

CT Image Denoising with Noise Augmentation

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and Marc Kachelrieß^{1,2}

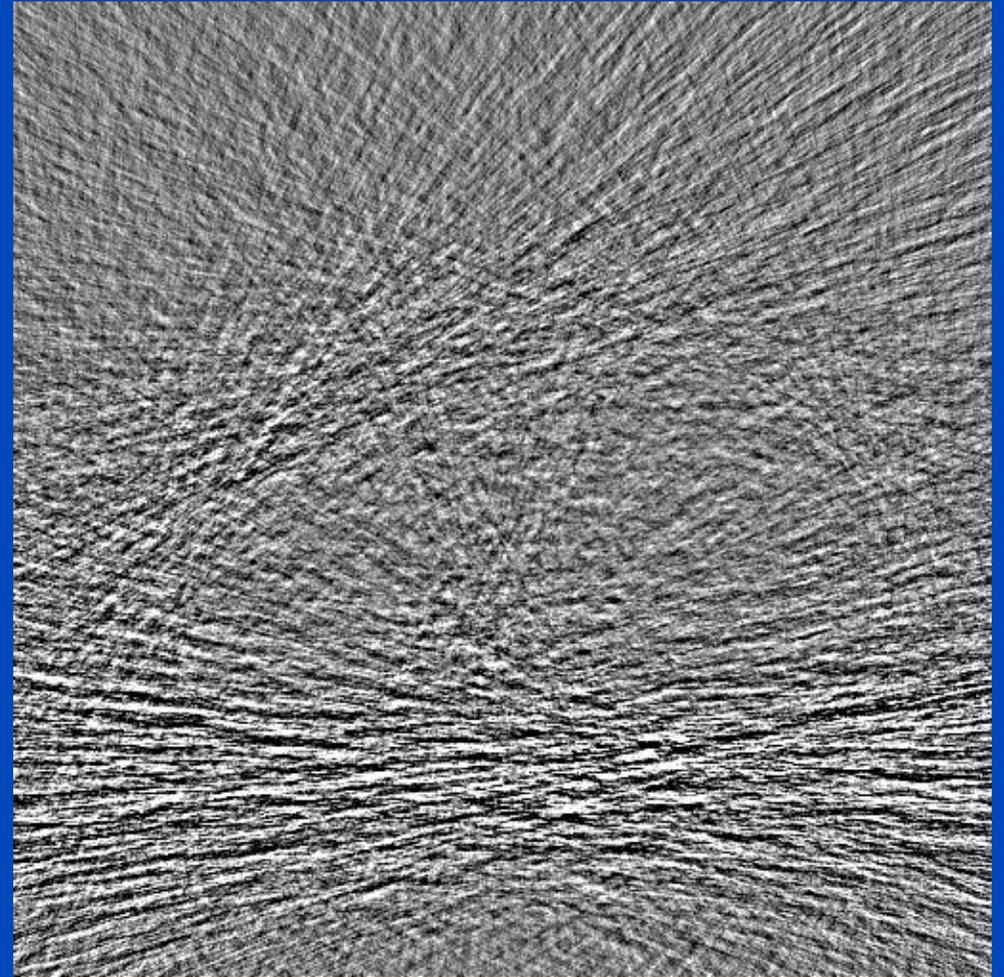
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²Ruprecht-Karls-University, Heidelberg, Germany

Images and Noise Only Images



C = 0 HU, W = 600 HU

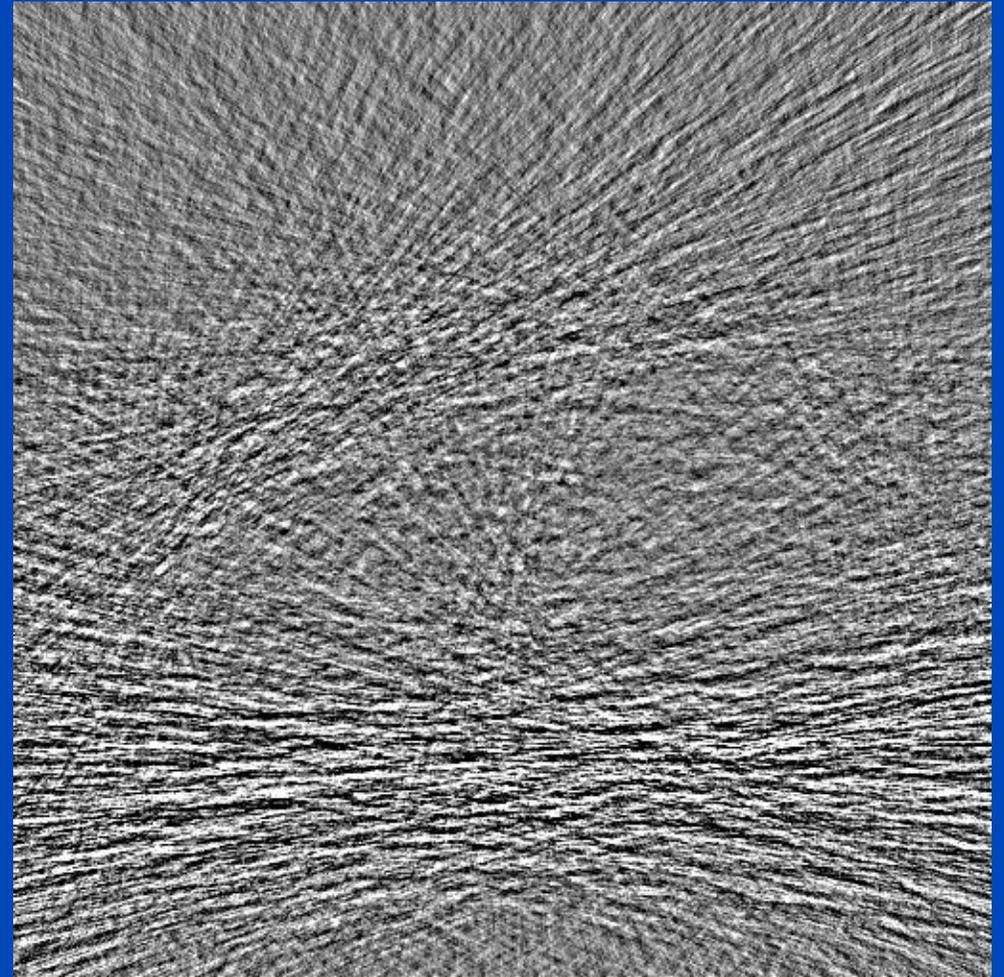


C = 0 HU, W = 150 HU

Images and Noise Only Images



C = 0 HU, W = 600 HU

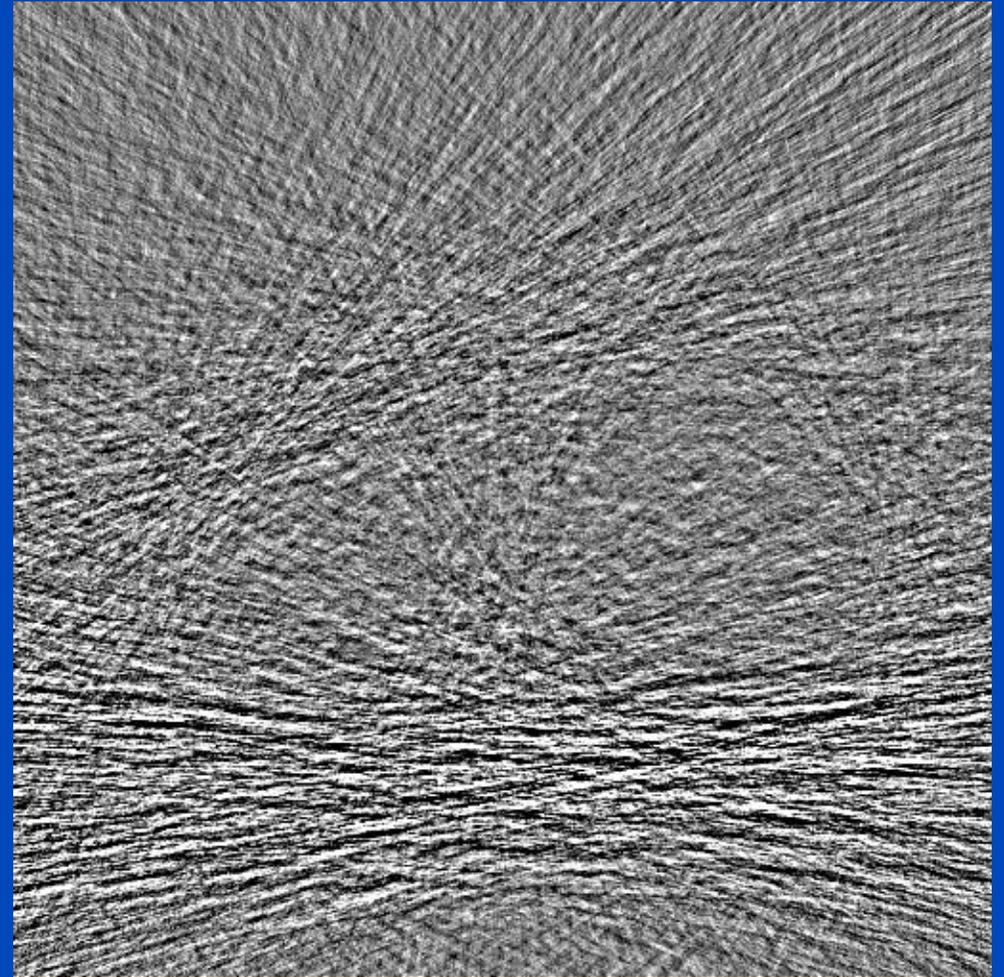


C = 0 HU, W = 150 HU

Images and Noise Only Images



C = 0 HU, W = 600 HU



C = 0 HU, W = 150 HU

NADD: Background, Aim and Idea

NADD = Noise-augmented deep denoising

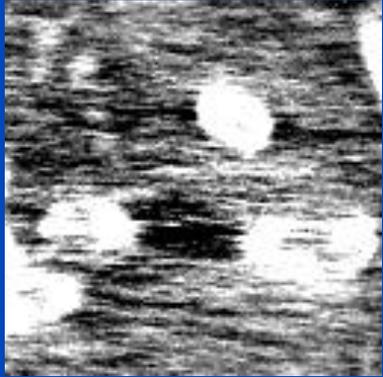
- **Background:** CT noise is strongly correlated between pixels. The correlation depends on the patient's attenuation properties and on the tube current curve that was used to generate the images.
- **Aim:** To find out whether noise reduction networks in CT benefit from seeing more than one noise realization.
- **Idea:** Generate, by rawdata noise injection and reconstruction, several noise realizations and provide them to existing denoising networks in addition to the noisy image.

**NADD = 1 measurement
+ 10 simulated noise realizations
+ a denoising network**

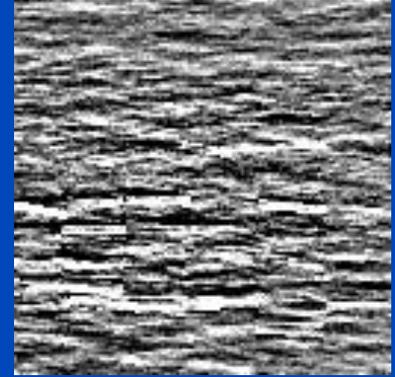
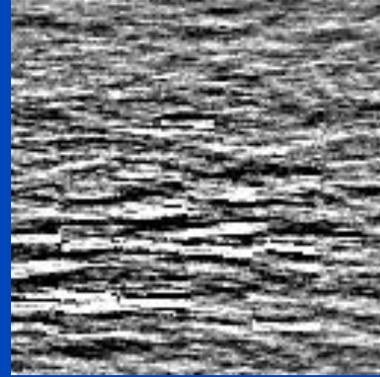
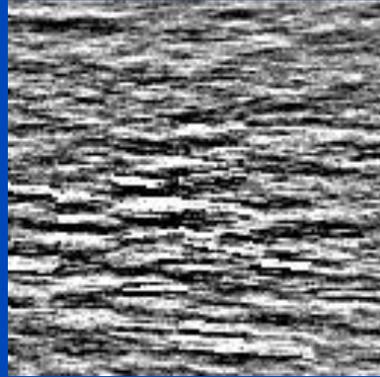
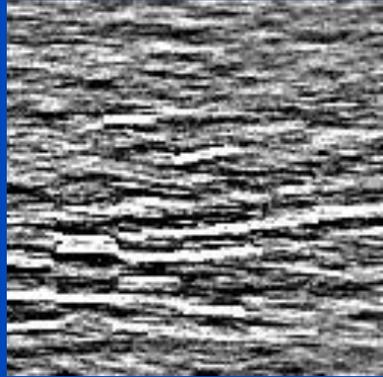
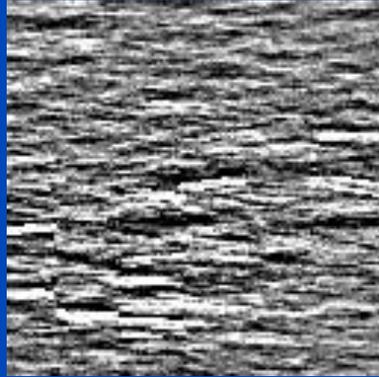
Low Dose, Std Dose and all 10 Noise Only Realizations

Network input

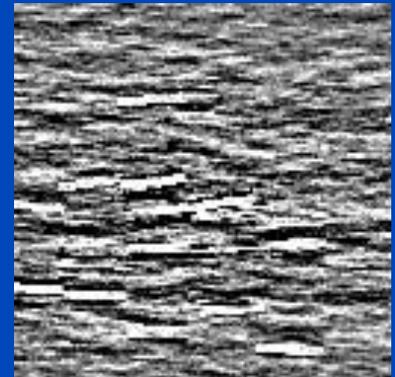
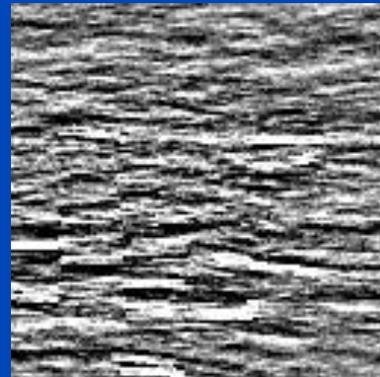
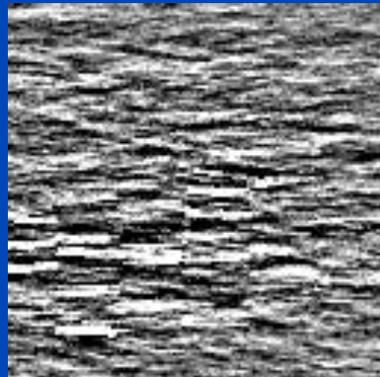
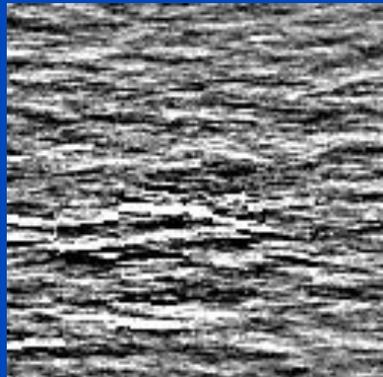
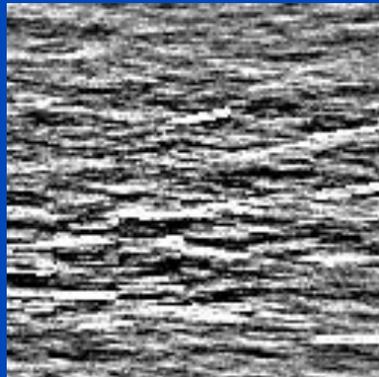
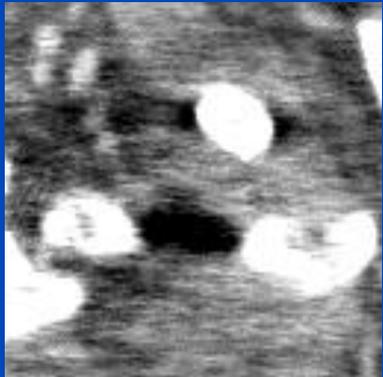
Low Dose



+10 simulated noise realizations (simulation must be done in rawdata domain)



Std Dose



CT Images: $C = 0$ HU, $W = 600$ HU. Noise only images: $C = 0$ HU, $W = 550$ HU.

Noise Reduction Networks

- We use a couple of popular noise reduction networks
 - CNN10¹
 - ResNet²
 - WGAN-VGG³
- We adapt these networks to the case of $1+N$ input images
 - 1 image to be denoised
 - N noise-only images
- We mainly consider the cases $N = 0$ and $N = 10$ in the following.
- We will denote the method and the number N of additional noise-only realizations as following: Method_{+N}
 - For example, CNN10_{+10} will indicate the CNN10 method with 10 additional noise realizations as input.

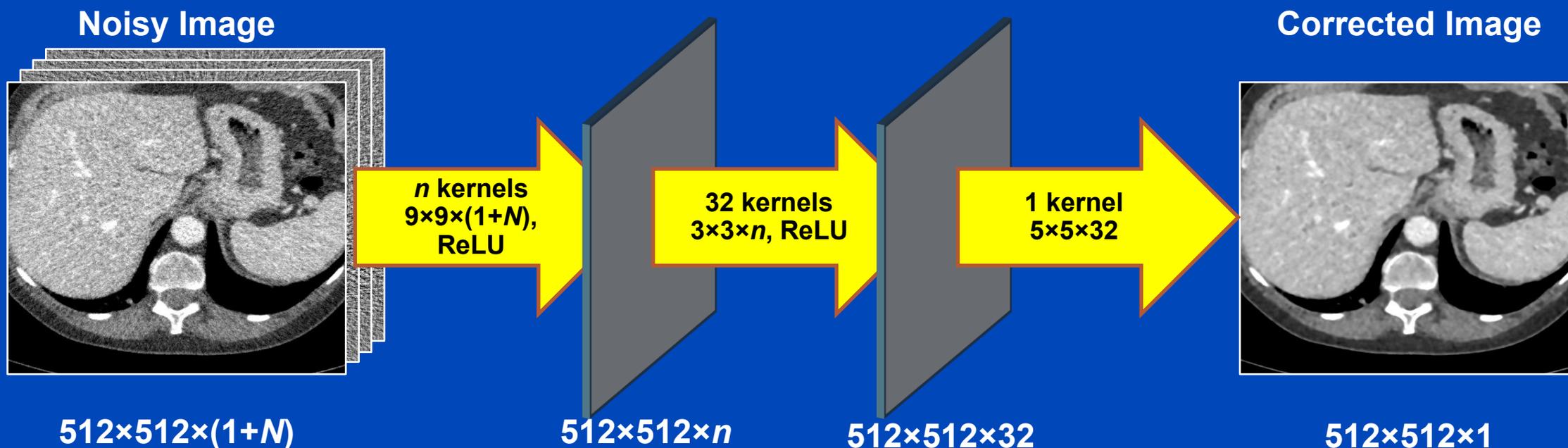
In the results slides: Low Dose = 10% Std Dose

¹H. Chen et al. Low-dose CT denoising with convolutional neural network. International Symposium on Biomedical Imaging (ISBI 2017):143-146, 2017.

²A. D. Missert et al. Noise subtraction for low-dose CT images using a deep convolutional neural network. Proc. of the Fifth Int. Conf. on Image Formation in X-Ray CT:399-402, 2018

³Q. Yanget al. Low-dose CT image denoising using a generative adversarial network with Wasserstein distance and perceptual loss. IEEE TMI 37(6):1348-1357, June 2018.

Network Architectures – CNN10_{+N}



Network Architectures – ResNet

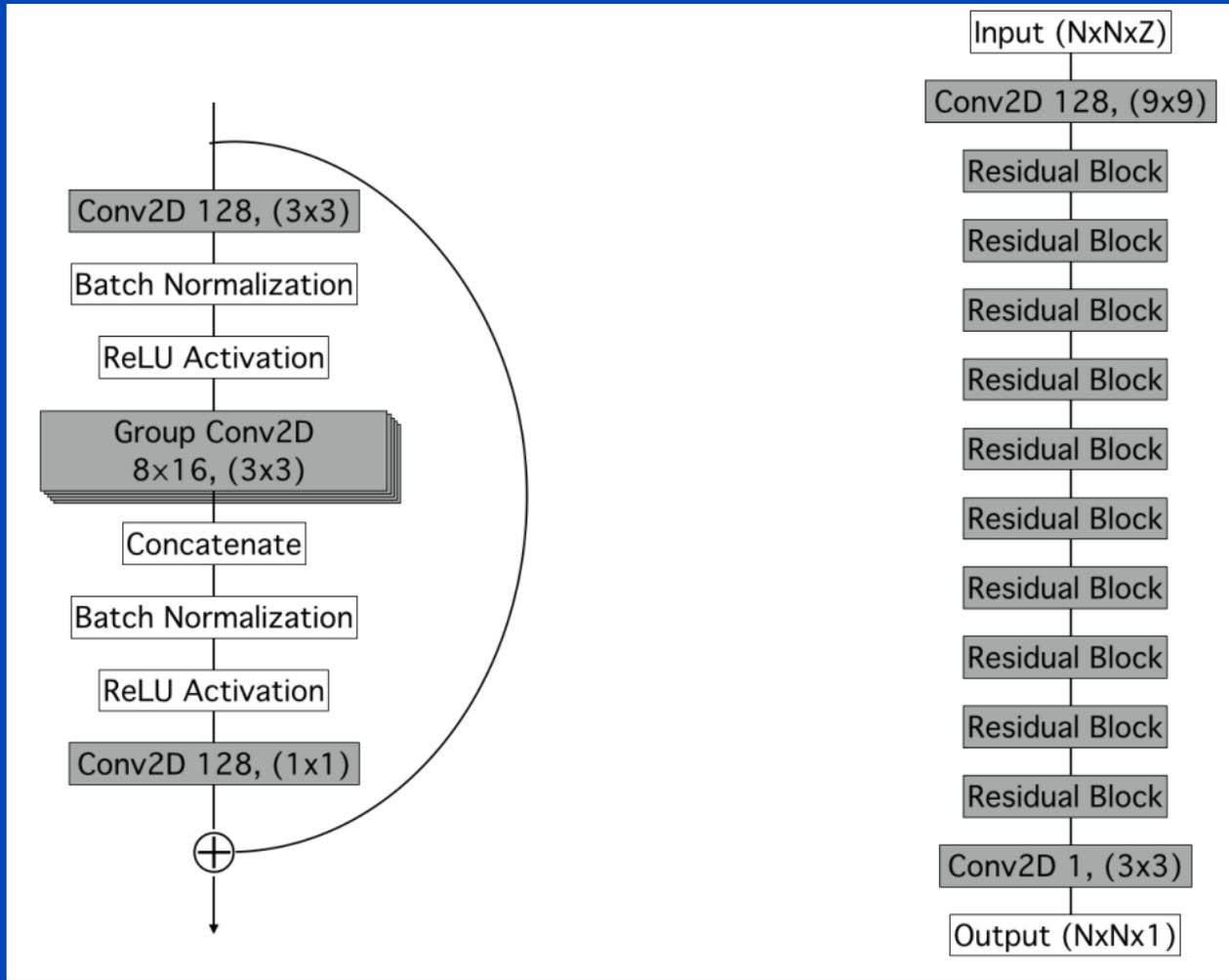
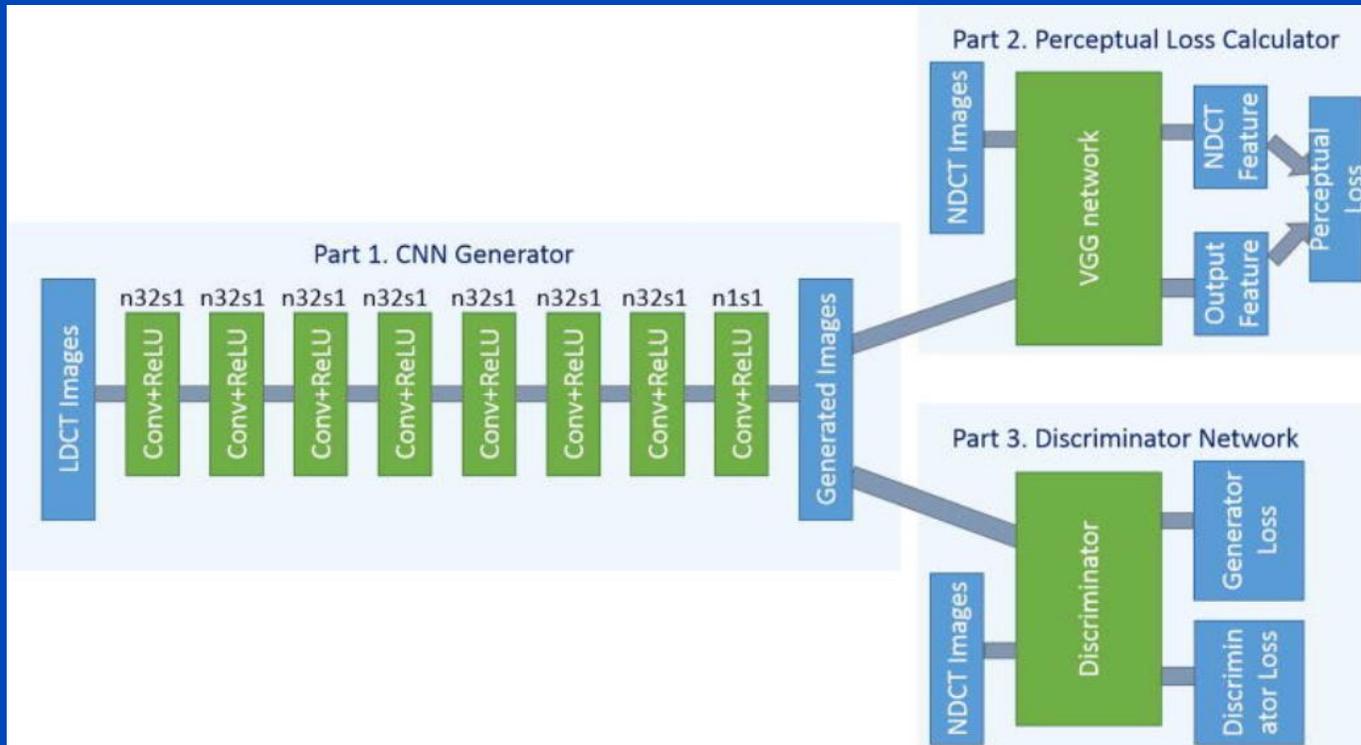


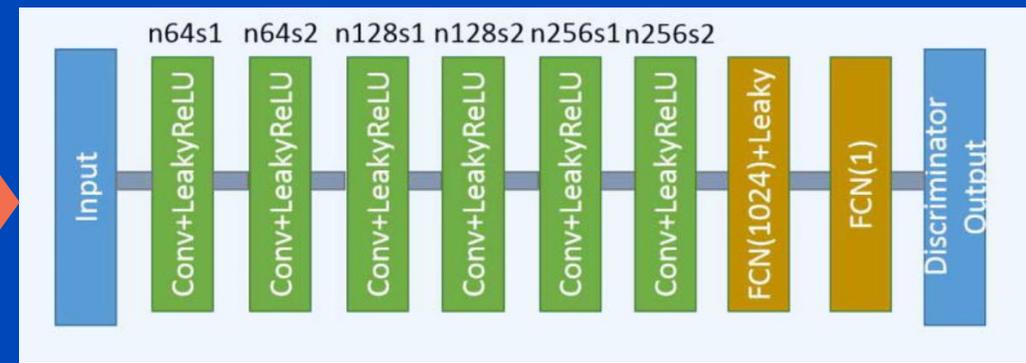
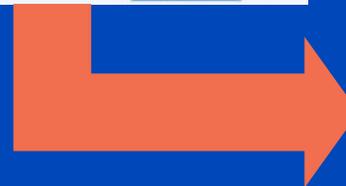
Image taken from [2]

- ResNet predicts the noise of the image
- The final prediction (a denoised image) is given by subtracting the output from the input

WGAN-VGG

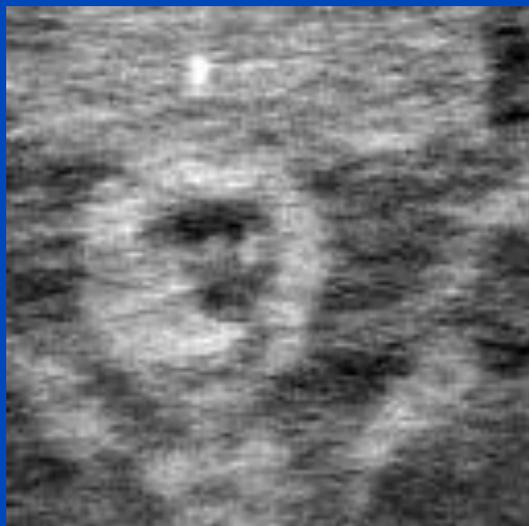


Images taken from [3]

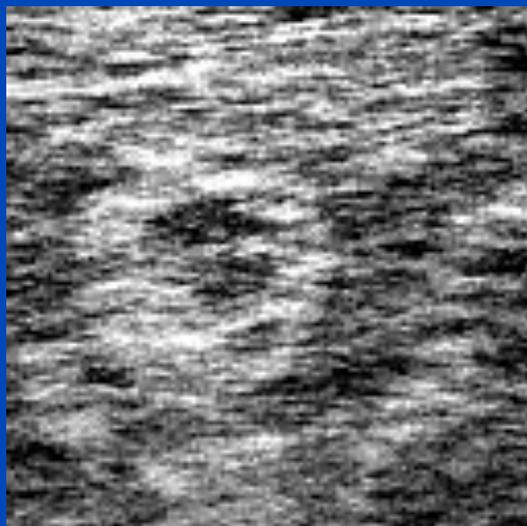
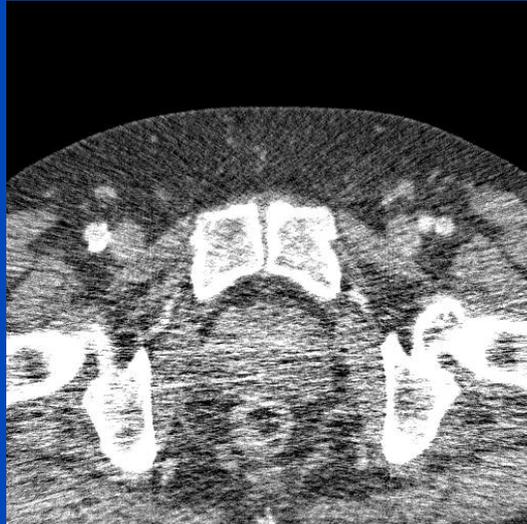


Results

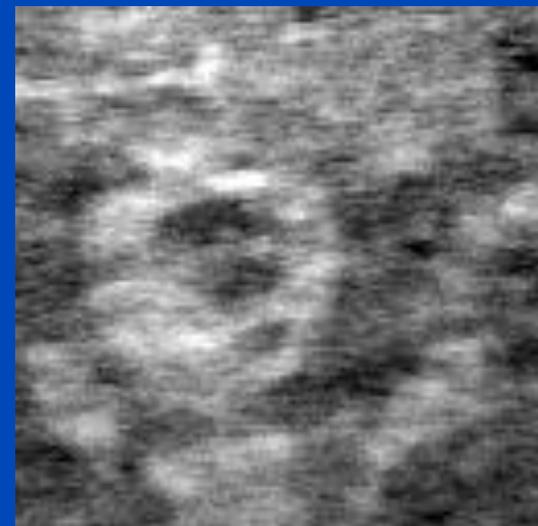
Std Dose



Low Dose



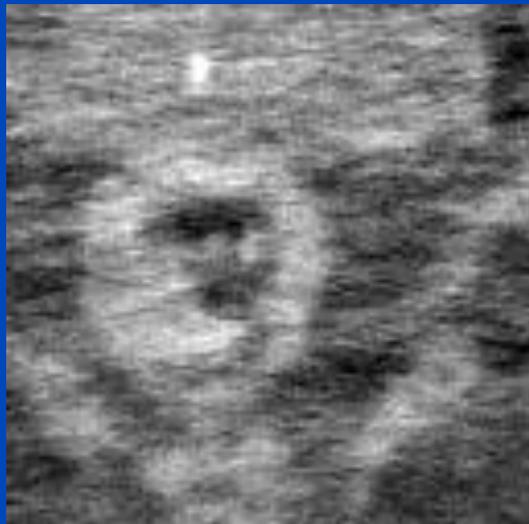
WGAN



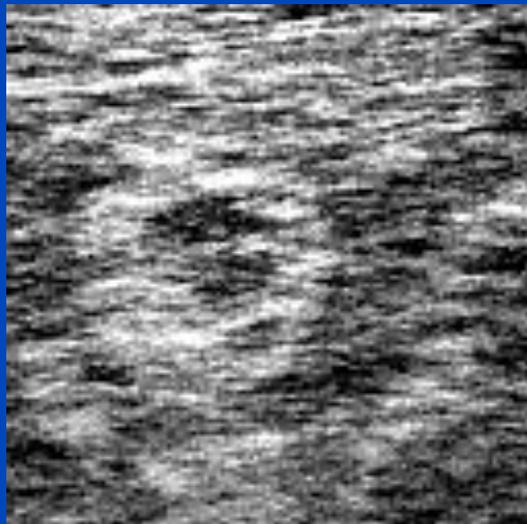
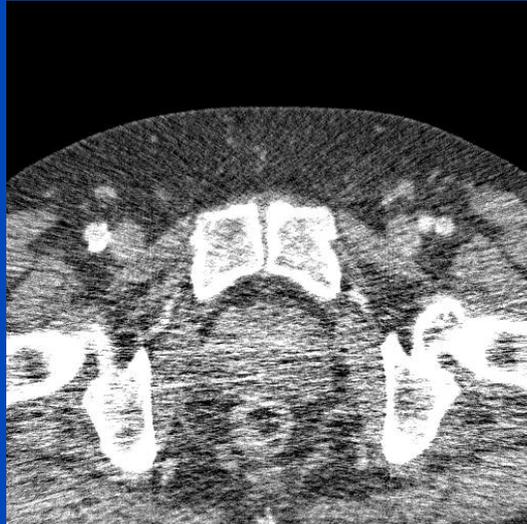
C = 0 HU, W = 500 HU

Results

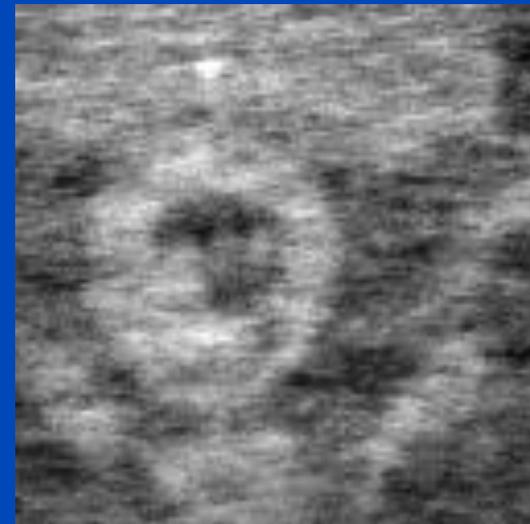
Std Dose



Low Dose

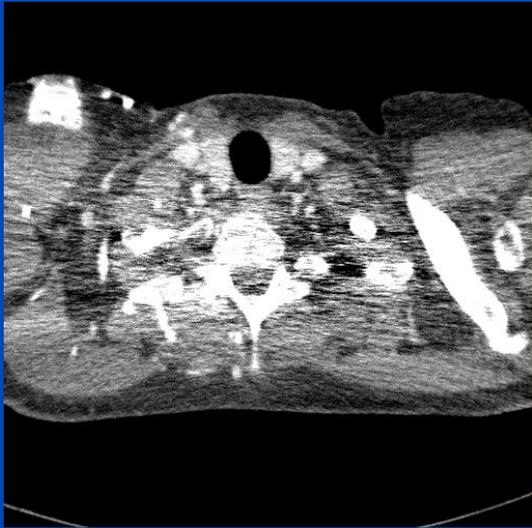


WGAN₊₁₀

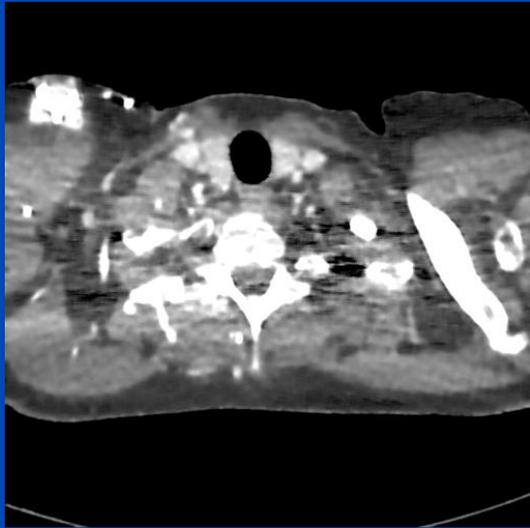


C = 0 HU, W = 500 HU

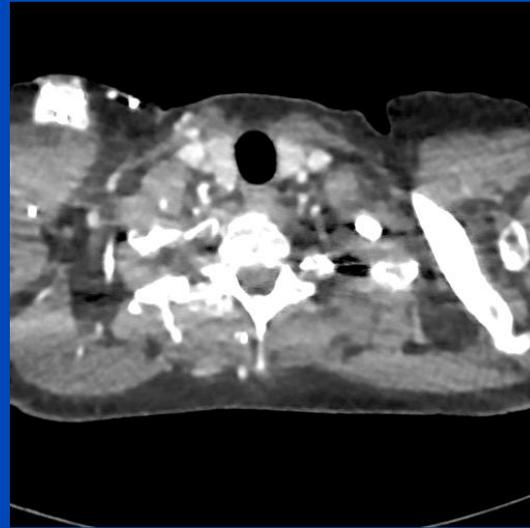
Low Dose



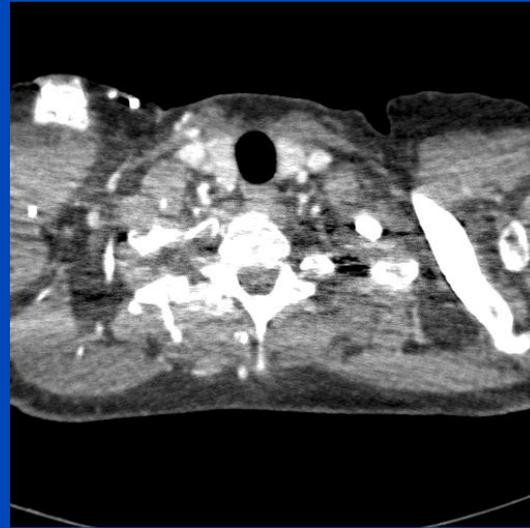
CNN10



ResNet



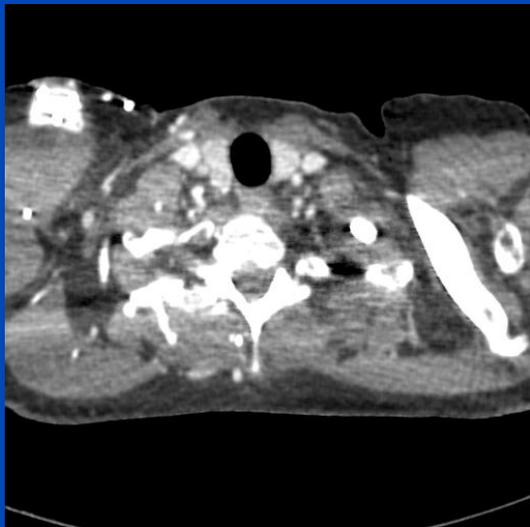
WGAN



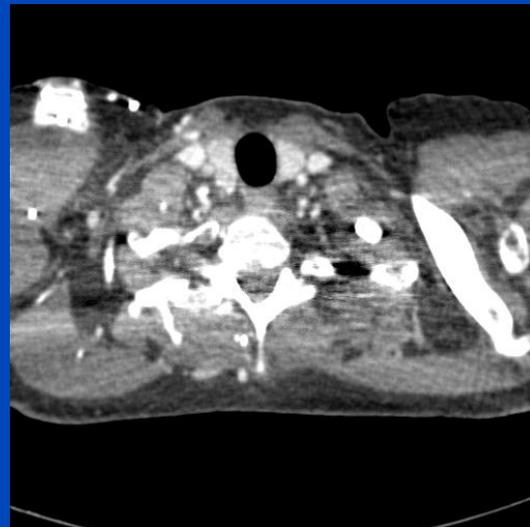
Std Dose



CNN10₊₁₀



ResNet₊₁₀

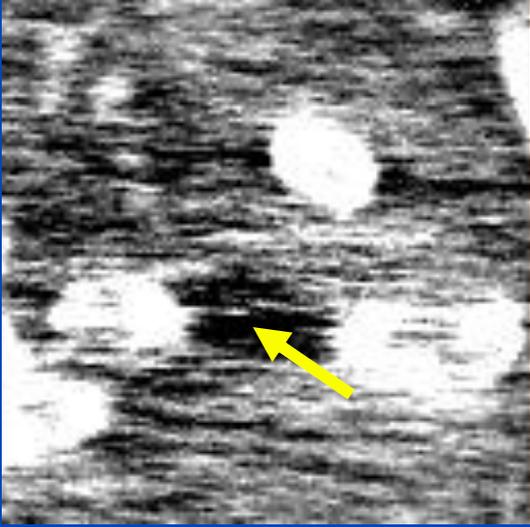


WGAN₊₁₀

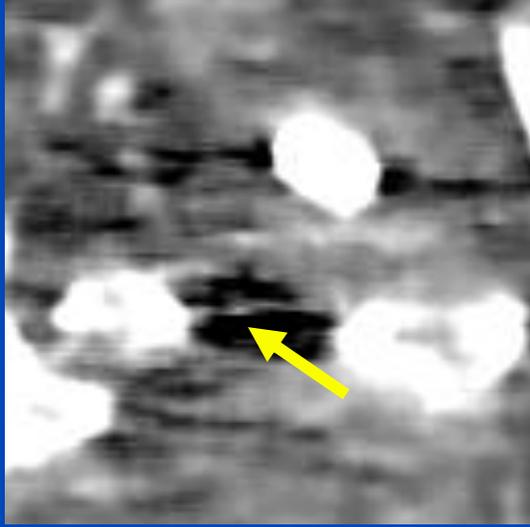


C = 0 HU, W = 600 HU

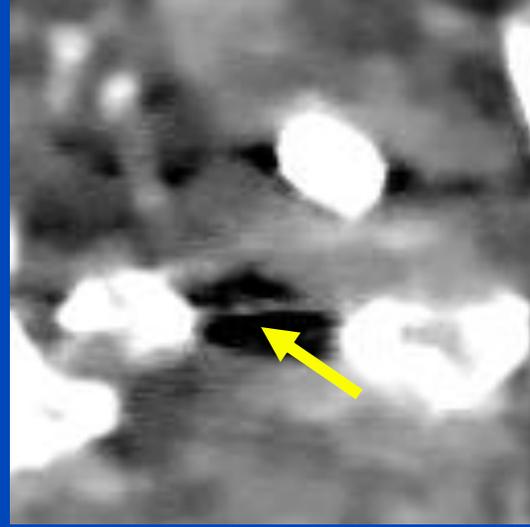
Low Dose



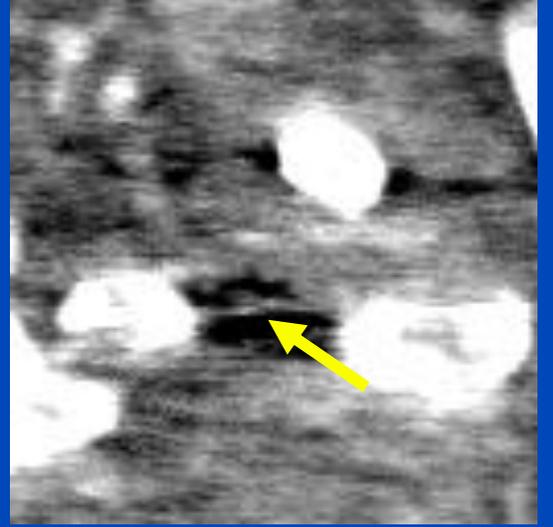
CNN10



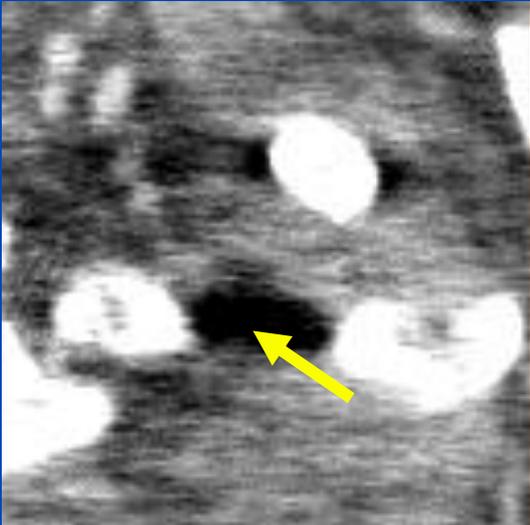
ResNet



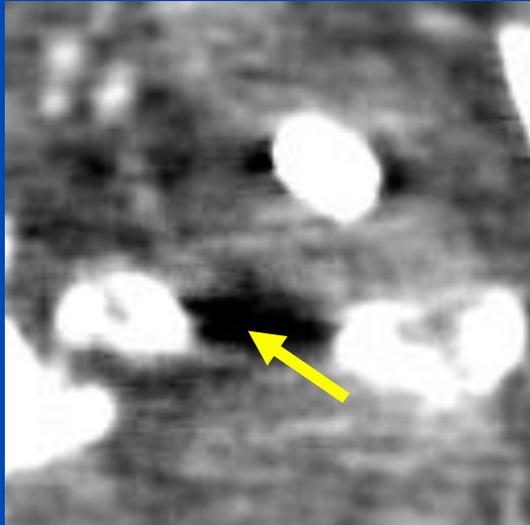
WGAN



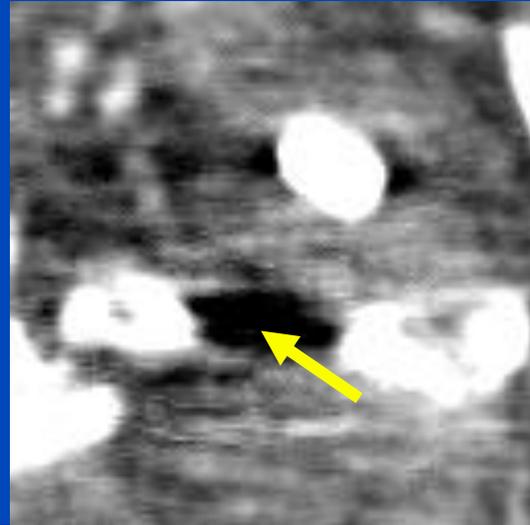
Std Dose



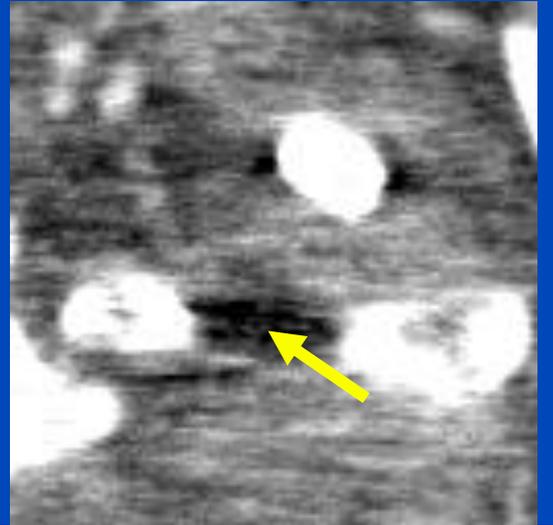
CNN10₊₁₀



ResNet₊₁₀



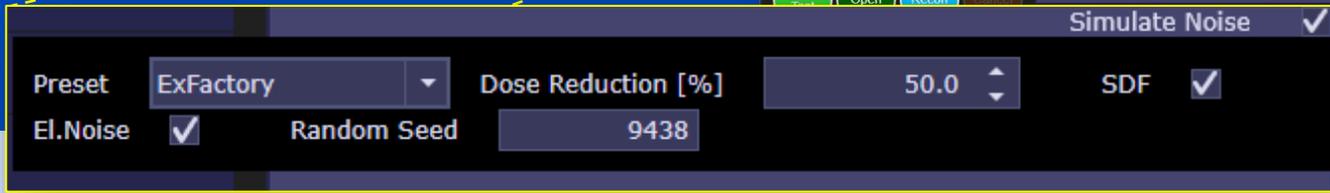
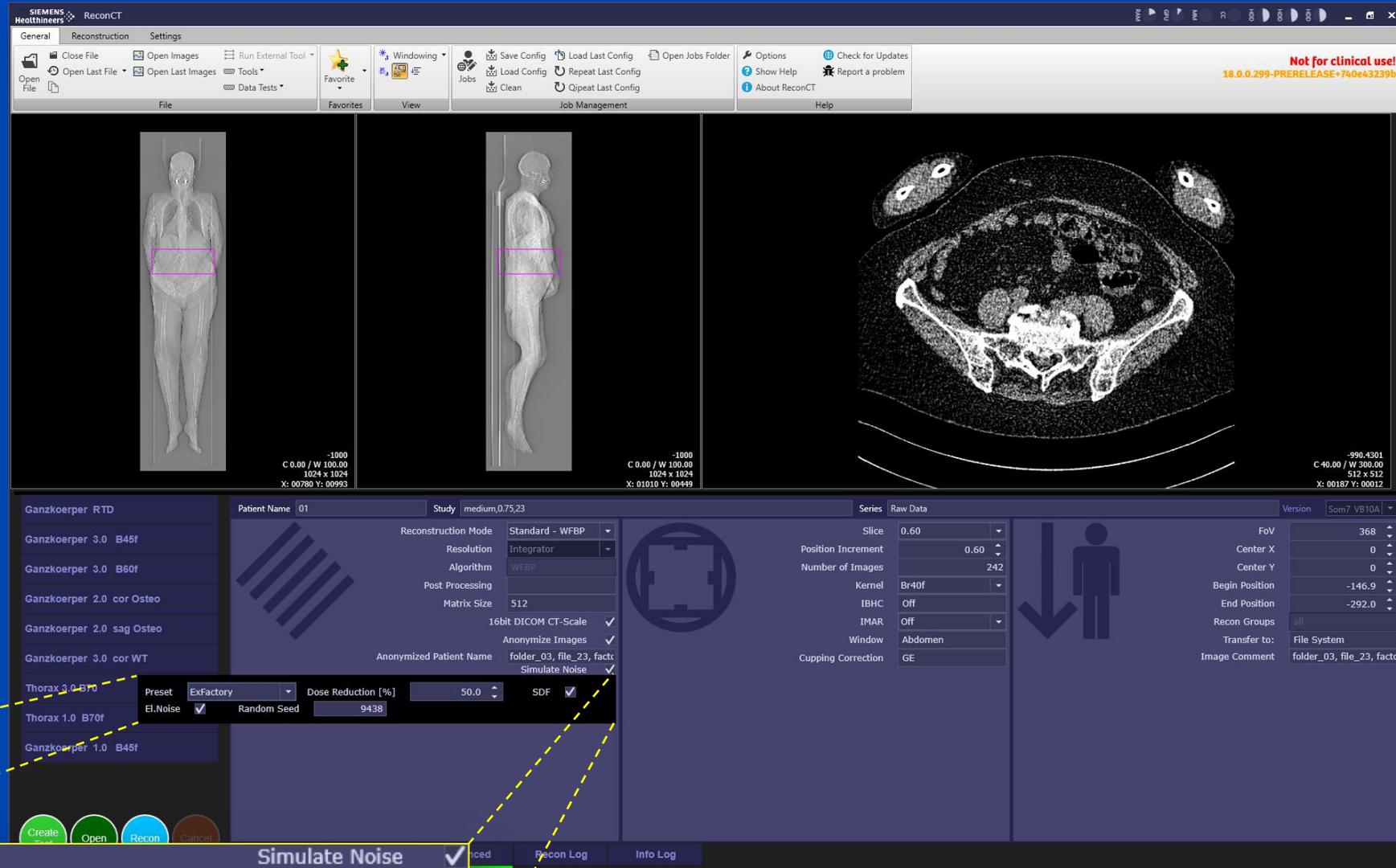
WGAN₊₁₀



C = 0 HU, W = 600 HU

Siemens ReconCT

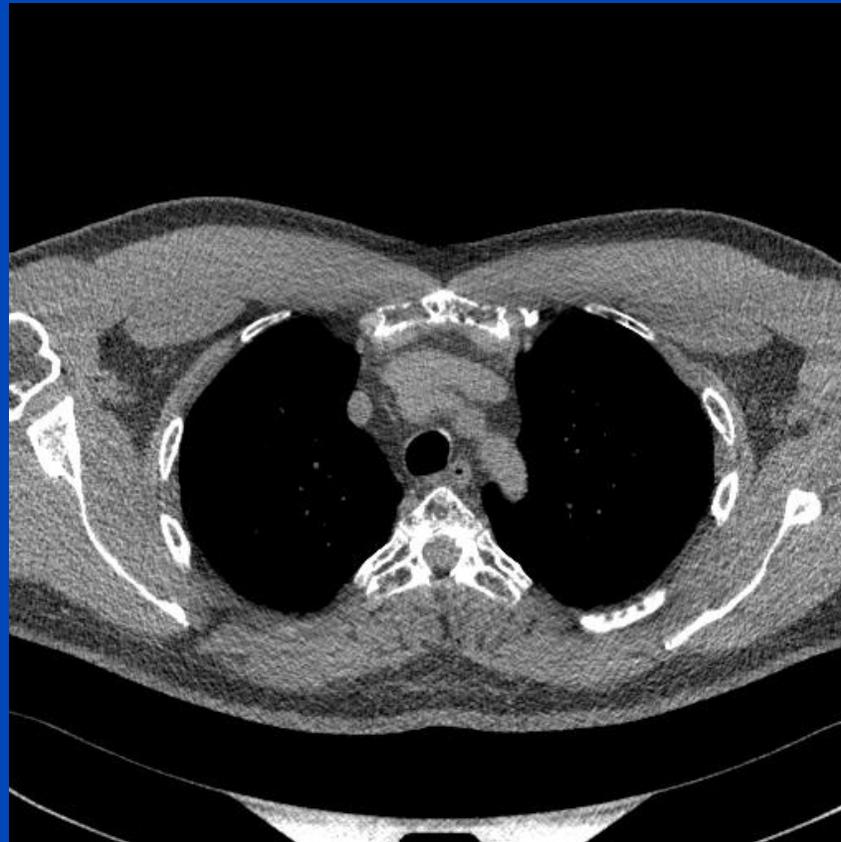
- **Proprietary software**
 - to reconstruct scanner rawdata
 - to inject noise into rawdata to simulate low dose scans
- **Allows to generate the 10 additional noise images needed for NADD.**



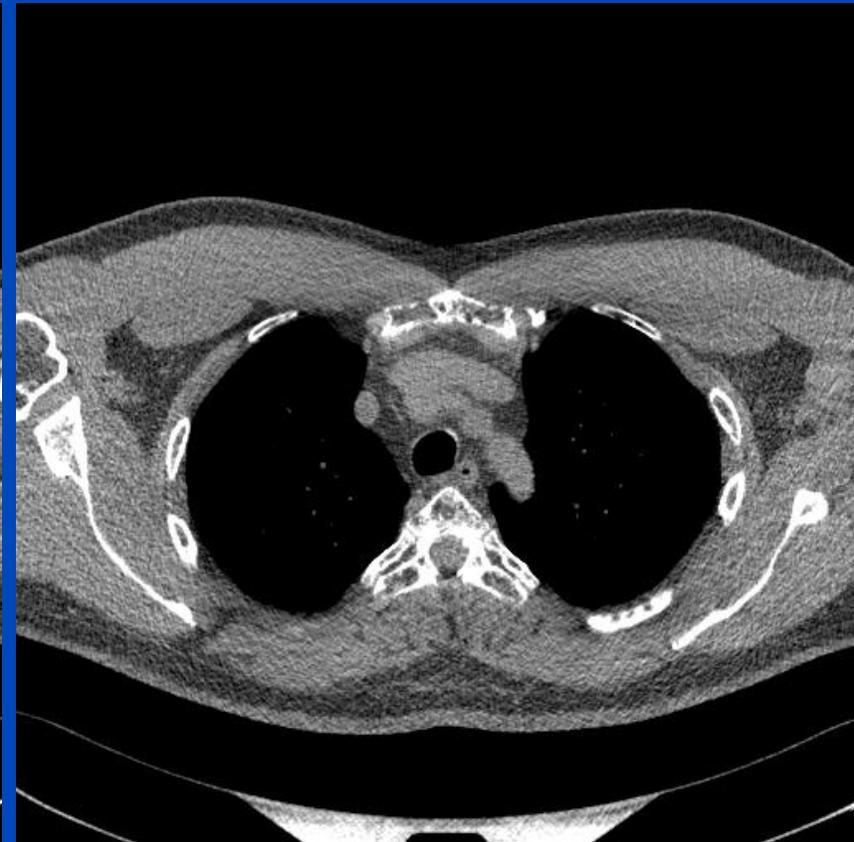
DKFZ vs. Siemens ReconCT vs. Siemens Scanner



DKFZ reconstruction (100% dose)



ReconCT (100% dose)



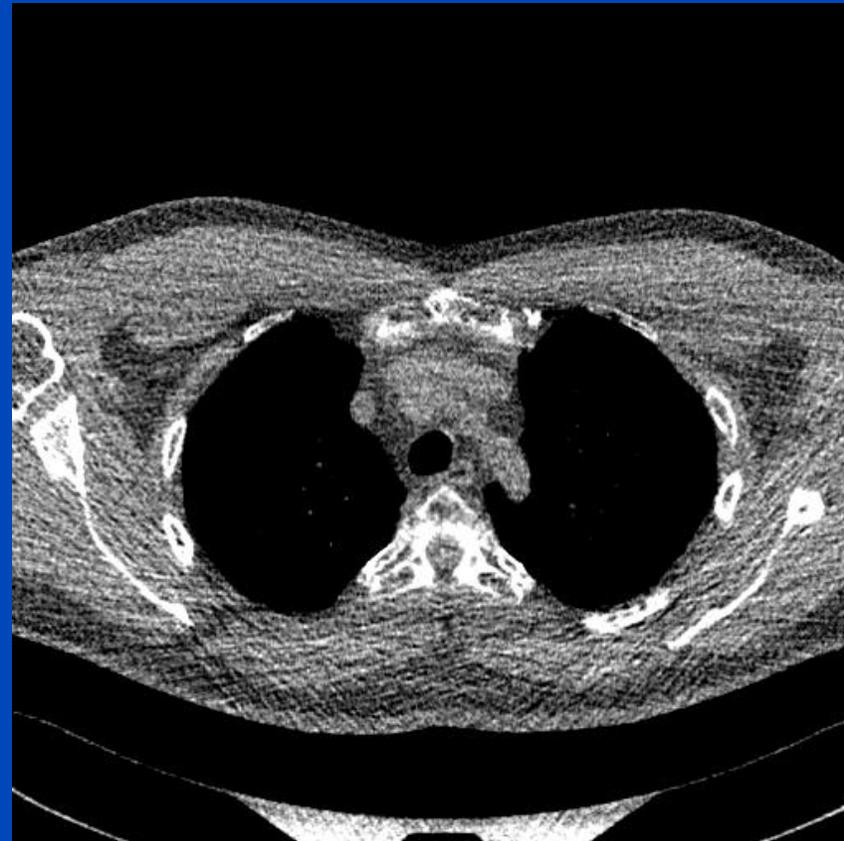
Definition Flash (100% dose)

C = 30 HU, W = 500 HU

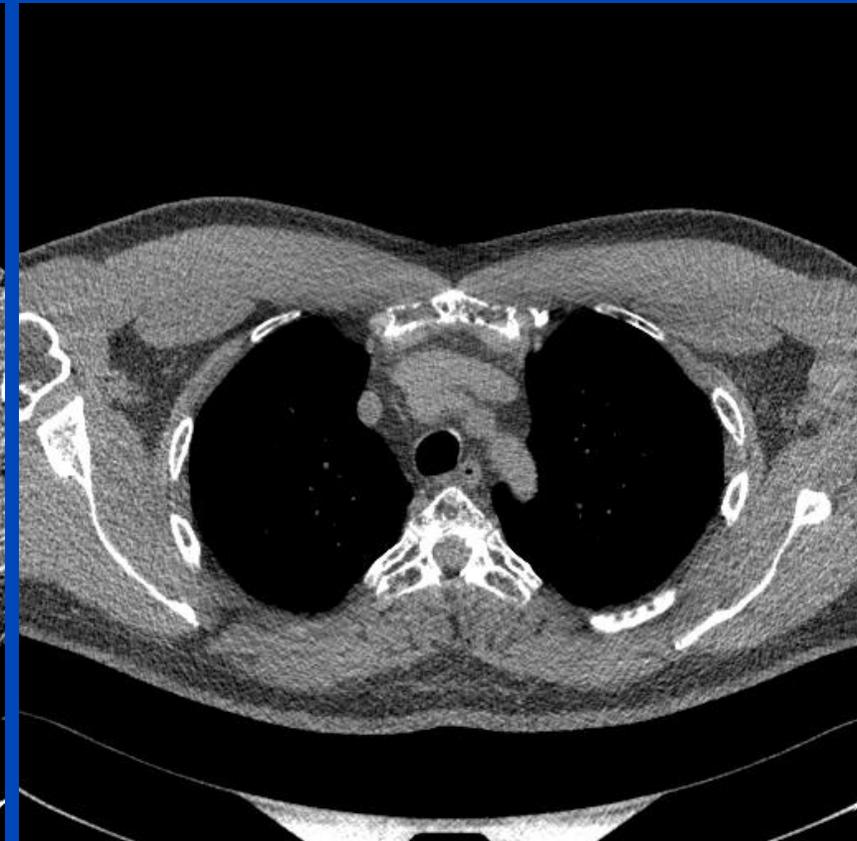
DKFZ vs. Siemens ReconCT vs. Siemens Scanner



DKFZ reconstruction (10% dose)



ReconCT (10% dose)



Definition Flash (100% dose)

C = 30 HU, W = 500 HU

NADD Results

High Dose



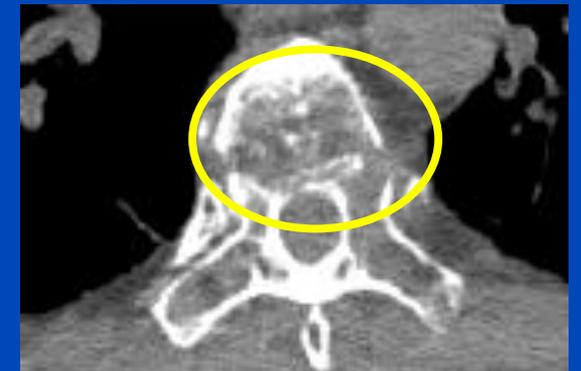
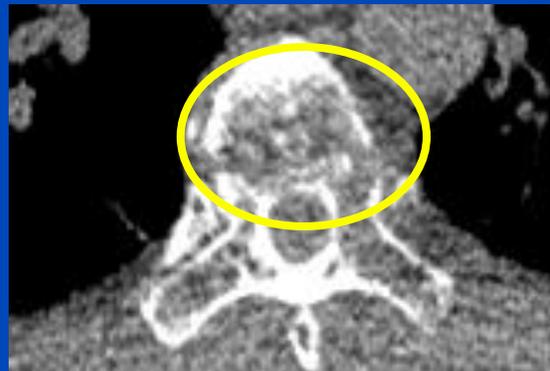
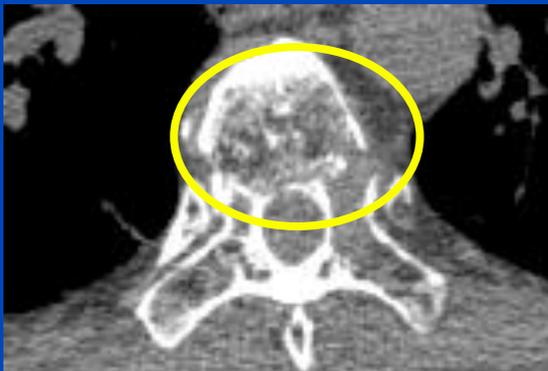
Low Dose



ResNet



ResNet₊₁₀



All images reconstructed with ReconCT using the B37f kernel. $C = 30$ HU, $W = 660$ HU

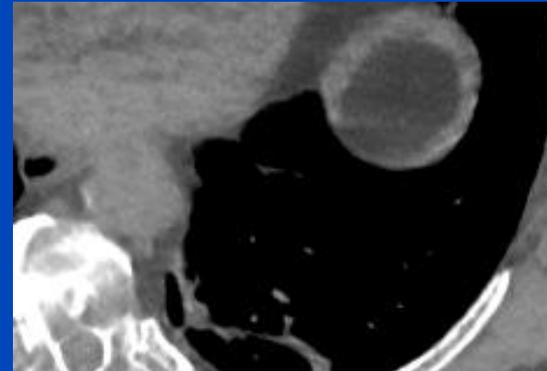
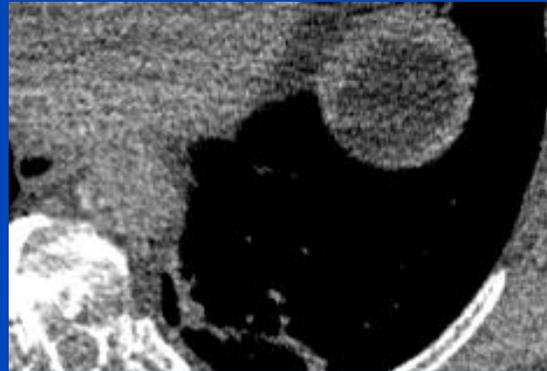
NADD Results

High Dose

Low Dose

ResNet

ResNet₊₁₀



All images reconstructed with ReconCT using the B37f kernel. $C = 30$ HU, $W = 660$ HU

Conclusions

- Additional noise only realizations significantly improve the networks' denoising capabilities.
- A disadvantage is the necessity of 10 additional image reconstructions.

Thank you!

- This presentation will soon be available at www.dkfz.de/ct.
- Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (marc.kachelriess@dkfz.de).
- Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.