Metal Artifact Reduction in Photon Counting CT Using Pseudo-Monochromatic Images

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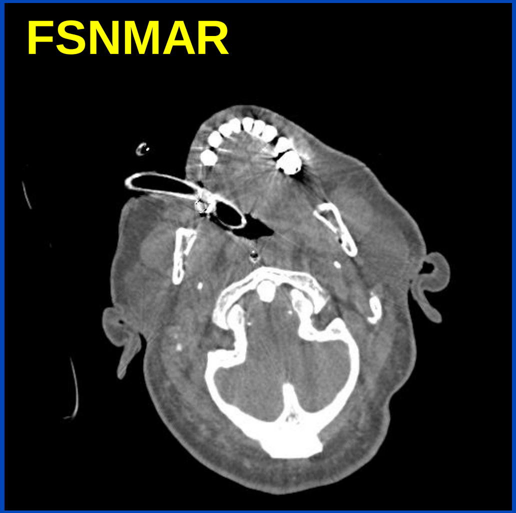
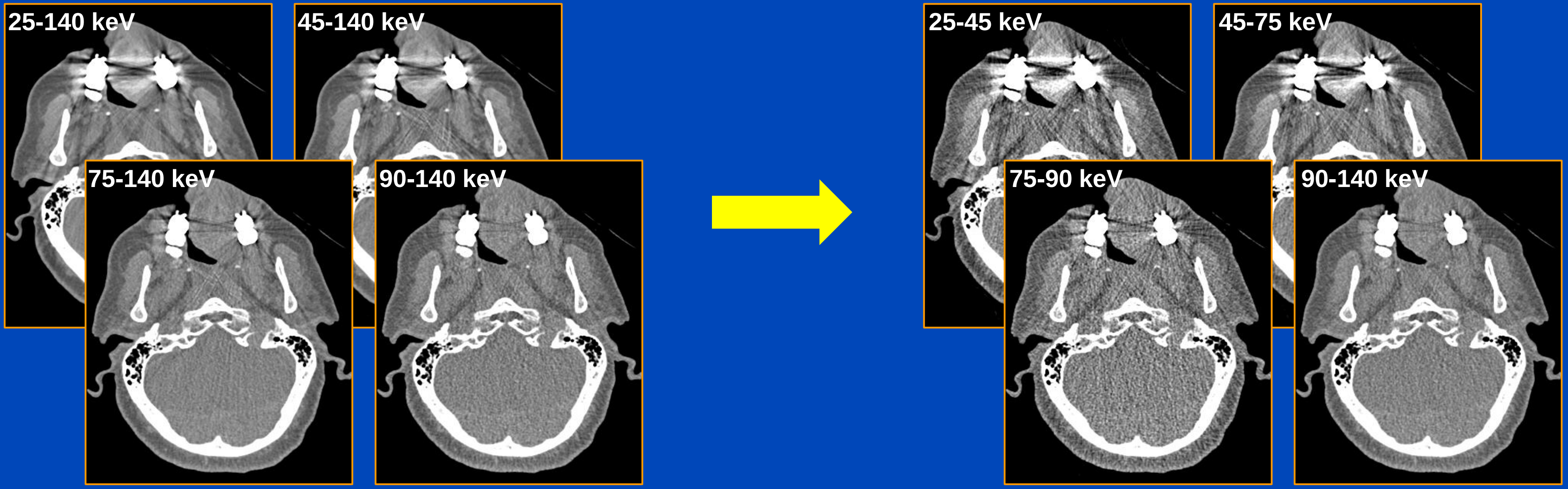
Introduction

- Metal artifacts strongly reduce the diagnostic value of CT images
- Even frequency split normalized metal artifact reduction (FSNMAR), the gold standard, cannot fully remove artifacts
- Since metal artifacts are partially due to beam hardening, a true monochromtatic image should show very little artifacts



Photon Counting CT

- Photon counting CT (PCCT) compares incoming photons to several thresholds
- If a photon has an energy higher than the threshold, it will contribute to the corresponding threshold image
- We can also produce bin images, where the contributing photons are between two thresholds

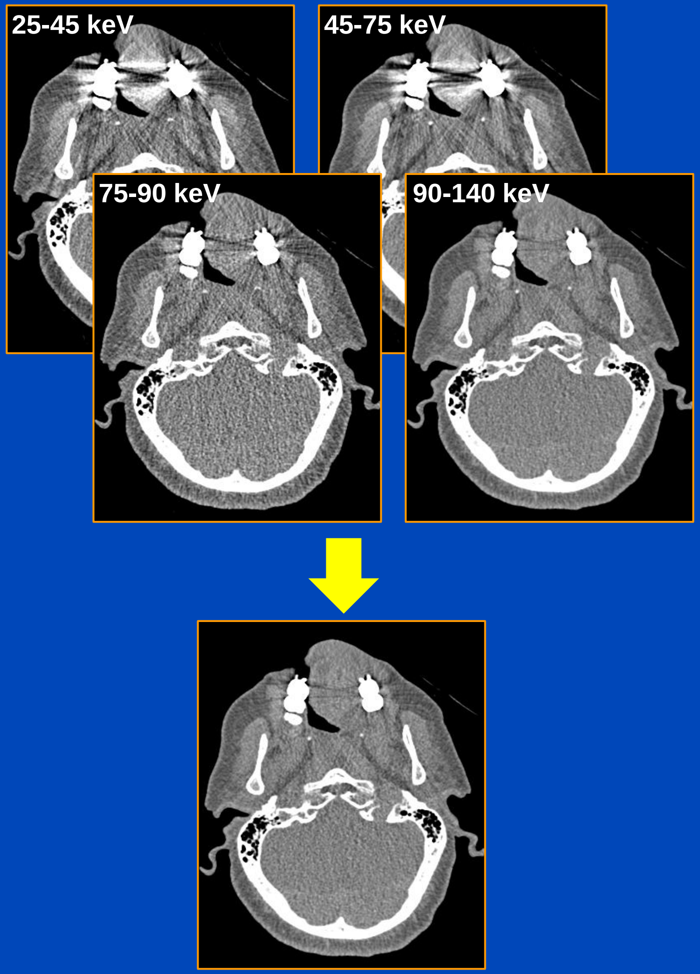


Threshold images   Bin images

C = 50 HU, *W* = 700 HU

Pseudo-Monochromatic Imaging

- A true monochromatic image does not have beam-hardening artifacts
- Virtual monochromatic images are generated by combining the raw data
- Pseudo-monochromatic images are produced by linearly combining the reconstructed bin images f_i
- The final image (for four energy bins) is then defined as $f_{\alpha,\beta,\gamma} = \alpha f_1 + \beta f_2 + \gamma f_3 + (1- \alpha - \beta - \gamma) f_4$



PMI with α=-0.14 , β=-0.08, γ=0.36

Kuchenbecker, Faby, Sawall, Lell, and Kachelrieß, "Dual energy CT: How well can pseudo-monochromatic imaging reduce metal artifacts?" Med. Phys 42(2):1023-1036, 2015

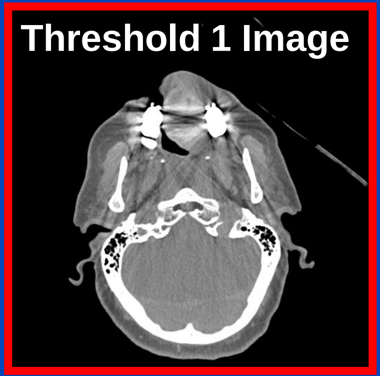
Linear Coefficients

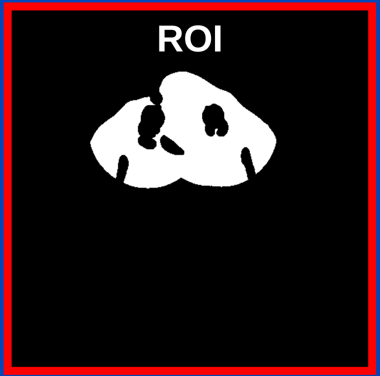
- To find the linear coefficient, we use a Nelder-Mead algorithm that minimizes a cost function *C*

$$C(\alpha,\beta,\gamma) = L(\alpha,\beta,\gamma) + \lambda TV(\alpha,\beta,\gamma)$$

$$C(\alpha,\beta,\gamma) = \sum_{(i,j)\in \mathrm{ROI}} f^2_{\alpha,\beta,\gamma}(i,j) + \lambda \sum_{(i,j)\in \mathrm{ROI}} |\nabla f_{\alpha,\beta,\gamma}(i,j)|$$

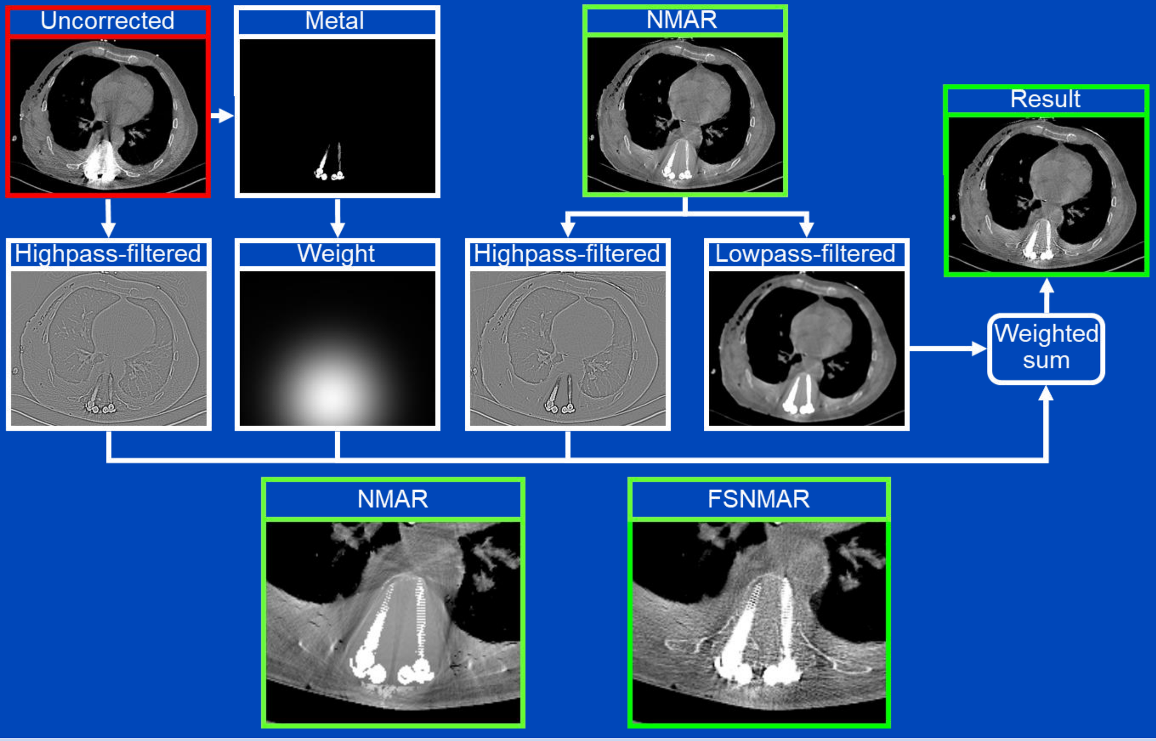
- The ROI includes only soft tissue close to the metal
- $TV(\alpha,\beta,\gamma)$: reduces streaks and smooths the image
- $L(\alpha,\beta,\gamma)$: penalizes large homogeneous artifacts





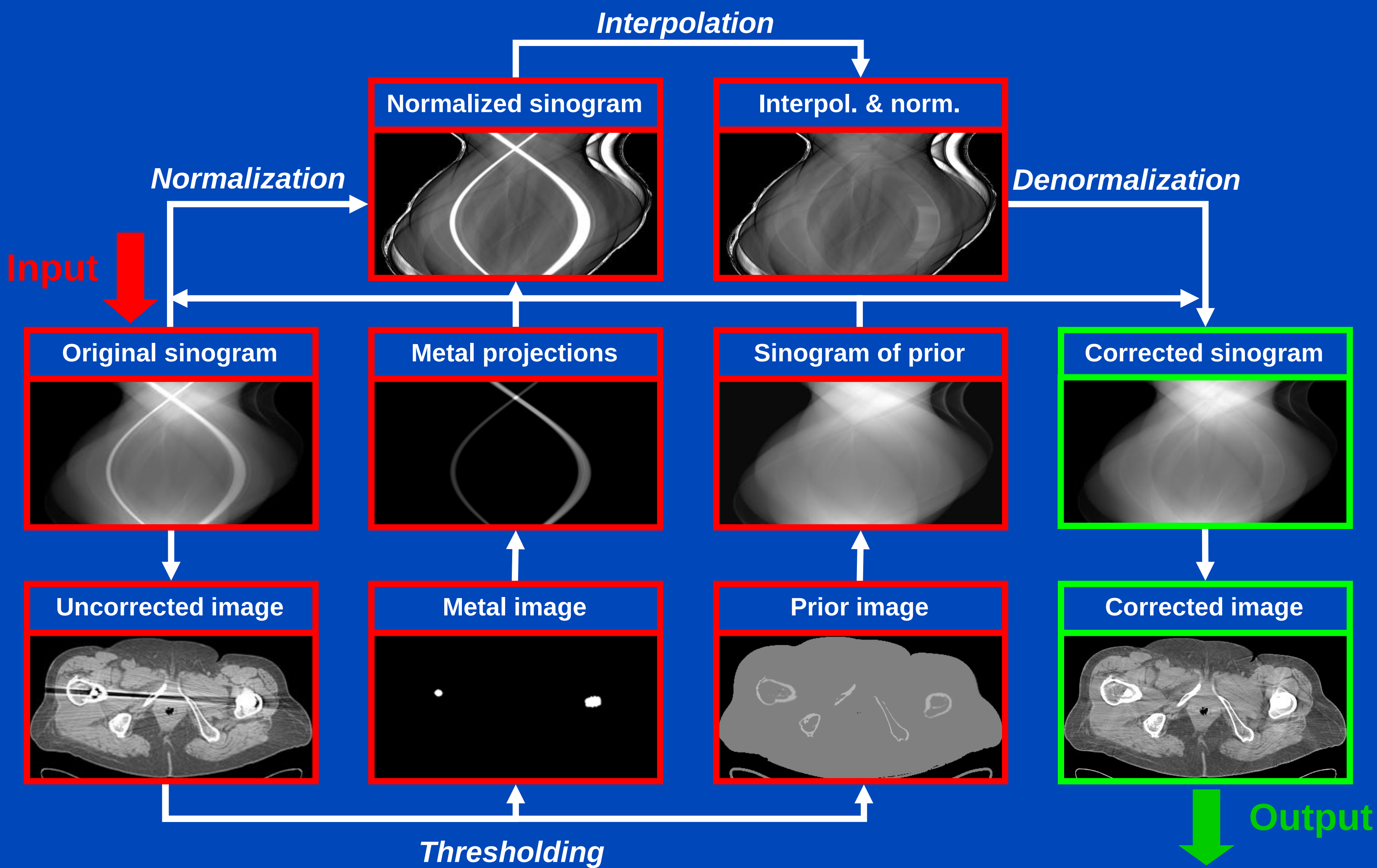
FSNMAR

- To gauge how well PMIs can reduce metal artifacts, they are compared to a state of the art inpainting method, FSNMAR
- FSNMAR is applied to the lowest threshold image T1, which contains the most photons, and to the PMIs



Meyer, Raupach, Lell, Schmidt, and Kachelrieß, “Frequency split metal artifact reduction (FSMAR) in computed tomography”, Med. Phys. 39(4):1904-1916, 2012.

Normalized MAR (NMAR)



Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Normalized metal artifact reduction (NMAR) in computed tomography", Med. Phys. 37(10):5482-5493, 2010.

Measurements

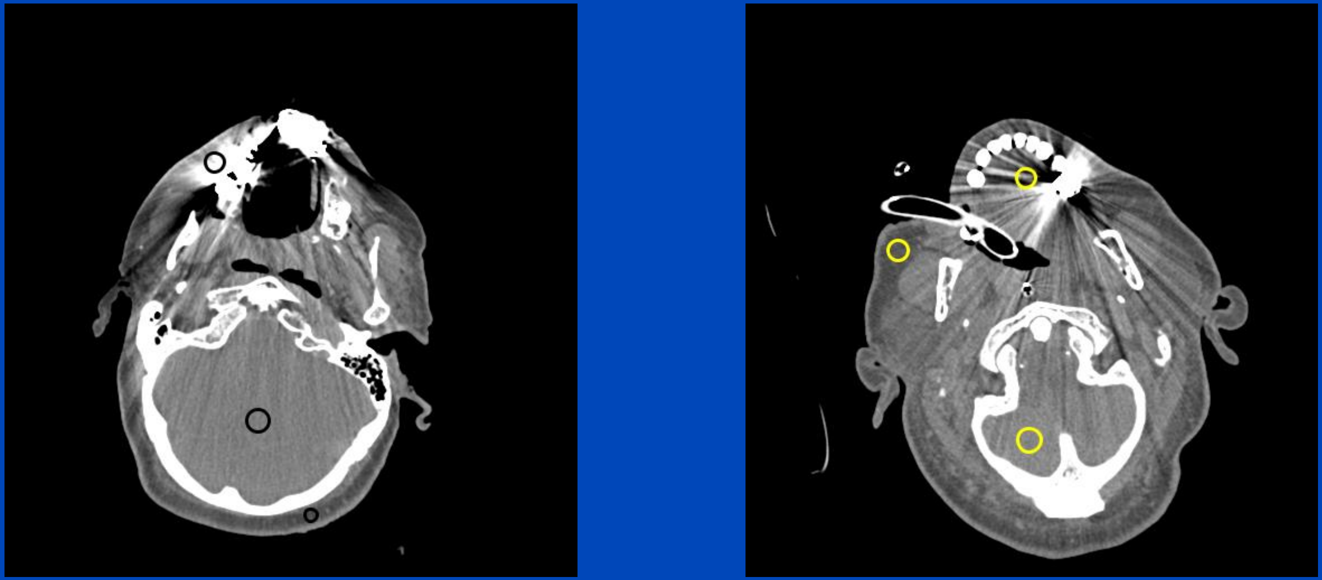
CT data of forensic specimen specimen were obtained from a Siemens SOMATOM CounT with

- Voltage: U = 140 kV
- Tube current: I_{eff} = 300 mAs
- Eff. slice thickness: S_{eff} = 0.6 mm
- Pixel size: $\Delta x = \Delta y$ = 0.5 mm
- Energy thresholds Chess mode: 25/45/75/90 keV
- Energy thresholds Macro mode: 25/90 keV
- Reconstruction kernel: B40f

All experiments were approved by the local ethics committee (S-388/2014)

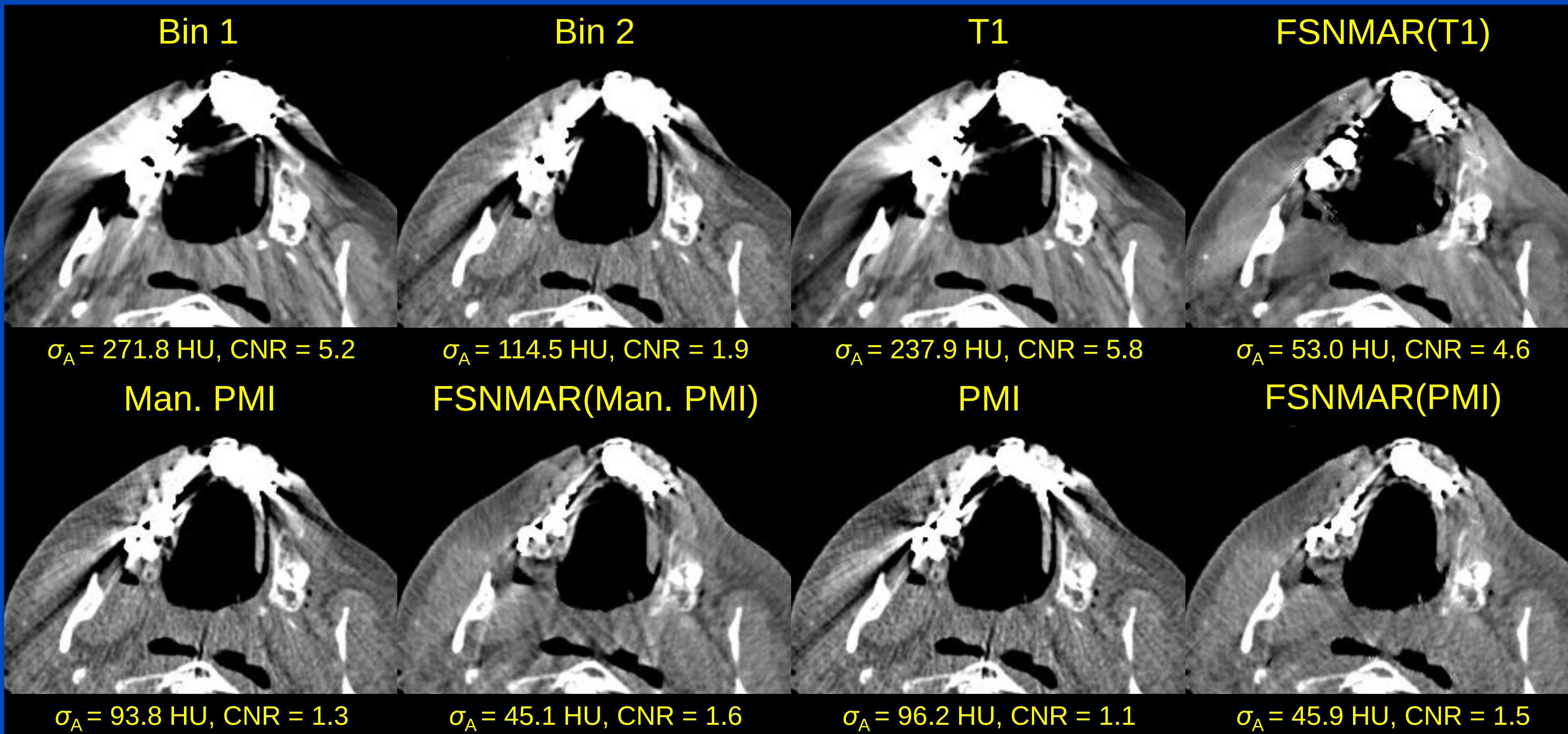
Analysis

- **To quantify image quality, we employ these measurements:**
  - **Artifact content: standard deviation of an ROI with metal artifacts**
  - **Image quality: contrast-to-noise ratio of soft tissue and fat; one ROI in each tissue**



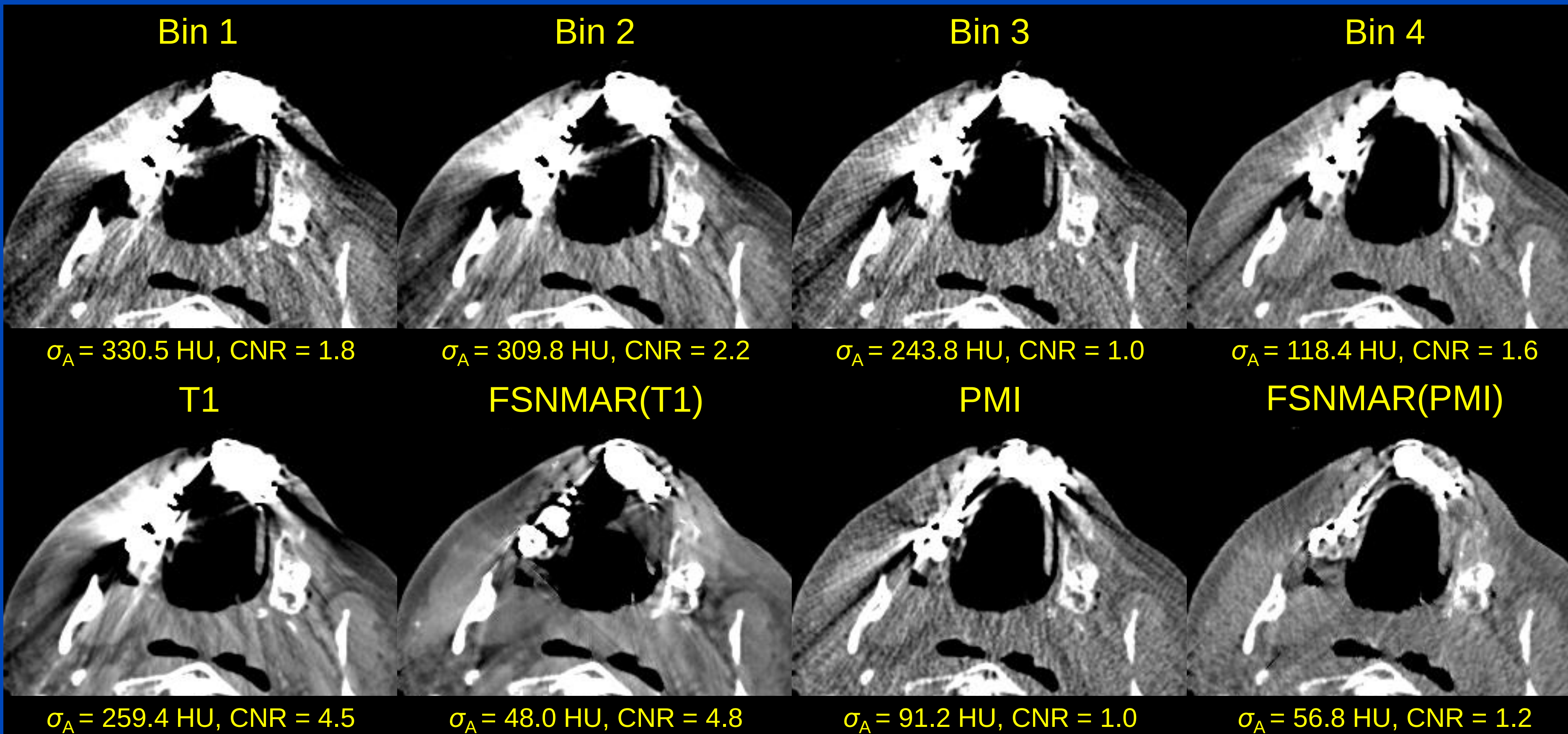
C = 50 HU, W = 700 HU

Results: Case 1, 2 Bins



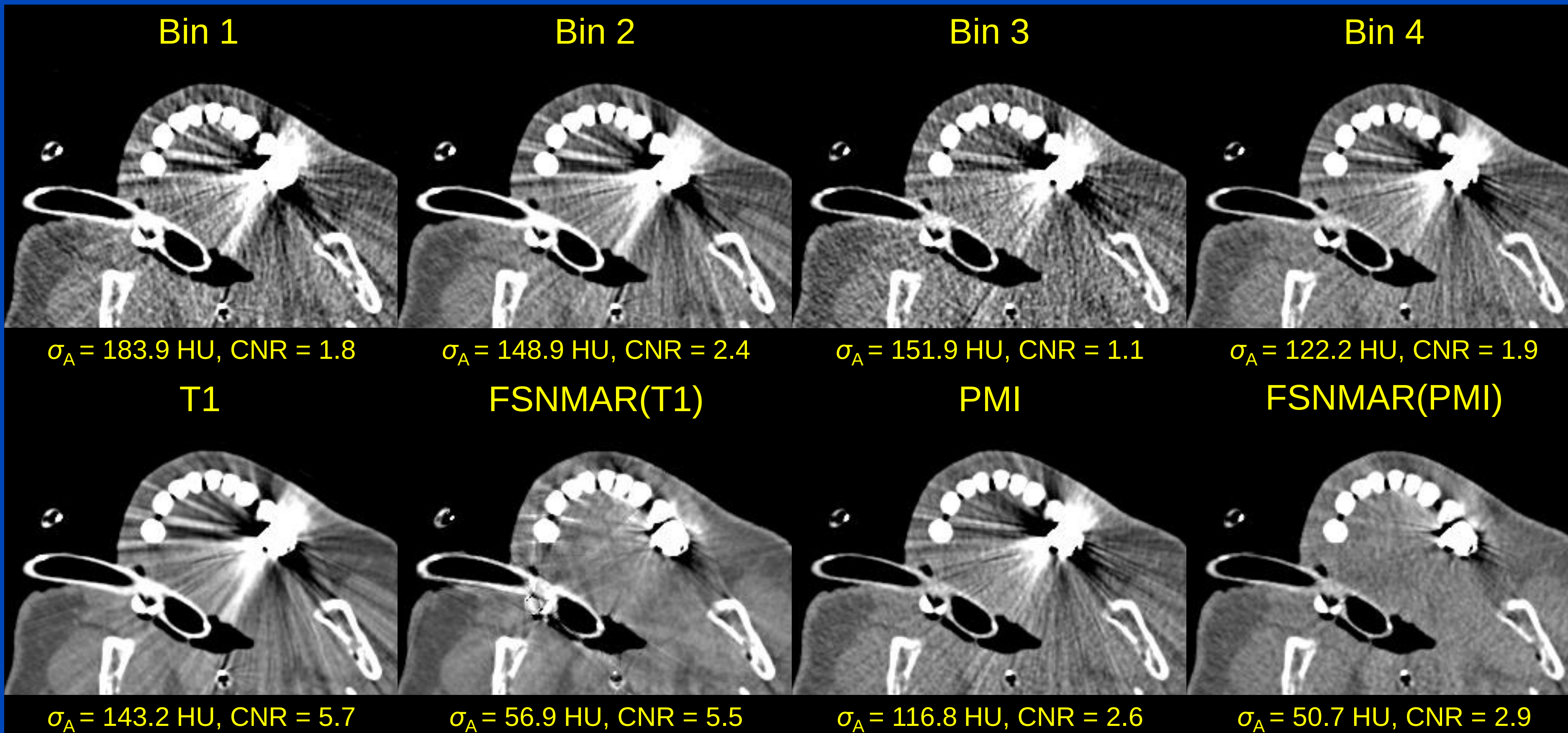
C = 50 HU, W = 700 HU

Results: Case 1, 4 Bins



C = 50 HU, W = 700 HU

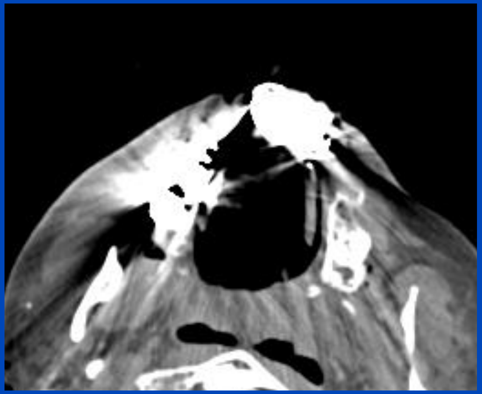
Results: Case 2, 4 Bins



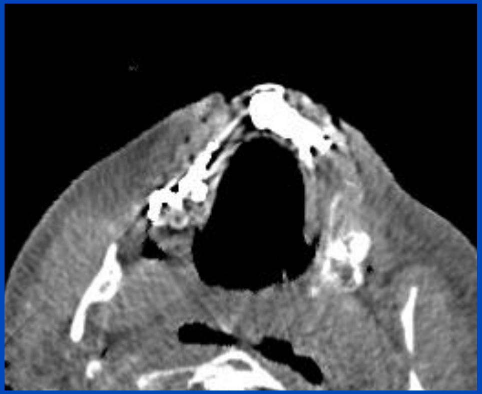
C = 50 HU, W = 700 HU

Conclusions

- PMIs reduce metal artifacts in PCCT for both 2 and 4 energy bins.
- Artifact reduction is often marginal and comes at the cost of reduces CNR.
- FSNMAR reduces artifacts better than PMIs, without decreasing CNR.
- Combining PMIs with FSNMAR yields the best artifact reduction, and structures close to the metal retain more detail.
- Future research: PMIs could be used to reinsert detail into a NMAR corrected image.



Threshold 1



FSNMAR(PMI)

Thank You!

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

Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through Marc Kachelriess (marc.kachelriess@dkfz.de).

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