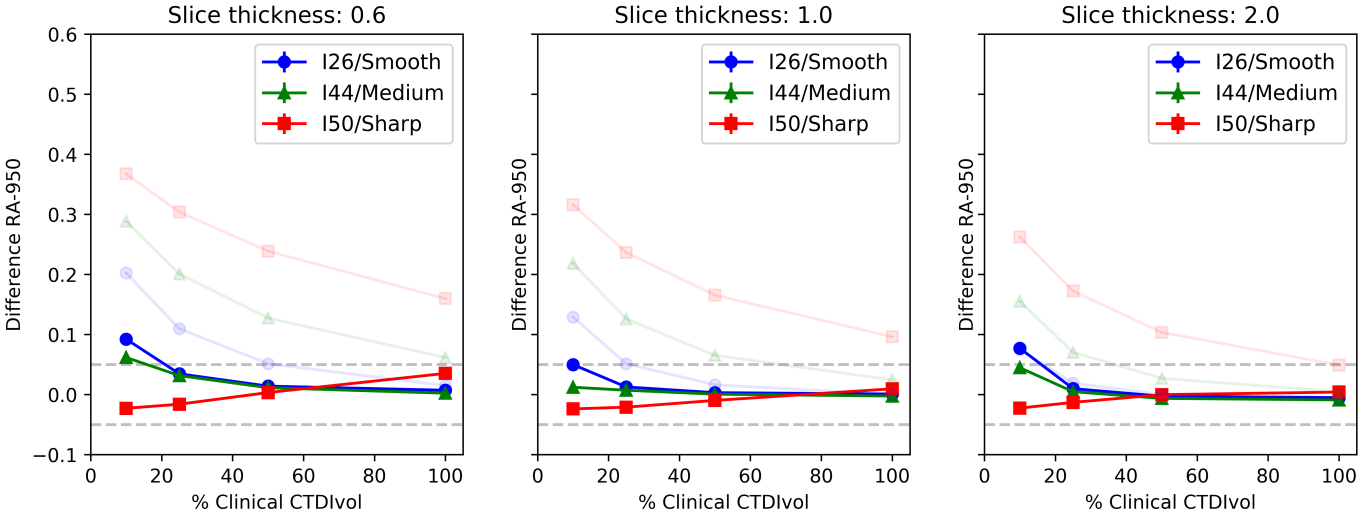
Specific Aim 3

Results: SAFIRE

Results: SAFIRE



Results: SAFIRE + bilateral filtering



Specific Aim 3

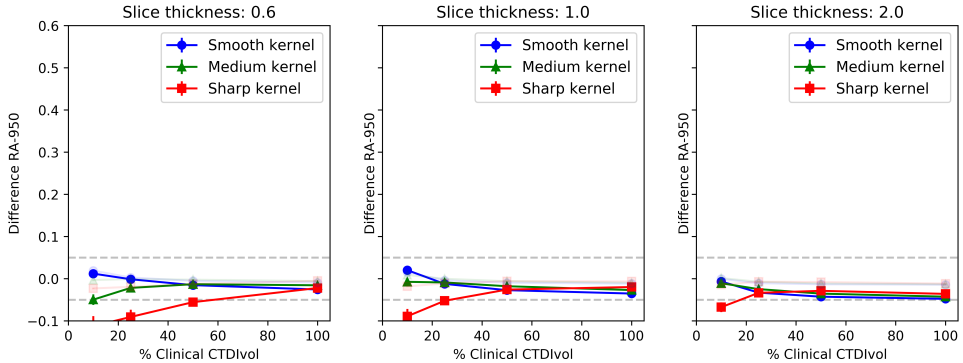
Results: SAFIRE + bilateral filtering

Conclusions

- Bilateral filtering *very* effective
  - Removes influence of dose, slice thickness, kernel
  - Possible pathway for improving robustness of emphysema scoring
- More effective for wFBP than SAFIRE
  - Quantitatively supported with regression analysis

Limitations

- Screening study population with relatively low emphysema



Subjects with RA-950 >= 0.05 at reference (N=17)

Limitations

- Screening study population with relatively low emphysema

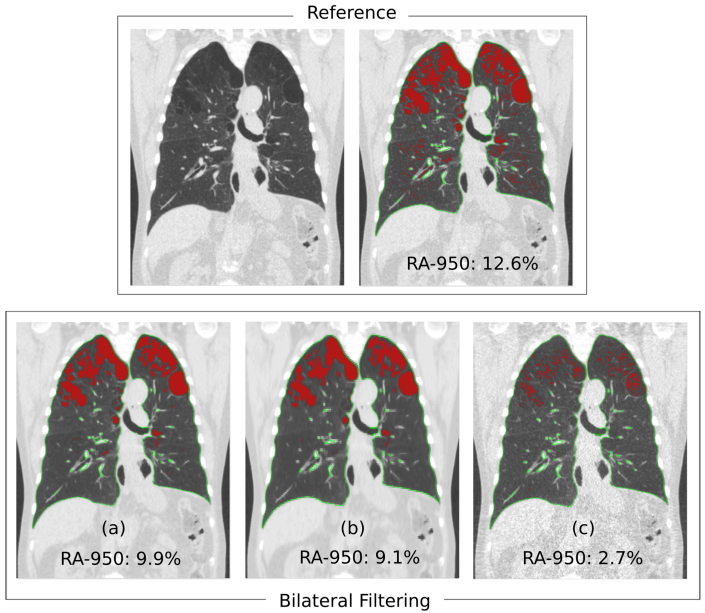


FIGURE 4-12 SAMPLE CORONAL IMAGES OF RA-950 MASK IN A HIGH-BASELINE EMPHYSEMA PATIENT. 100% DOSE IS SHOWN. TOP ROW SHOWS THE REFERENCE RECONSTRUCTION AND CORRESPONDING RA-950 MASK. BOTTOM ROW SHOWS THREE EXAMPLES WITH BILATERAL FILTERING: (A) REFERENCE RECONSTRUCTION (100% DOSE, 1.0MM SLICE THICKNESS, SMOOTH RECONSTRUCTION KERNEL) (B) 100% DOSE, 2.0MM SLICE THICKNESS, SMOOTH KERNEL, AND (C) 25% DOSE, 0.6MM SLICE THICKNESS, SHARP KERNEL (NOT USABLE).

Thank you! Questions?

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