20th National Day of Biomedical Engineering
11/10/2022, Brussels

Dose Reduction and Image Enhancement in Preclinical Mouse Imaging using Deep Learning

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Topic: Biosystems & Medical Imaging

Preclinical PET and CT imaging provide a powerful toolset to non-invasively acquire functional and anatomical images of laboratory animals, yet both modalities involve ionizing radiation. While delivered dose levels are normally non-lethal to the animal, they can be substantial enough to impact experimental outcomes of animal models, especially in longitudinal studies (i.e., acquisitions at multiple imaging time points). Dose reduction is therefore important, however noise is inherent to low dose acquisitions which consequently degrades image quality. Various denoising techniques already exist, but deep learning (DL) has become increasingly popular for image quality enhancement. Nevertheless, research has mostly focused on clinical imaging with limited investigations on preclinical systems.

Our work aims to investigate the use of convolutional neural networks (CNN) to denoise low dose images from micro-CT (study 1) and micro-PET (study 2). We developed an image-to-image CNN framework to predict higher quality images from noisier images acquired at lower doses. In both studies, a 2D CNN was trained with L1 loss and adopted a 4-layer U-Net. The micro-CT study was based on 38 *ex-vivo* mice scans (with one noise level as input), while the micro-PET study included 36 ^{18}F-FDG PET mice scans (with three different noise input levels generated from list mode sorting).

Both studies (Figure 1) showed that CNN denoising outperformed more conventional filtering methods; they were able to effectively suppress noise, while preserving contrast details in finer structures for micro-CT and keeping quantitative accuracy in micro-PET. From additional phantom and animal studies we estimated a dose reduction factor of 3.2 for micro-CT and found that sub-1MBq micro-PET acquisitions (10x dose reduction) are feasible. This will enable ultra-low dose longitudinal scanning of rodents in preclinical research.

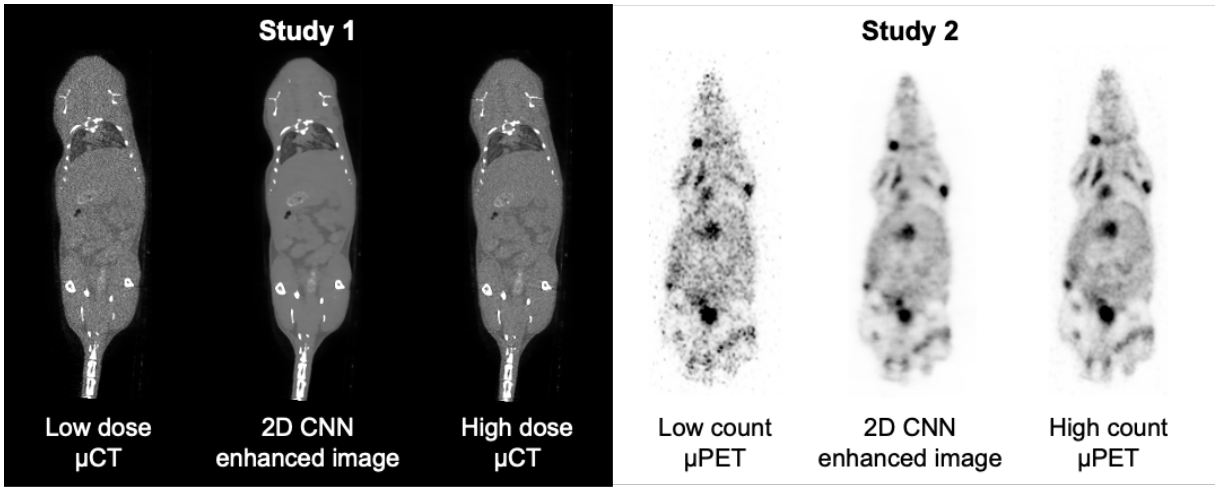

Figure 1: Examples of low-high dose image pairs and the resultant 2D CNN enhanced image.

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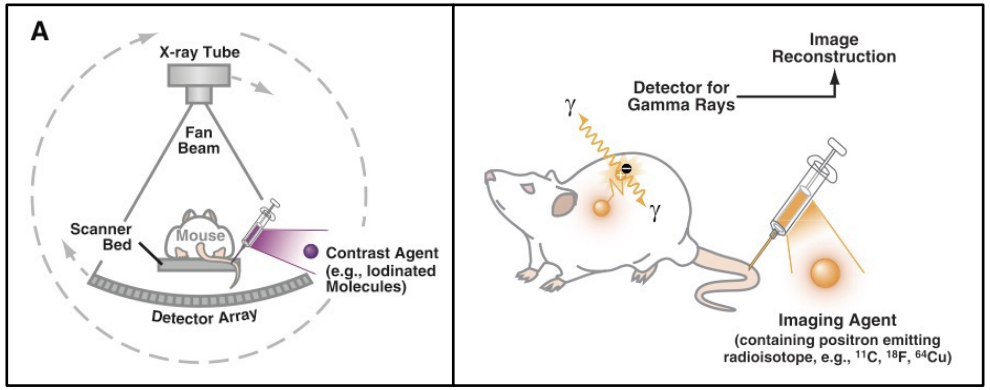
CONCERNS IN PRECLINICAL IMAGING

Micro-CT Micro-PET



Source images: James ML & Gambhir SS. A Molecular Imaging Primer: Modalities, Imaging Agents, and Applications. Physiol. Rev 2012; 92.

- Both imaging modalities involve ionizing radiation
- Concerned about the effects of radiation exposure

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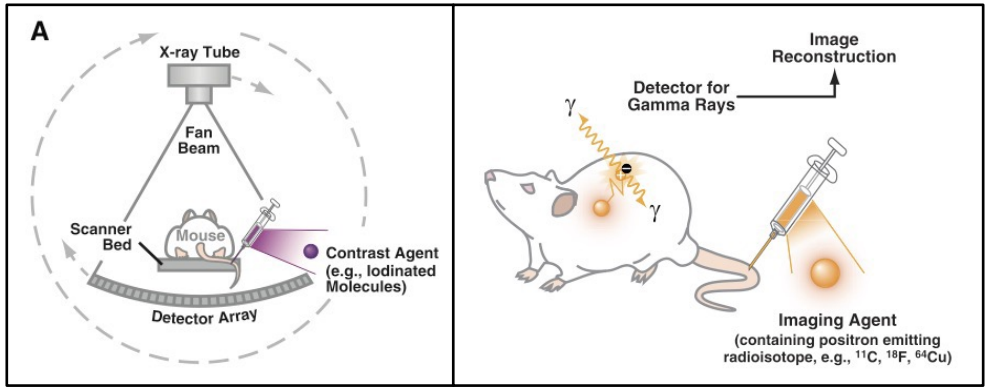
CONCERNS IN PRECLINICAL IMAGING

Micro-CT Micro-PET



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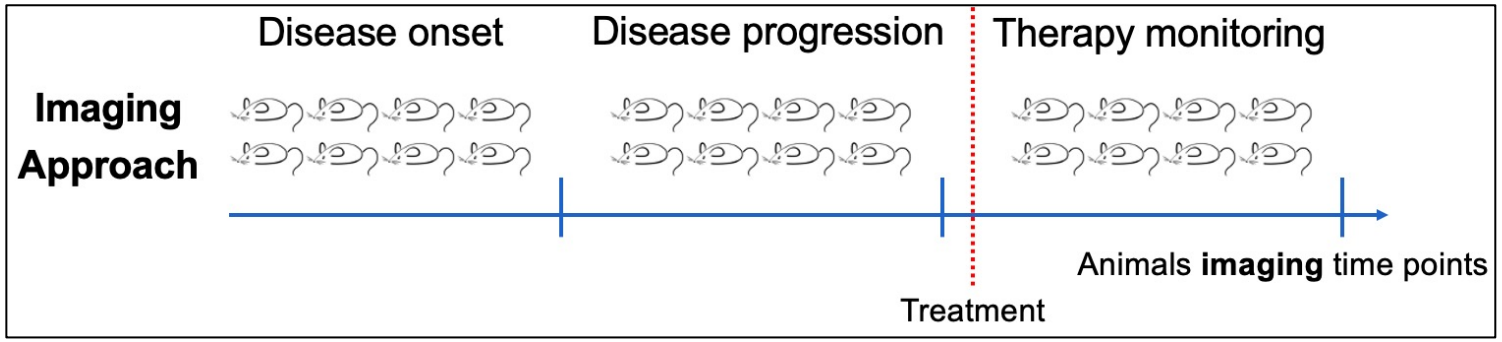
- Both imaging modalities involve ionizing radiation
- Concerned about the effects of radiation exposure

- Especially in longitudinal studies: **accumulation of dose** (!)



Dose reduction

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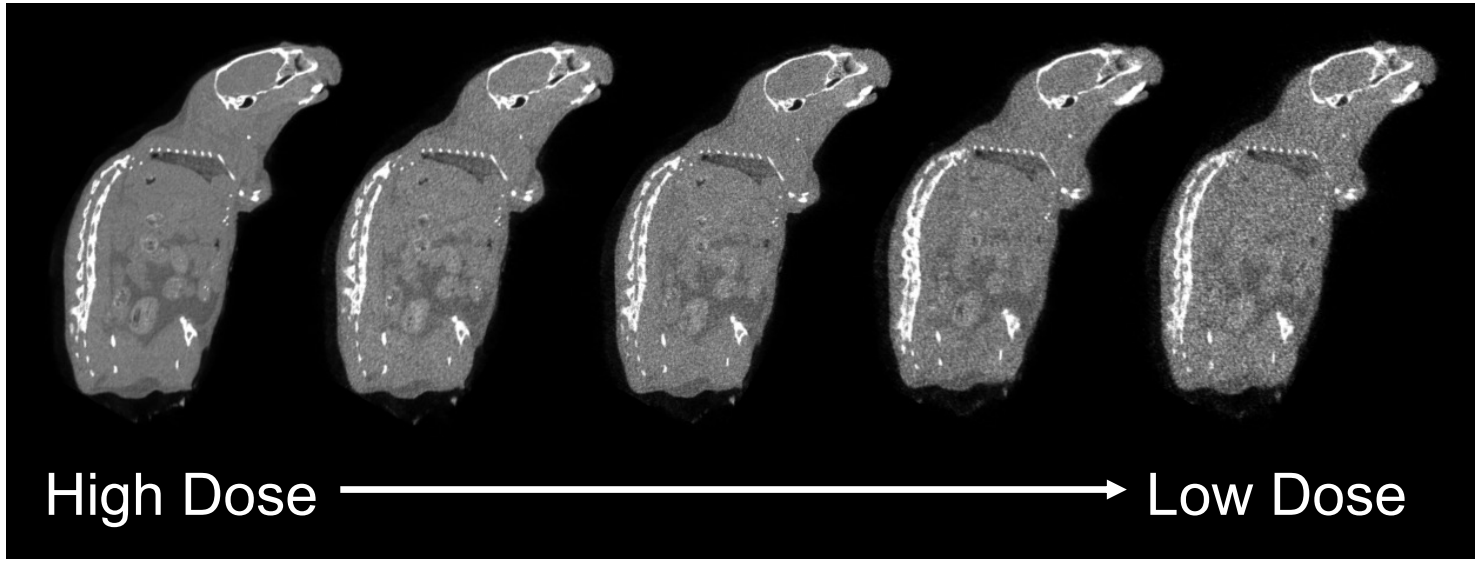
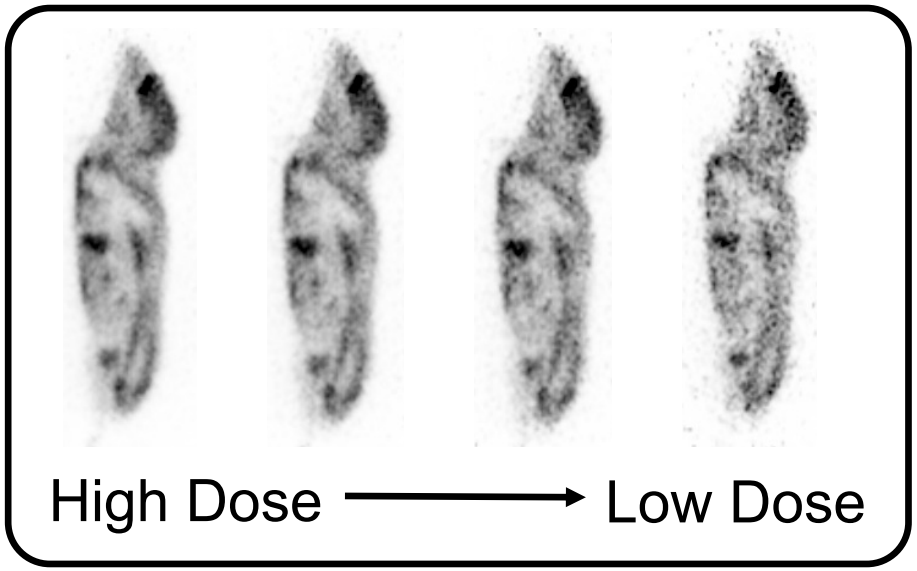
BUT…

The challenge with **low dose acquisitions** is the **inherent noise**…

➡ Degradation of image quality



Micro-CT



Micro-PET

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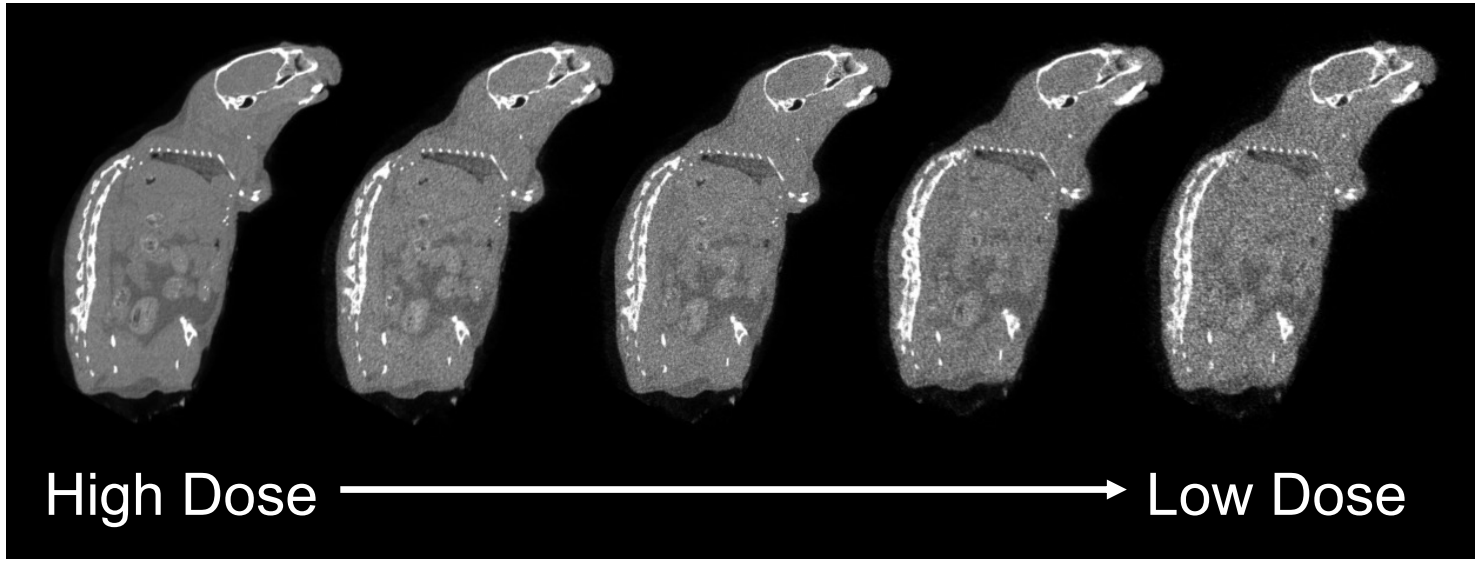
BUT…

The challenge with **low dose acquisitions** is the **inherent noise**…

➡ Degradation of image quality



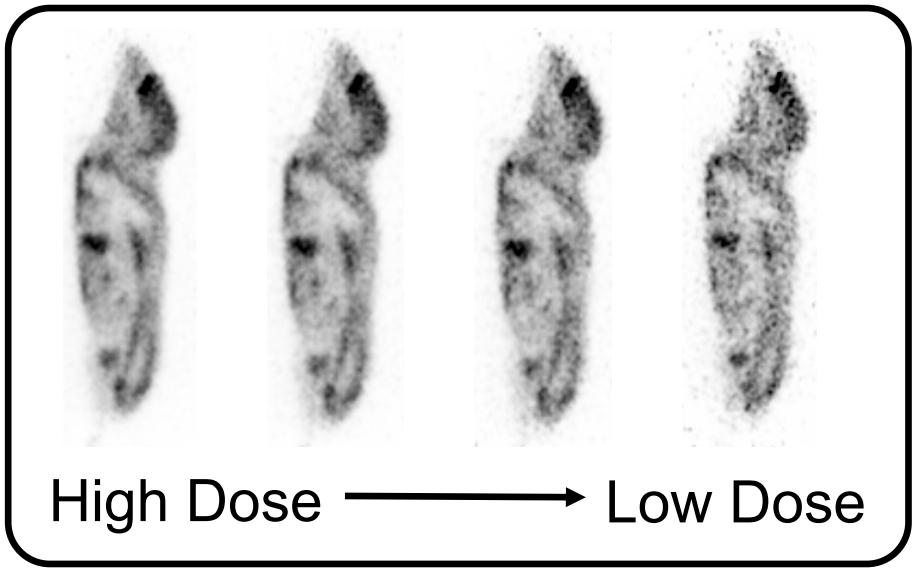


Image denoising to **enhance the quality** (reduce the noise) of **low dose preclinical images**

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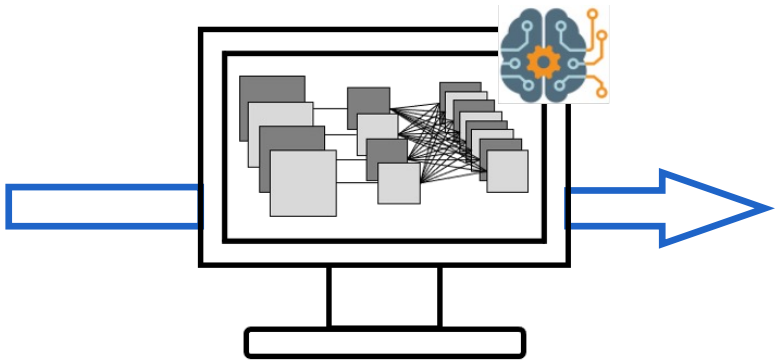
IMAGE DENOISING WITH DEEP LEARNING

Low dose



Deep learning algorithm (CNN)

High dose

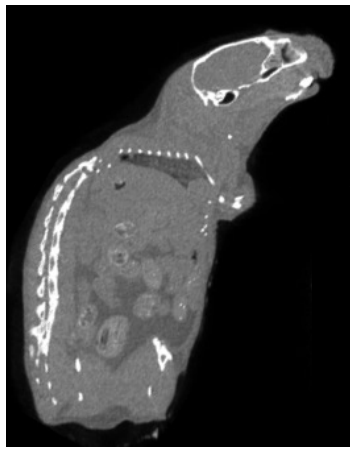


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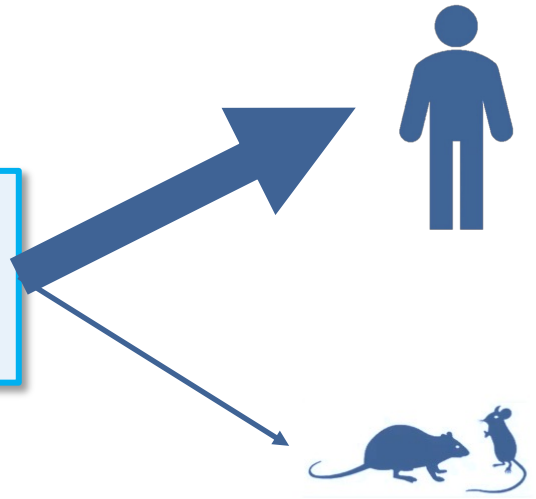
IMAGE DENOISING WITH DEEP LEARNING

Low dose

High dose

Deep learning image denoising



*extensively researched for **clinical imaging***

*very little investigated for **preclinical imaging***

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METHODOLOGY

Molecubes CUBES

1. Data Collection for µCT and µPET

X-CUBE

CT

38 *ex vivo* mice scans
(high-low dose image pairs)

β-CUBE

PET

36 ^{18}F-FDG mice scans
(high count image and three lower count reconstructions)

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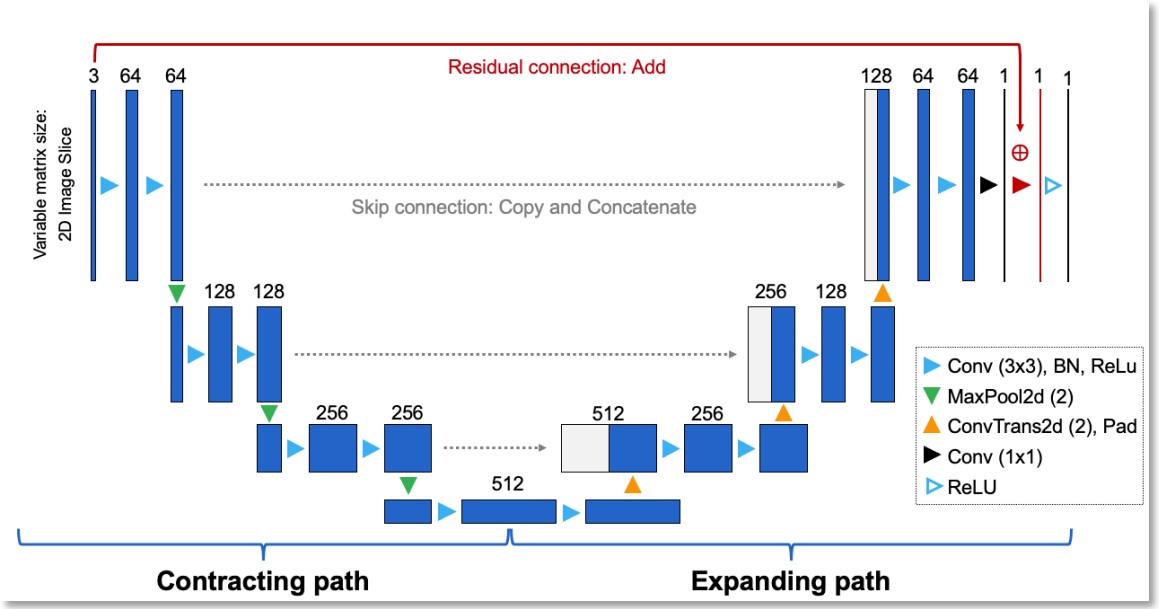
METHODOLOGY

Molecubes
CUBES

1. Data Collection for µCT and µPET

2. CNN Training: Image-to-image



4-layered U-Net

Mean Absolute Error

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METHODOLOGY

Molecubes CUBES

1. Data Collection for µCT and µPET

2. CNN Training: Image-to-image

3. Performance Evaluation

- Qualitative: Observer Studies
- Quantitative assessments

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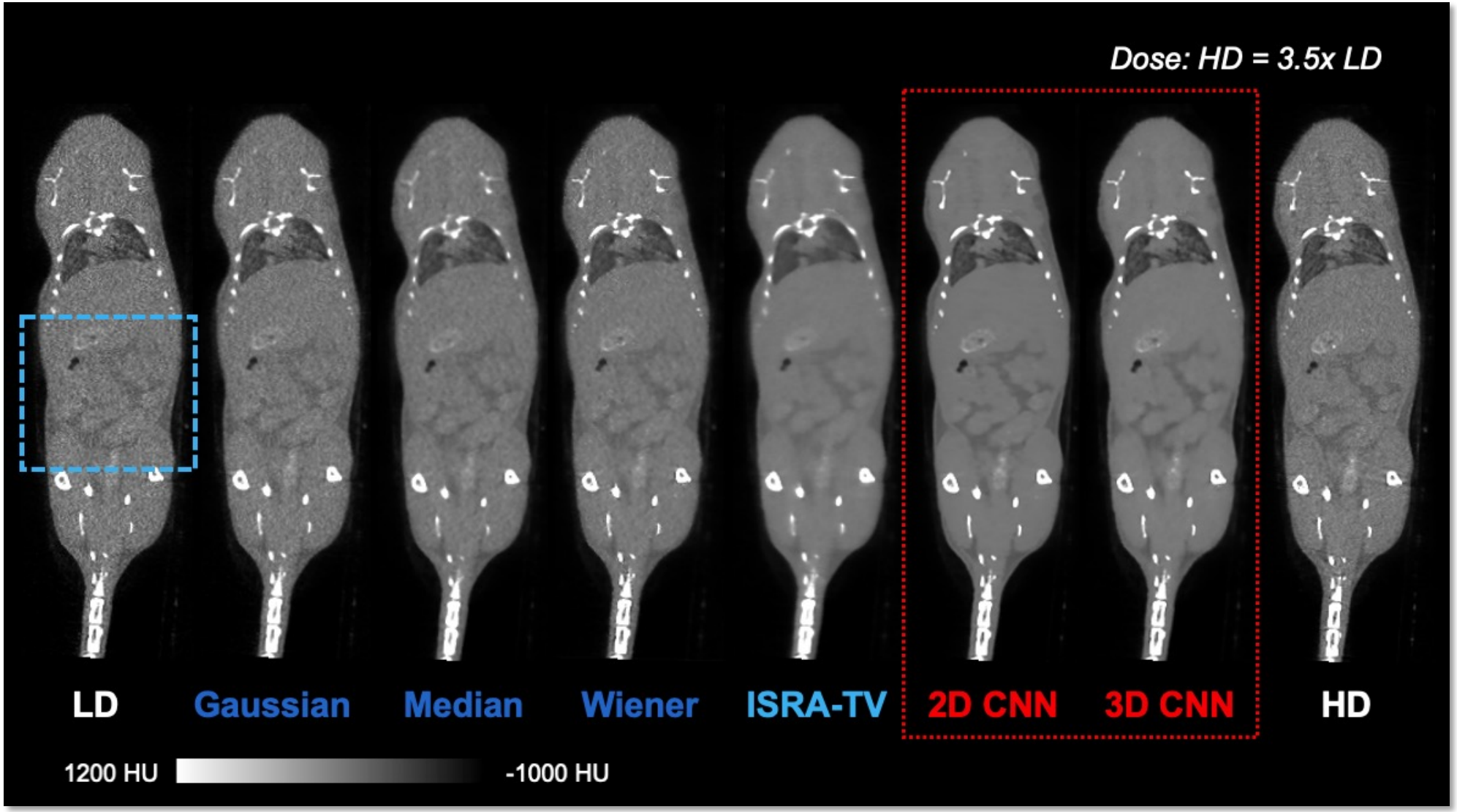
RESULTS: MICRO-CT



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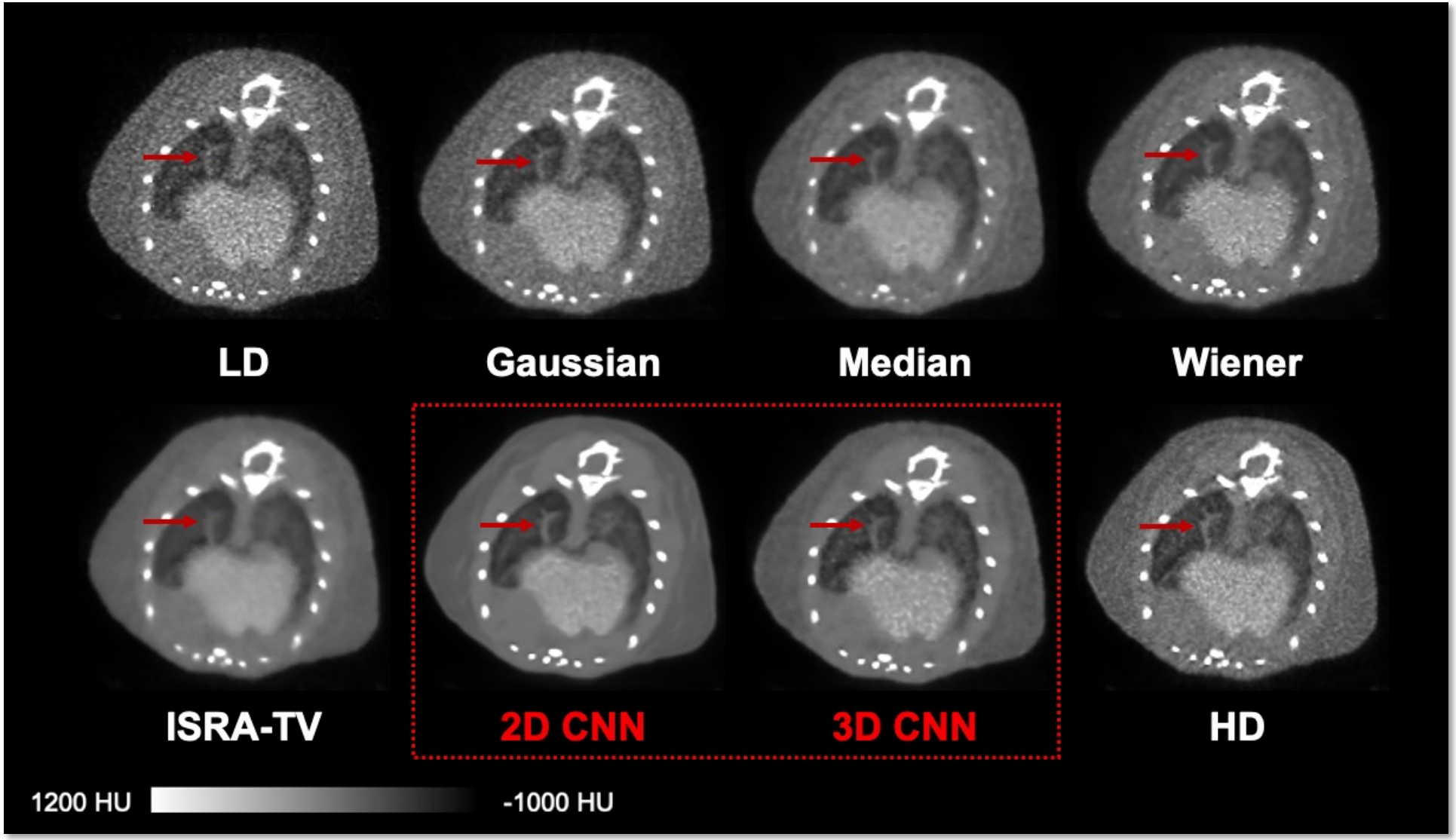
RESULTS: MICRO-CT



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RESULTS: MICRO-PET

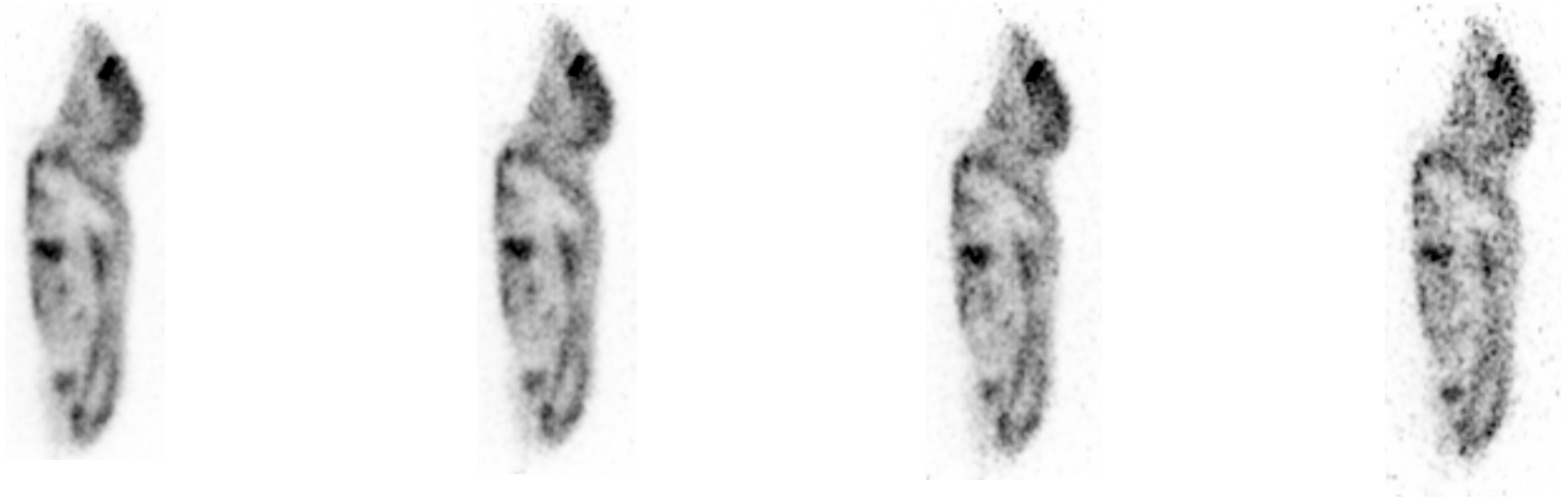
High count image (8 MBq)

Low count images

50% (4 MBq)

25% (2 MBq)

10% (0.8 MBq)



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RESULTS: MICRO-PET

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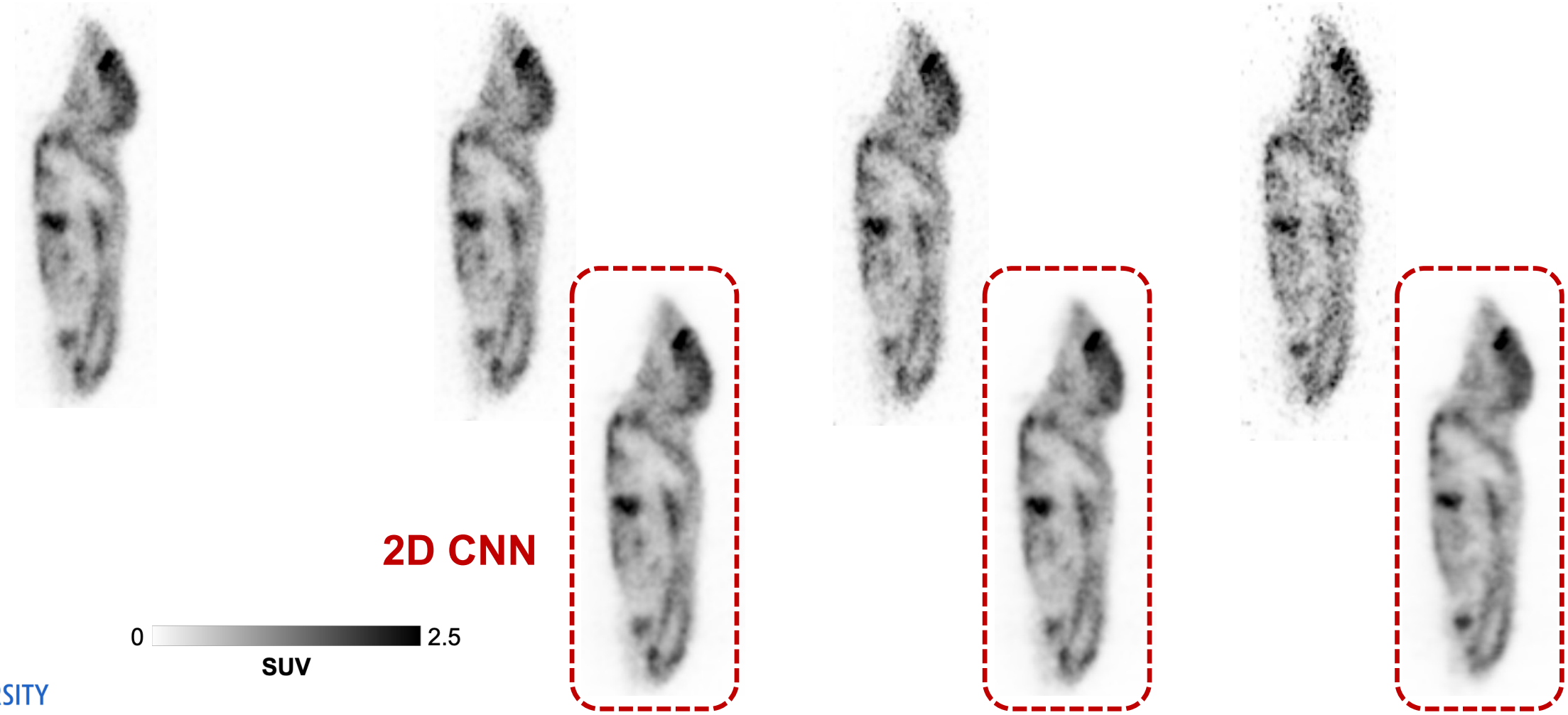

2D CNN

0 2.5

SUV

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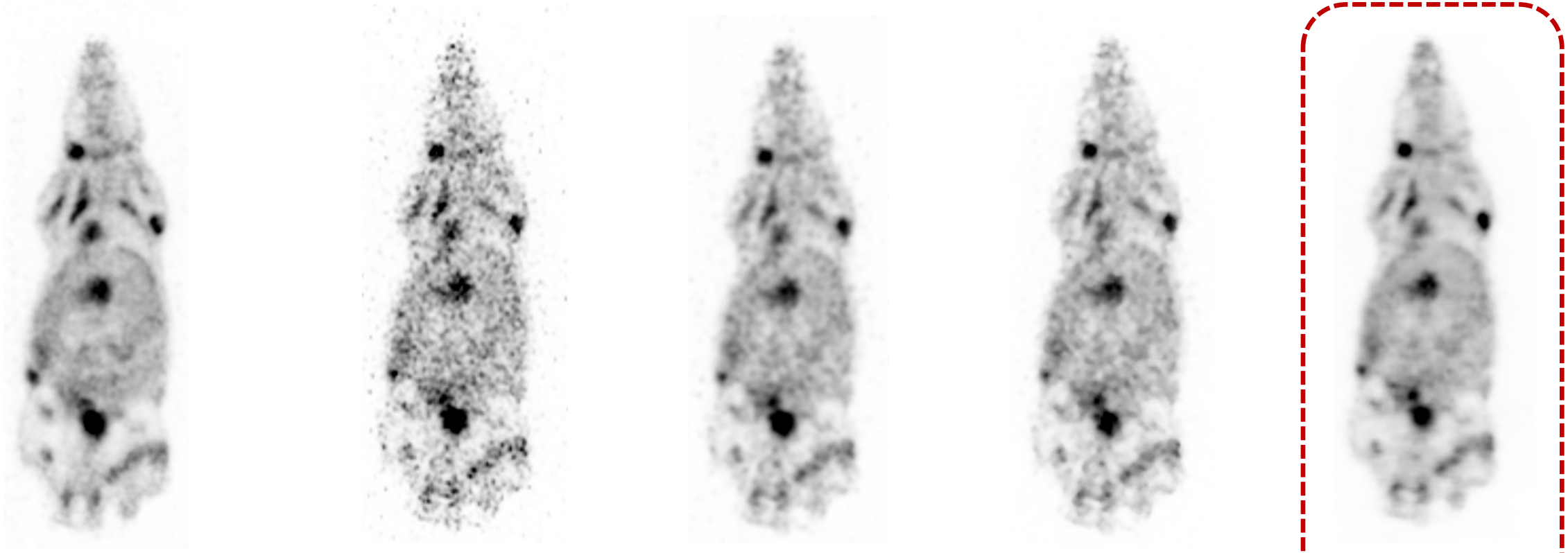
RESULTS: MICRO-PET



High count image (7.16 MBq)

10% low count image (0.7 MBq)

Gaussian

Median

2D CNN

0 2.5

SUV

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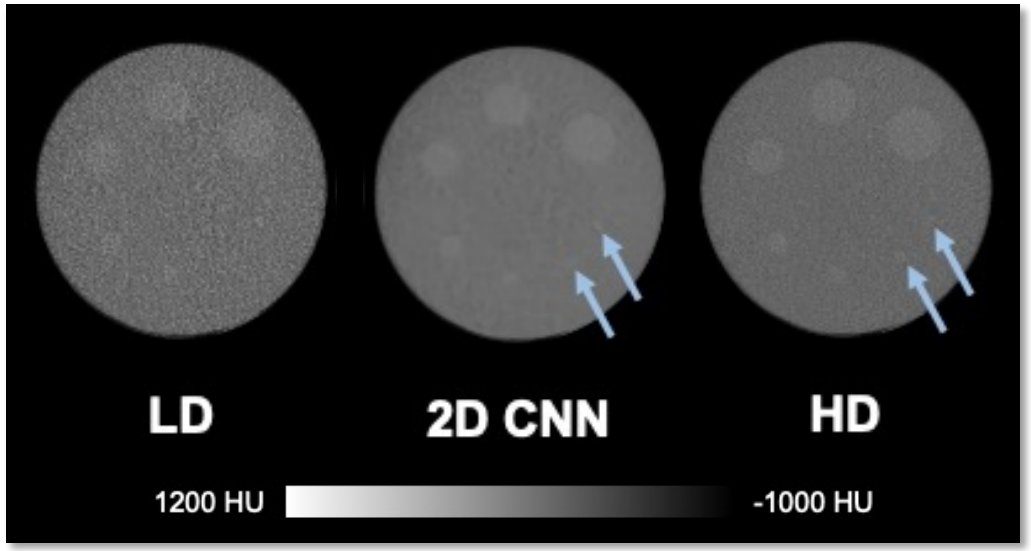
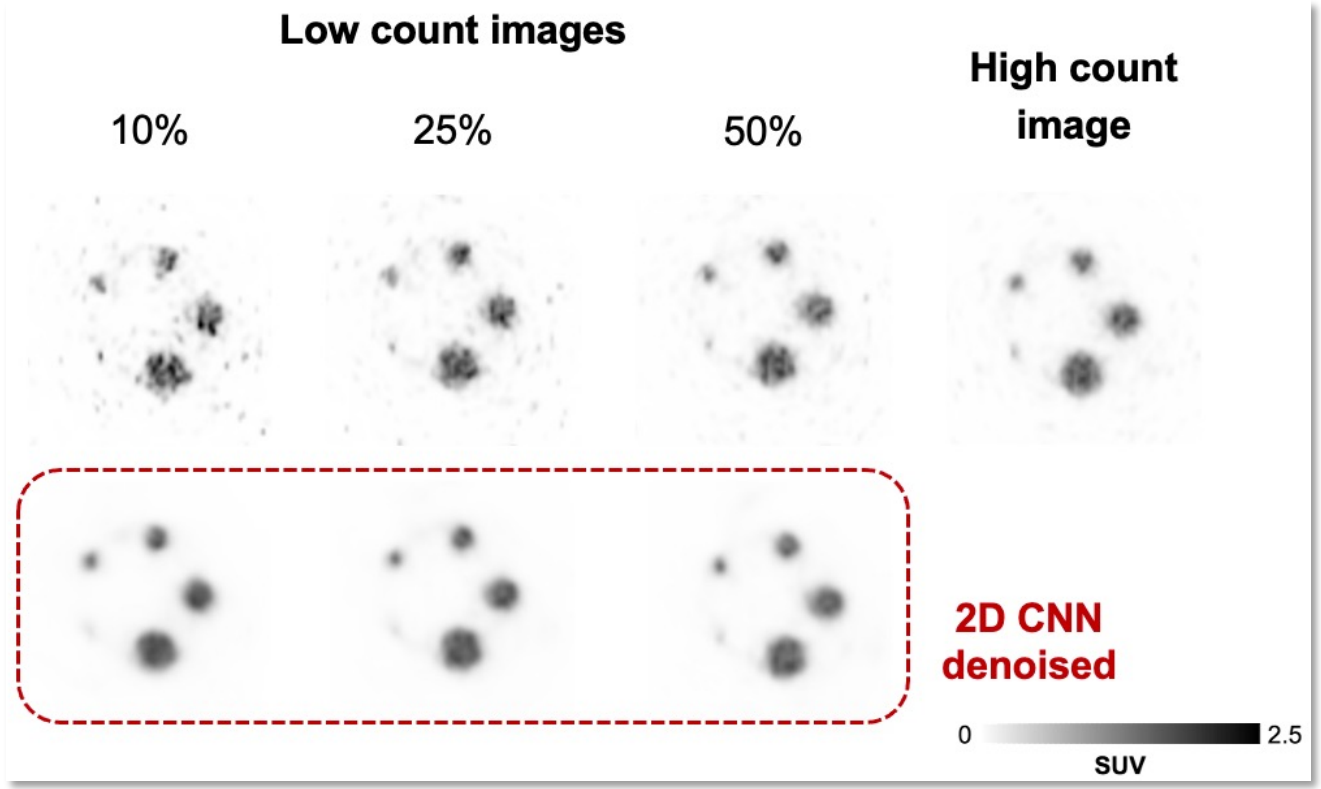
WHAT ABOUT PHANTOM IMAGES ?!

- Keep in mind that CNN is solely trained on mice images (!)

Micro-CT



Micro-PET



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CONCLUSIONS

- Compared to other, more standard denoising methods, **CNN**-based algorithms show **superior image enhancement performance** in preclinical imaging **at reduced doses.**

➔ Ultra-low dose longitudinal scanning of rodents

Micro-CT	Micro-PET
3.2x dose reduction factor	**Sub-1MBq** ^{18}F-FDG PET mouse imaging

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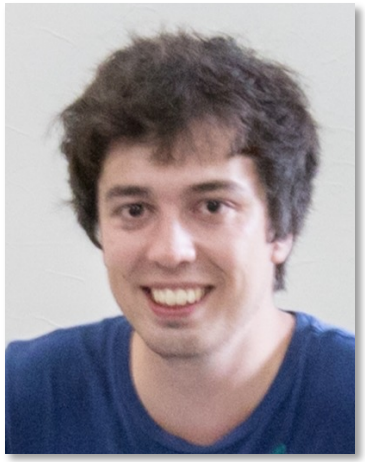
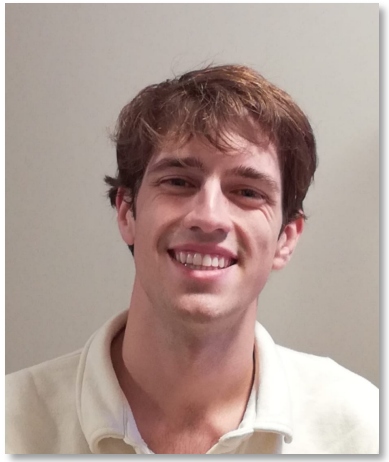
Thank You!

Chris Vanhove

Stefaan Vandenberghe



Jens Maebe



Boris Vervenne

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Thank You! Questions?

Florence Muller

Boris Vervenne, Jens Maebe, Christian Vanhove, Stefaan Vandenberghe

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