From Monte Carlo to Neural Networks

Transforming Nuclear Medicine with GPUs

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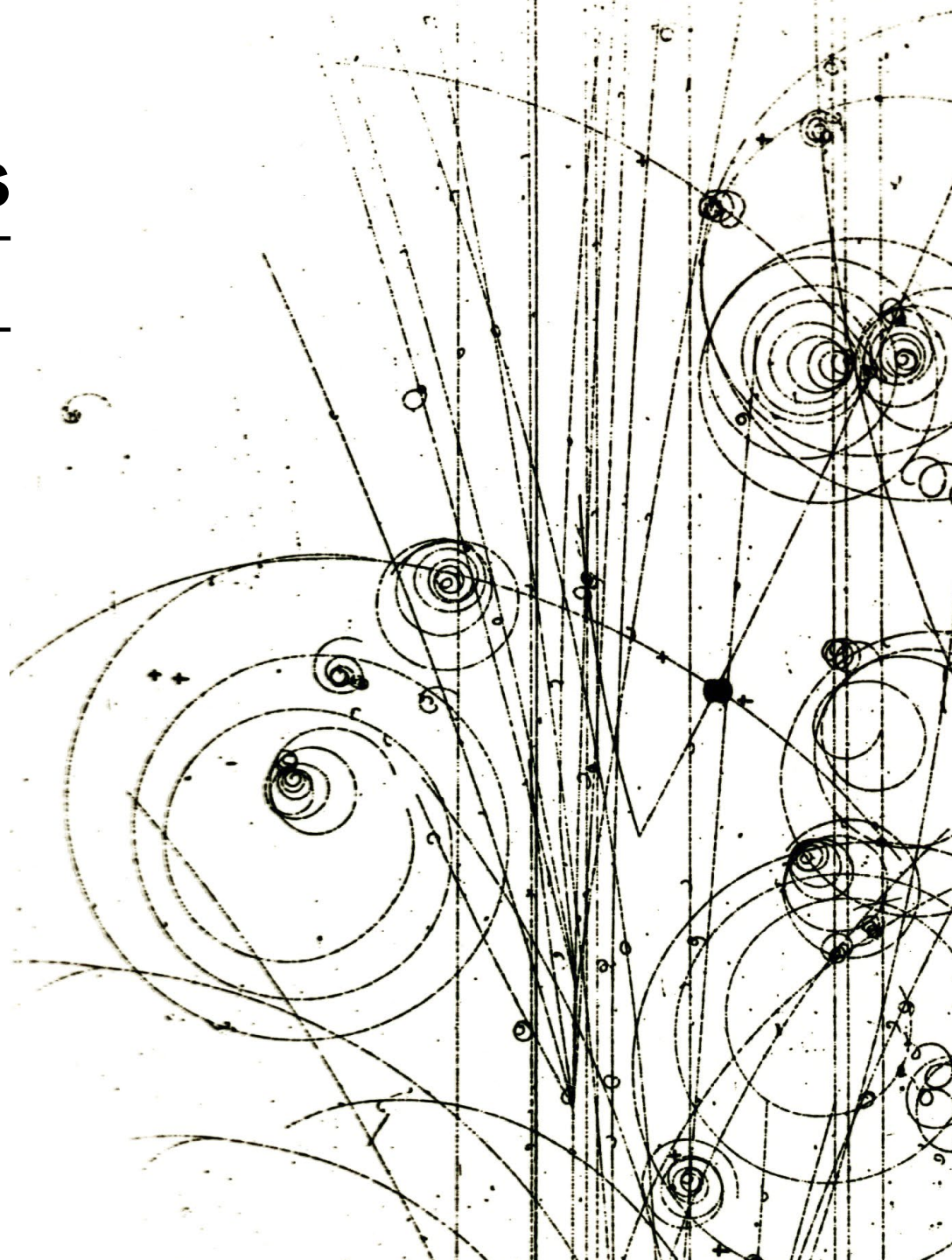


Mediso
Medical Imaging Systems

Mediso Product Lines

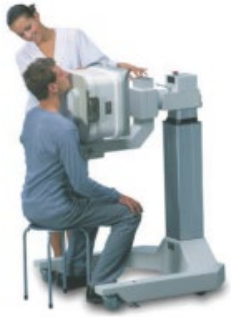
Manufacturing

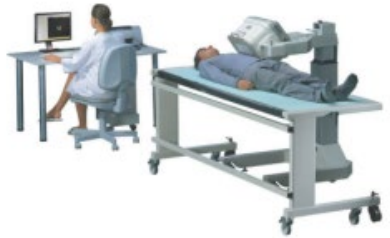
Service

HW Development

SW Development

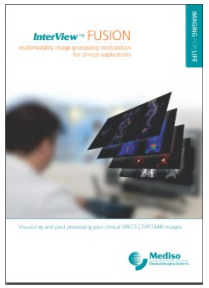
Clinical Products

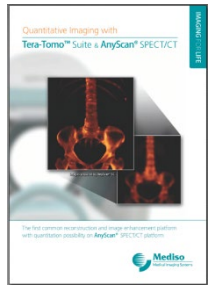


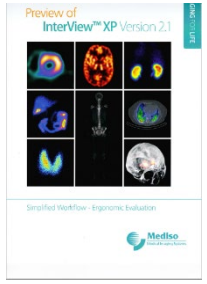


Preclinical (“Small Animal”) Products

Software Products







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Mediso GPU Usage

Development Tool
+
Product Component

Display (OpenGL)

Latest ASUS midrange Nvidia Geforces
Installed base: from 640s to 1060s

Reconstruction WS
(CUDA, TensorFlow)

Latest ASUS high-end Nvidia Geforces
Installed base: from GTX 580s to 2080s

HPC Servers
(CUDA, TensorFlow)

Supermicro 4028GR-TRT / TRT2
(8 / 10 GPUs)

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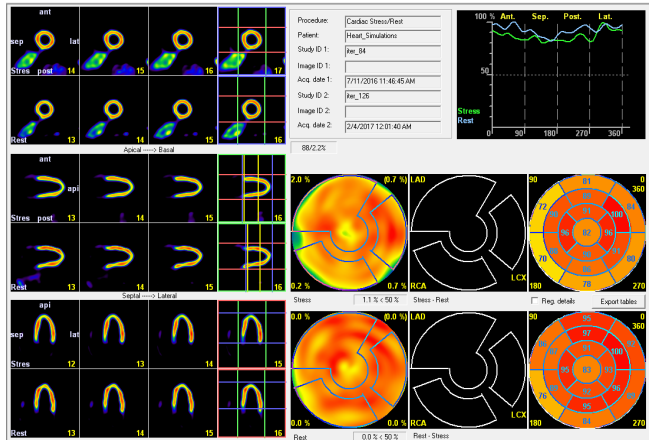
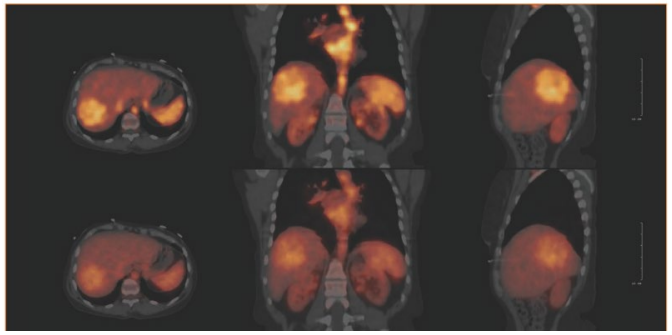
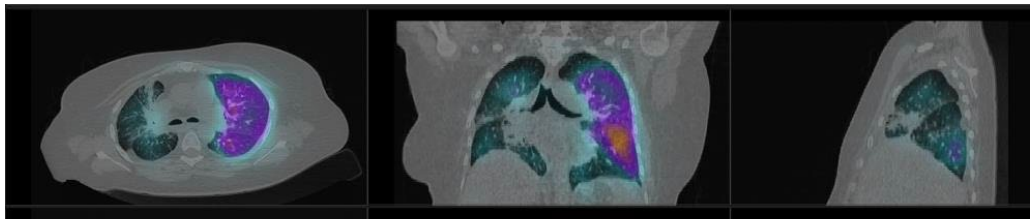
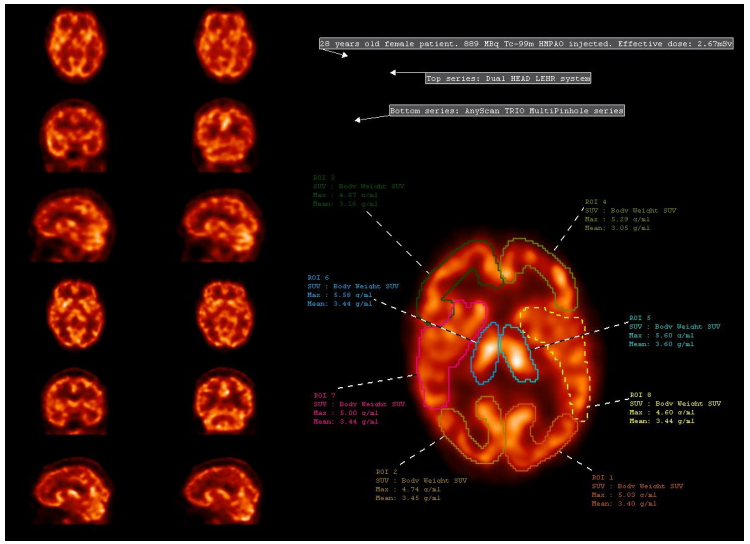
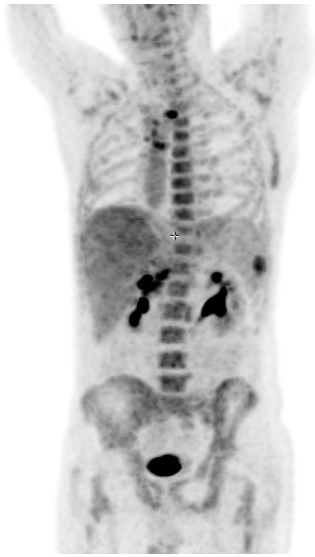
Imaging in Nuclear Medicine











Gastroenterology

Cardiology

Pulmonology

Nephrology

Nuclear Medicine

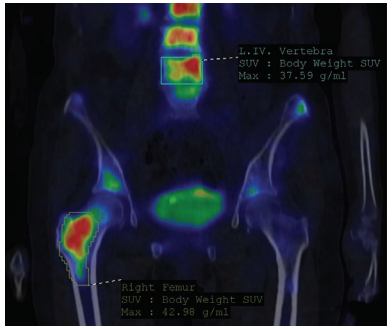
Neurology

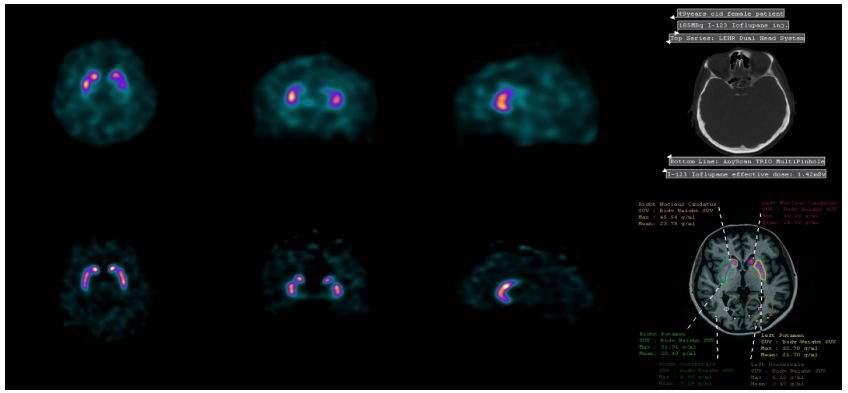
Oncology

Endocrinology

Osteology

Exocrinology





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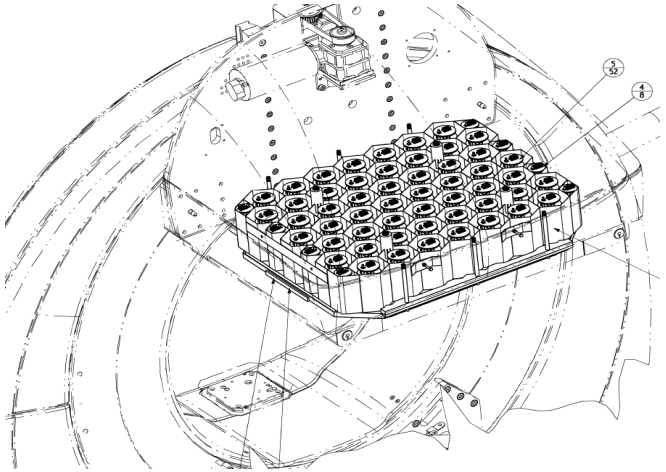
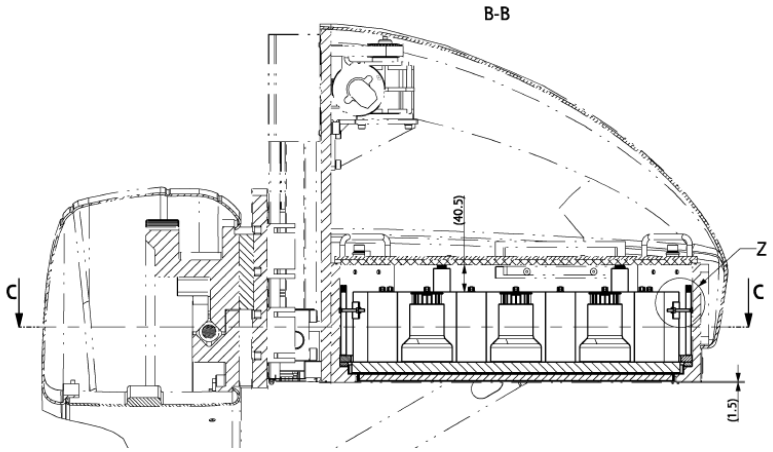
SPECT detector





Electronics
PMTs
Scintillator
Collimator

PET CT SPECT

Triple-Modality AnyScan SPECT/CT/PET

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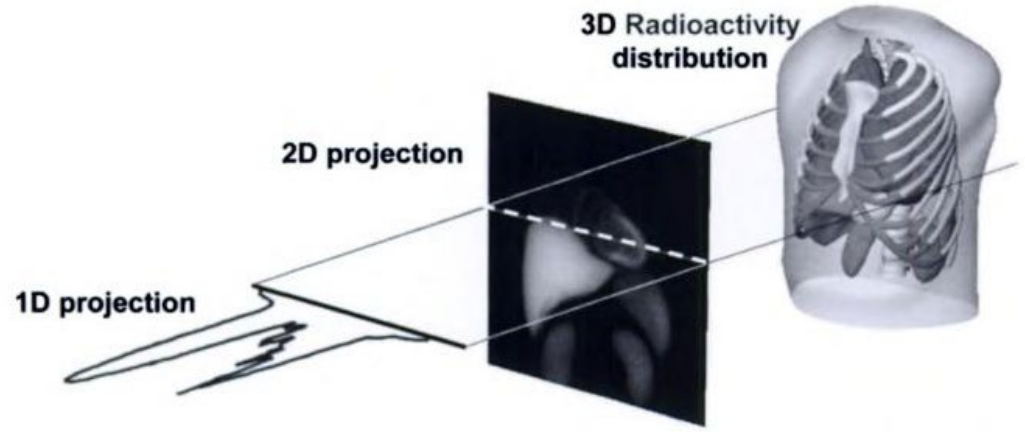
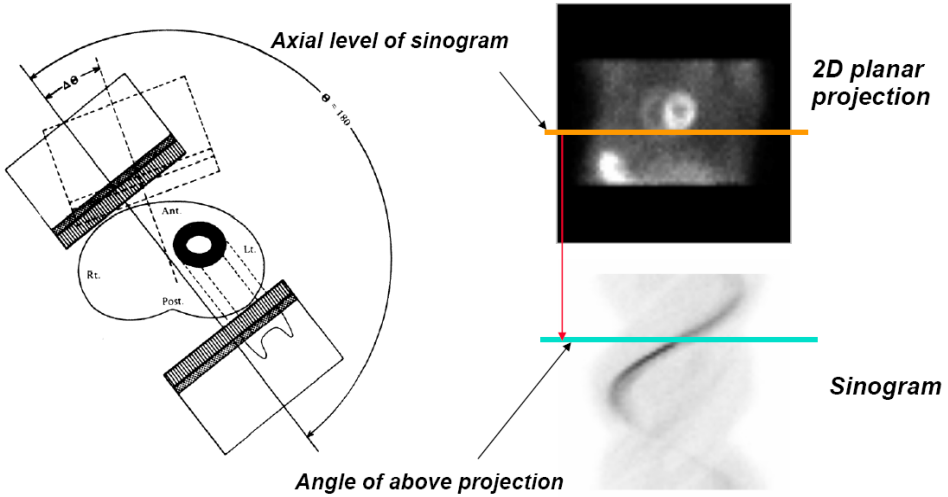
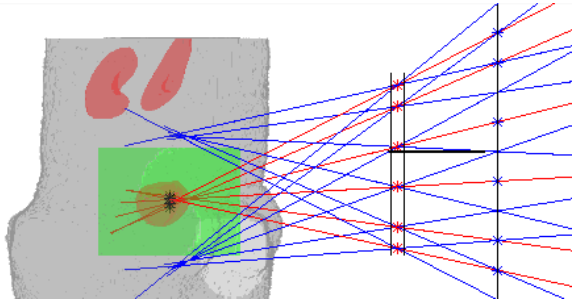
Imaging in Nuclear Medicine

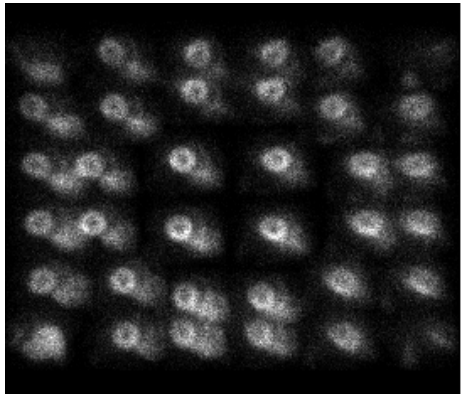


Imaging the 3D radioactivity distribution by detecting gamma photons

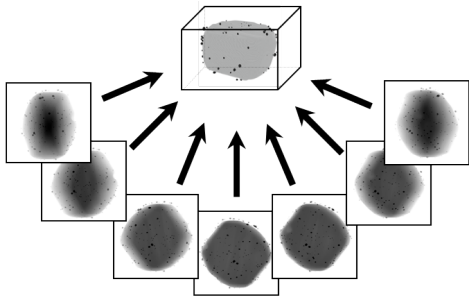


Repeating measurement from different angles around the patient





Alternative way of projecting the distribution onto the gamma camera with multiple pinholes



Reconstruction: calculate 3D distribution data from 2D projections

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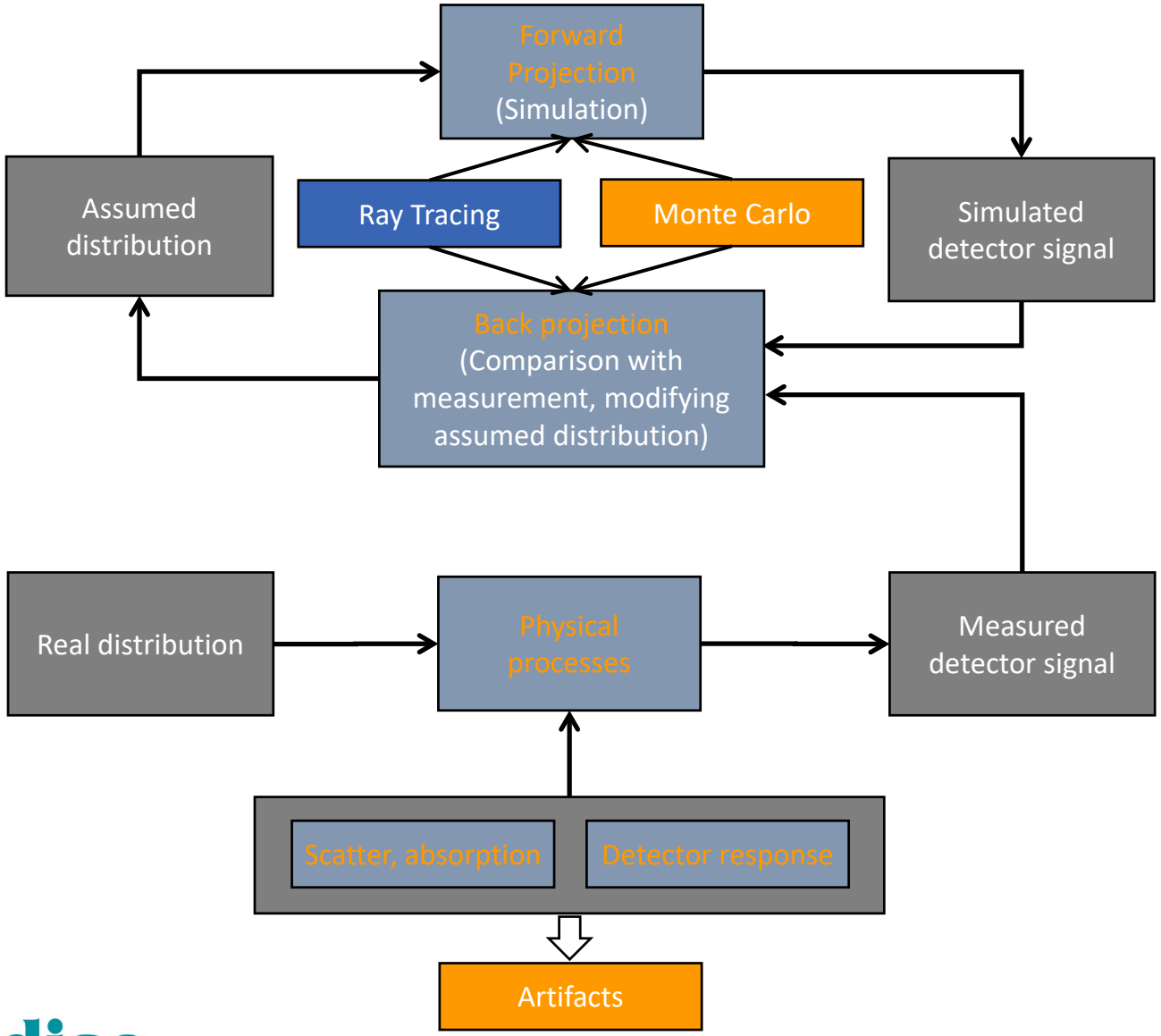
Iterative Reconstruction



- Gradually approximates the radioisotope distribution
- Accuracy of Forward Projection is crucial
- Physical processes has to be modelled precisely
- Time constraint makes reconstruction dependent on computational performance
- Parallelization of transport algorithms on GPU makes using Monte Carlo possible

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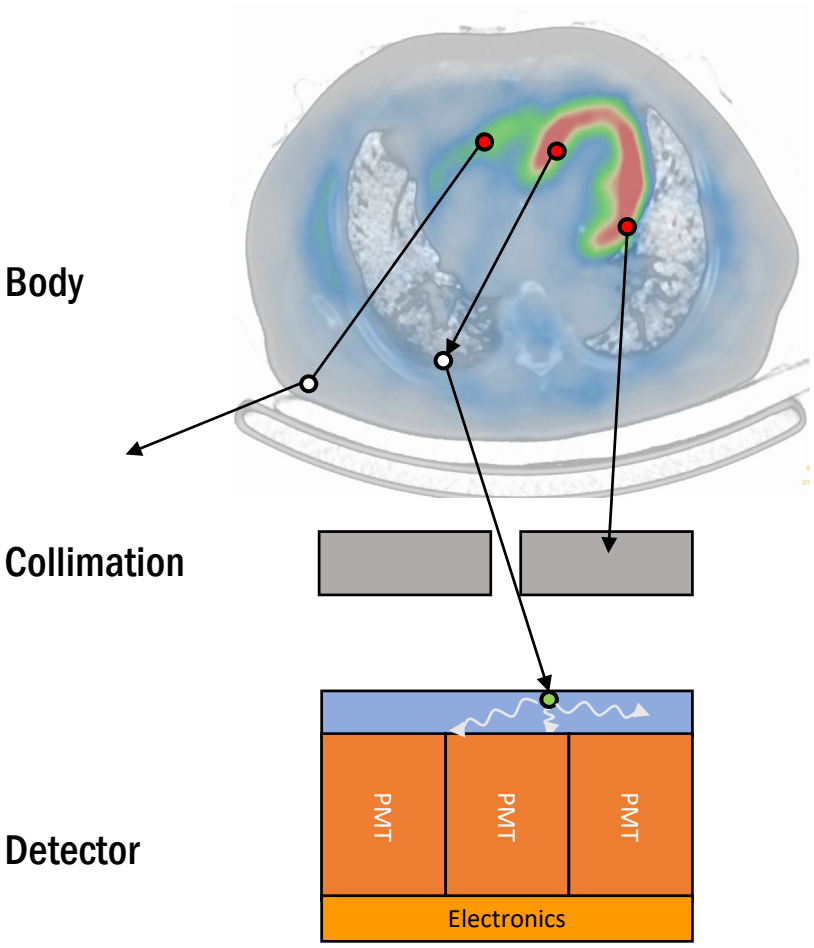
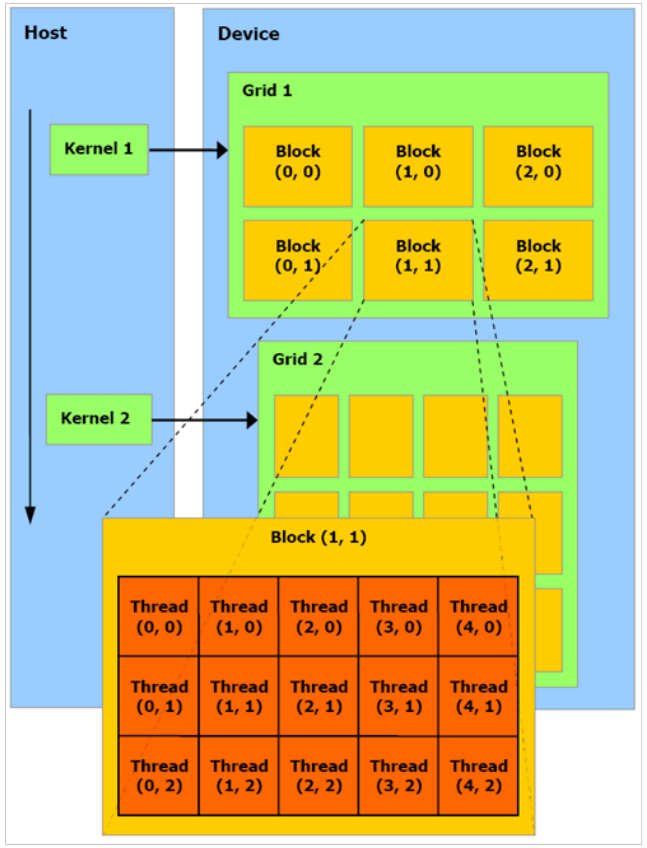
Monte Carlo Particle Transport on GPUs





Simulating single particle trajectory

1. Sampling source distribution

2. Simulating photon interactions with:

   collimation

   body tissues detector material

3. Registering counts in image matrix

Photon trajectories are independent:
Each photon can be simulated on a single GPU thread

Problem:
Photon trajectories are random, threads can diverge

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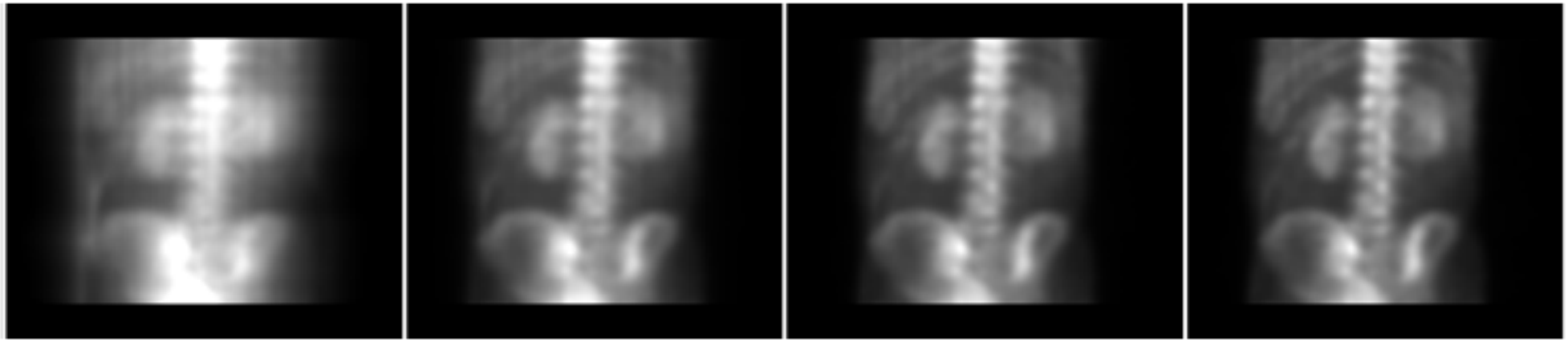
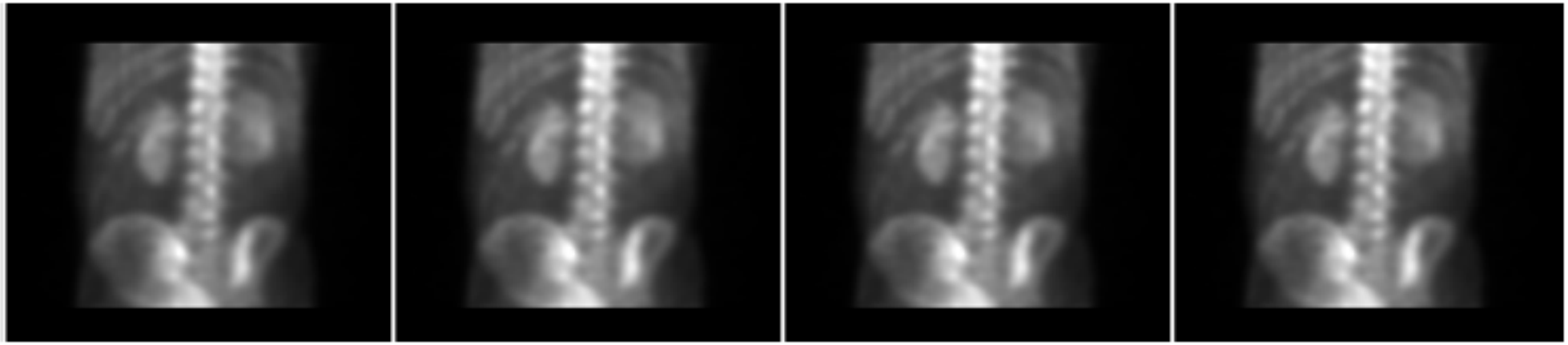
Iterative Reconstruction

Results of forward projections during the reconstruction of a bone SPECT



Iteration: 1 5 10 15



20 25 30 35

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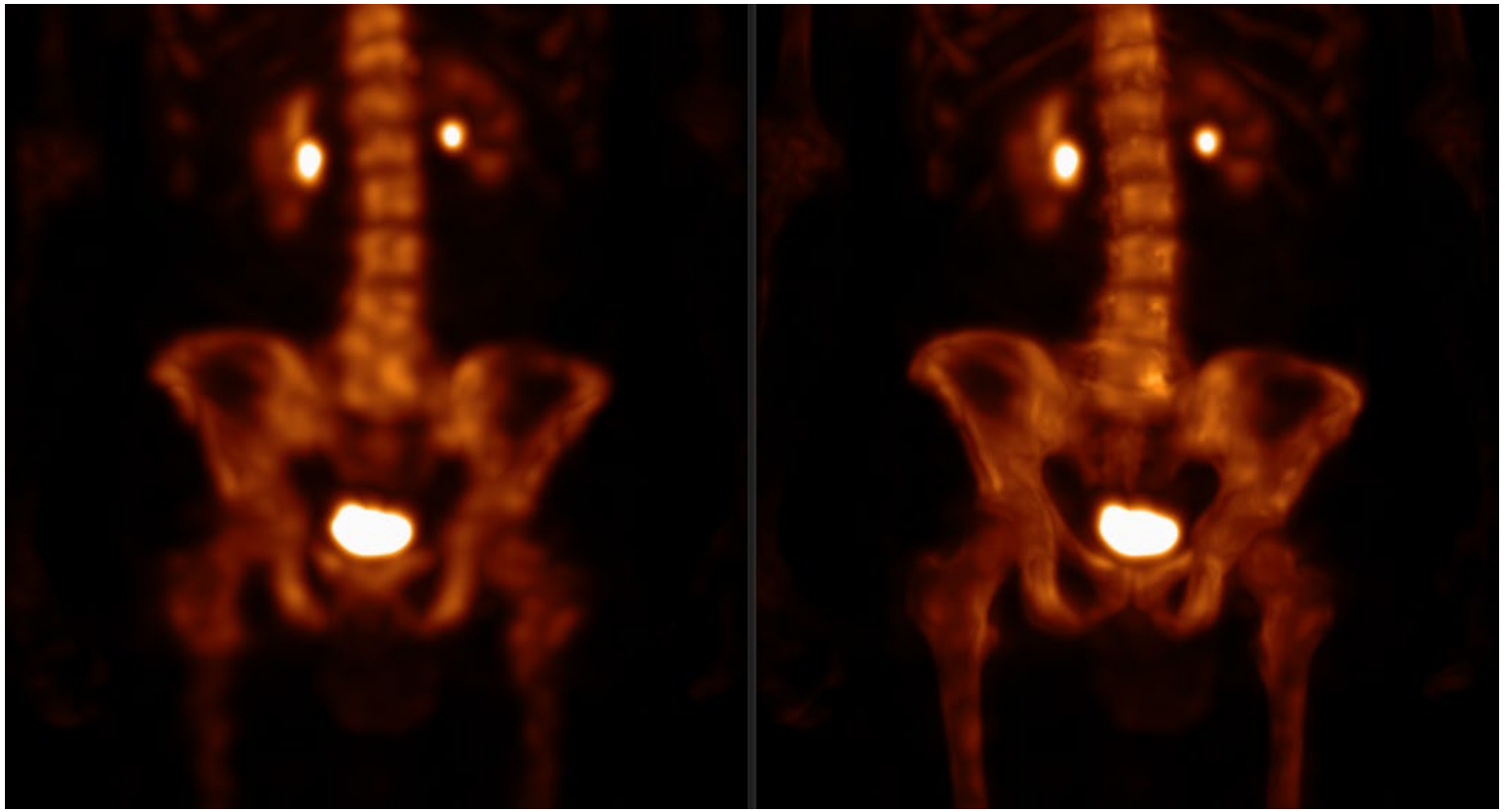
Iterative Reconstruction



Conventional 2D reconstruction

Monte Carlo based 3D iterative reconstruction

Benefits of Monte Carlo

- Superior resolution
- Lower scatter background
- Free of penetration background
- Can handle multiple isotopes
- Absolute quantitation:
  - activity in Bq/ml or SUV

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Noise Reduction

Development goals in nuclear medicine:

Shorter examination time

- Higher throughput
- Increased patient comfort
- Reduced movement artifacts

Lower amounts of radioisotope

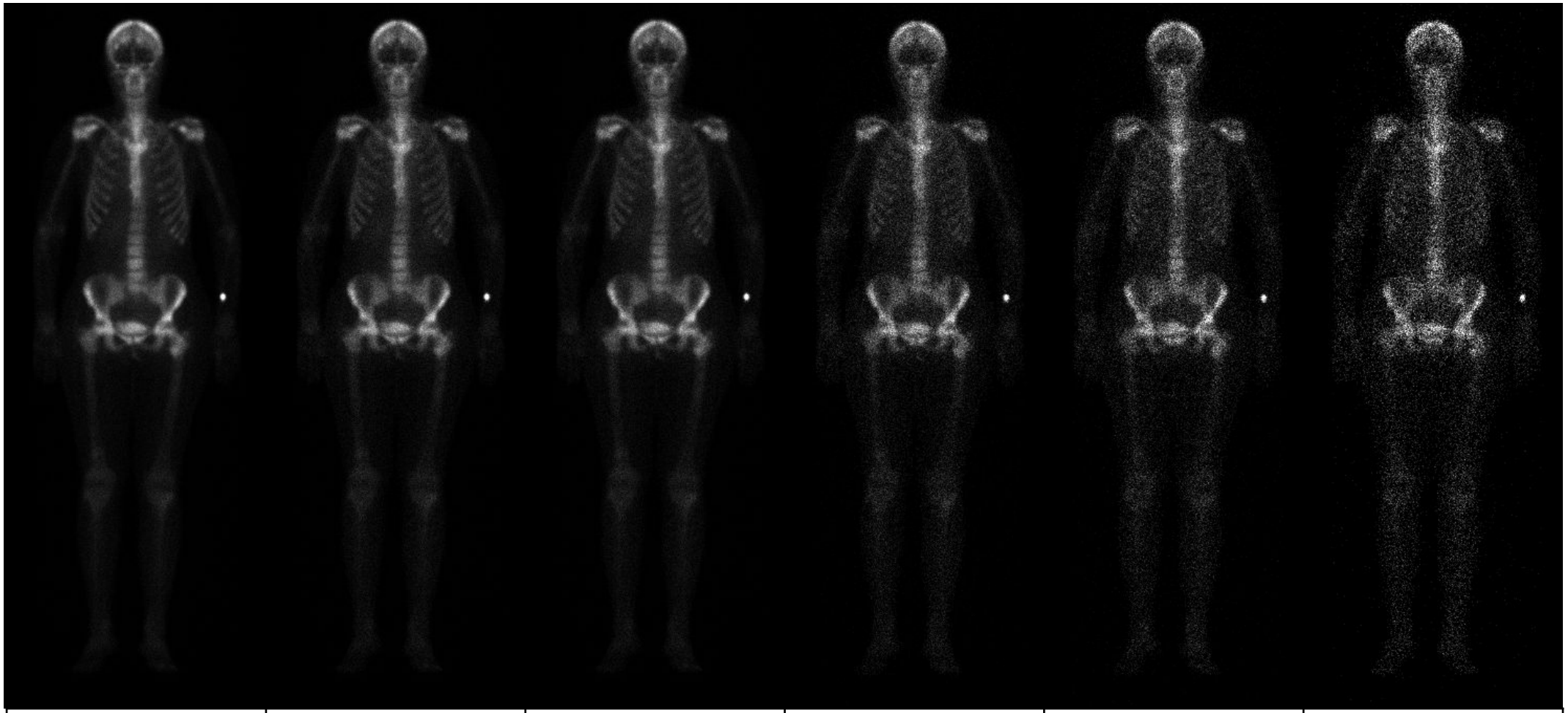
- Reduced radiation dose
- Decreased costs

Decreased image statistics
Higher noise levels

Development of noise reduction methods

Noise Reduction of Planar Bone Scintigraphy

Effect of reducing scan time on image quality:



stats:	original	1/2	1/4	1/8	1/16	1/32

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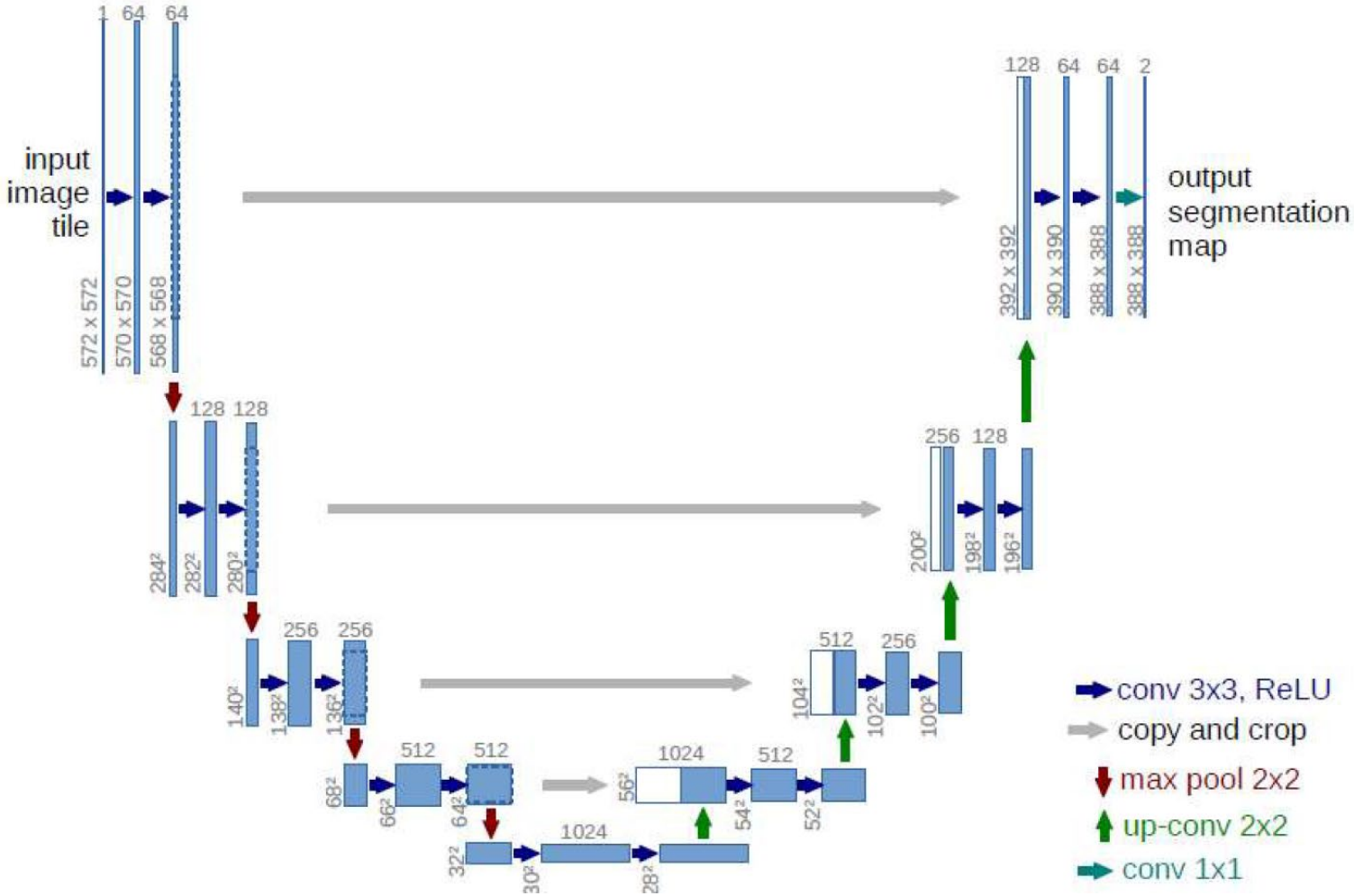
Neural Network Architecture

Original U-Net architecture:



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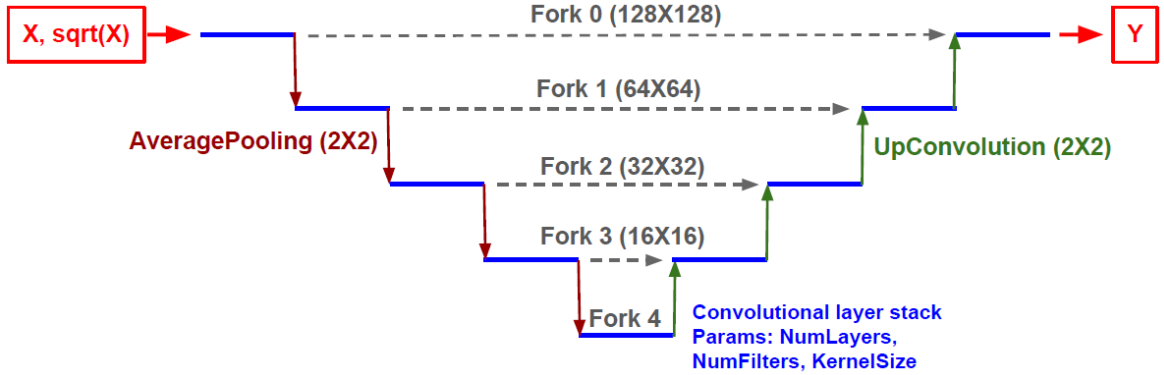
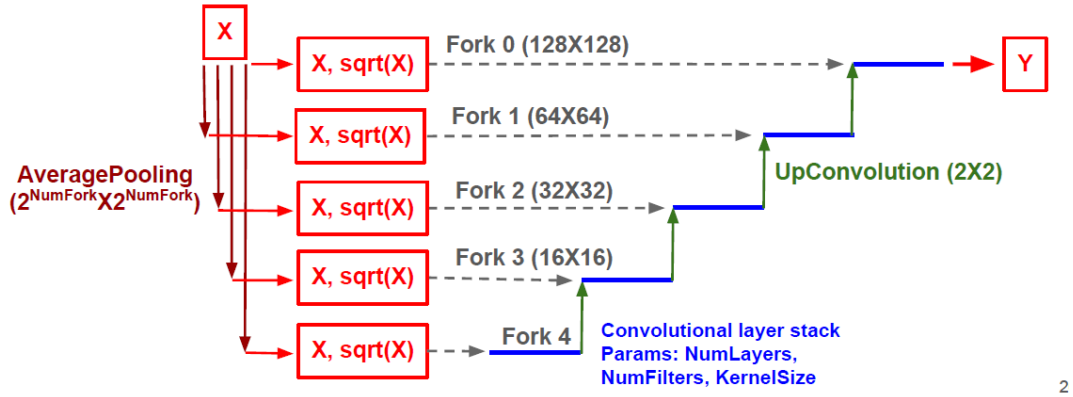
Neural Network Architecture

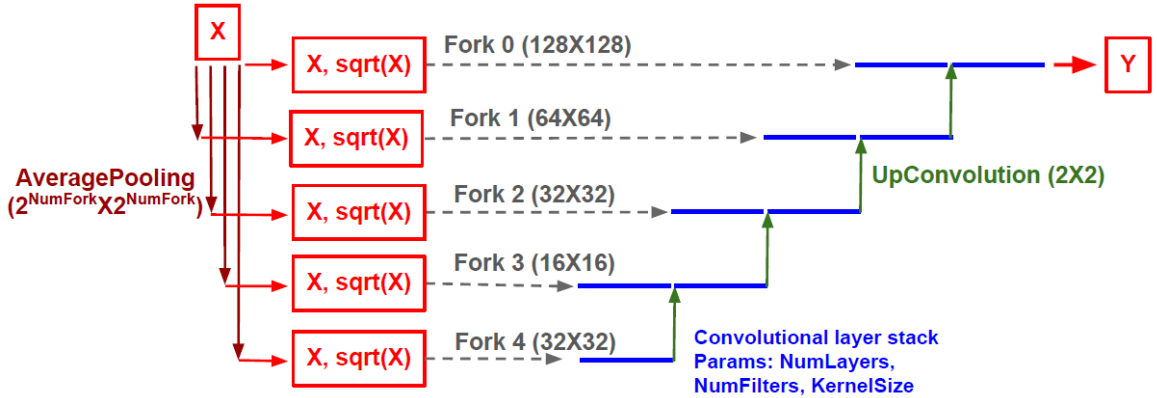
Following candidate architectures were implemented in TensorFlow:



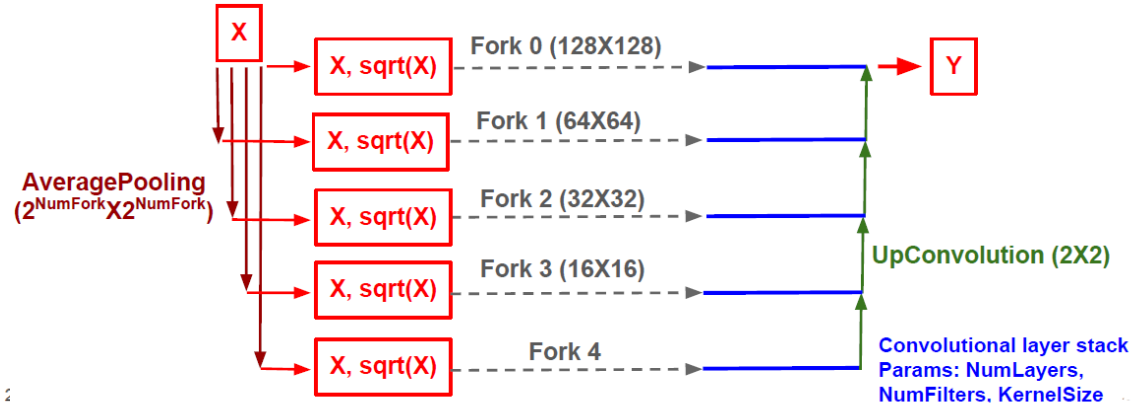
U-net adapted to current problem



Half U-net



Shortcut U-net



Fork-net

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Neural Network Strategy

Training:

1000 anonymized patient scan with standard statistics

Images with degraded statistics was generated from the original acquisitions using random binomial sampling

Degraded images was used as the input and the corresponding original image as the desired output

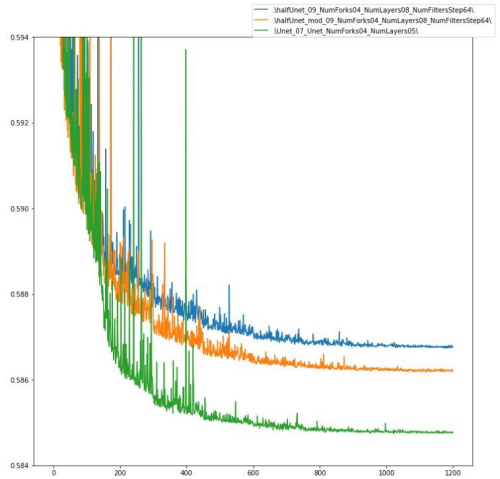
128 x 128 patches randomly selected

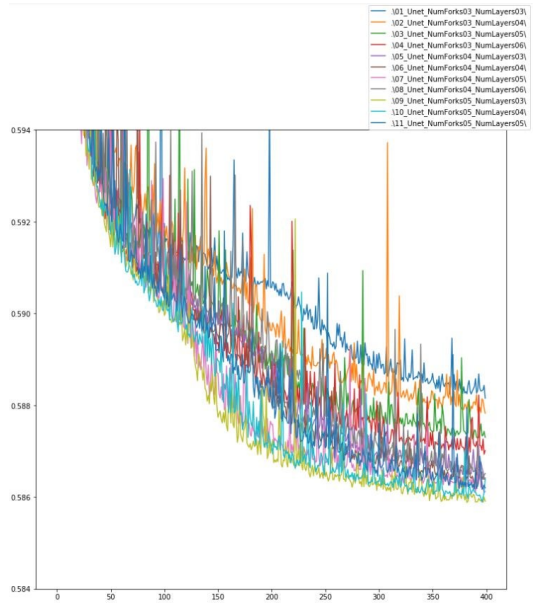
L1 (maximum value) loss was used

Learning rate:

Gradually decreased as 1/(1+C*iterations)

Through 400 epochs learning rate decreased one order of magnitude





Evaluation:

Visual evaluation

Quantitative analysis of image quality based on artificially generated lesions

Preliminary clinical test performed on 30 patients (lesion evaluation blind test)

Performance (4 x GTX 1080 Ti):

Training time: 30 sec / epoch
Inference time: 0.08 sec

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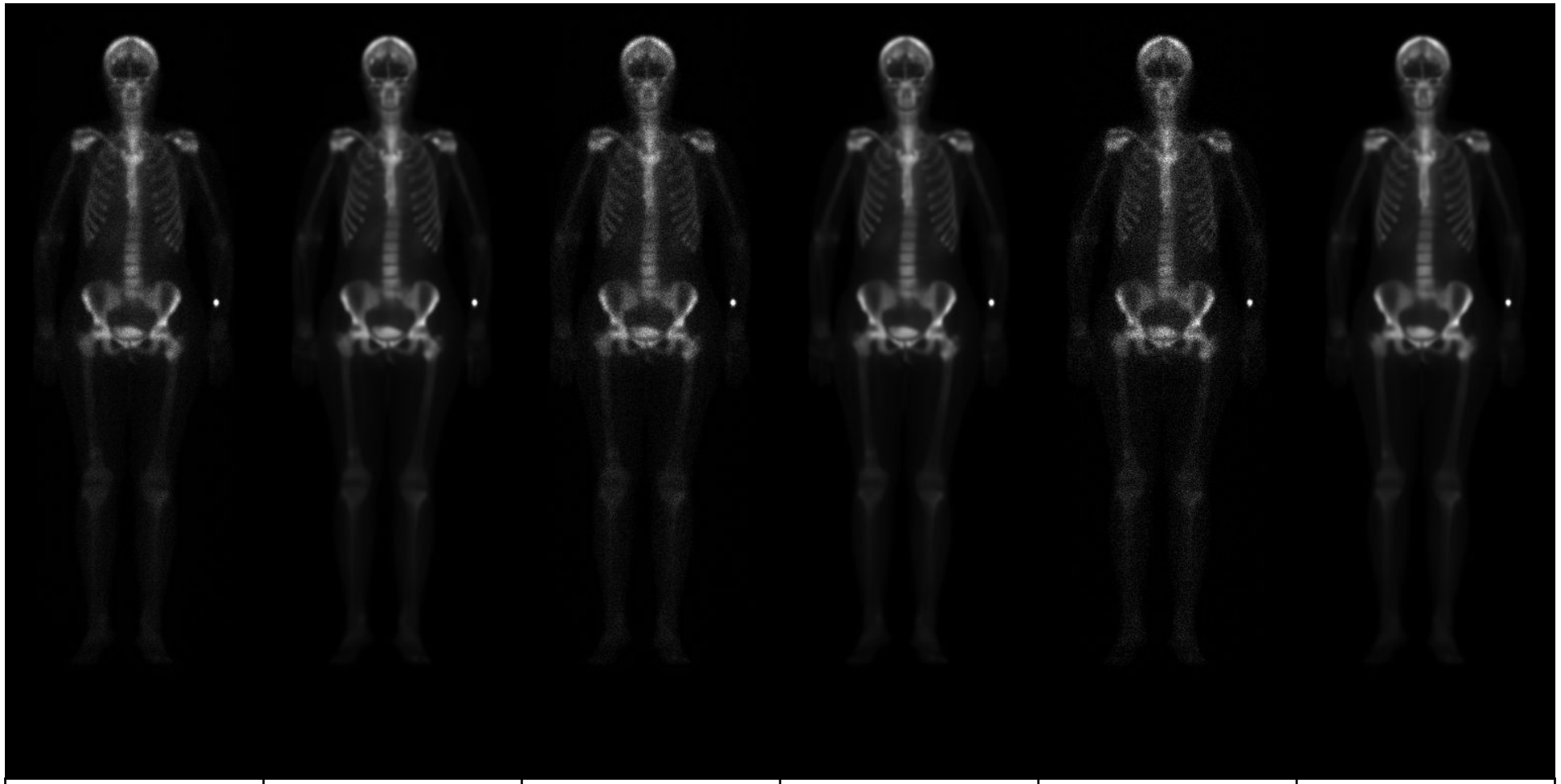
Evaluation — Visual Examples



	unfiltered	filtered	unfiltered	filtered	unfiltered	filtered
Stats:	original		1/2		1/4	

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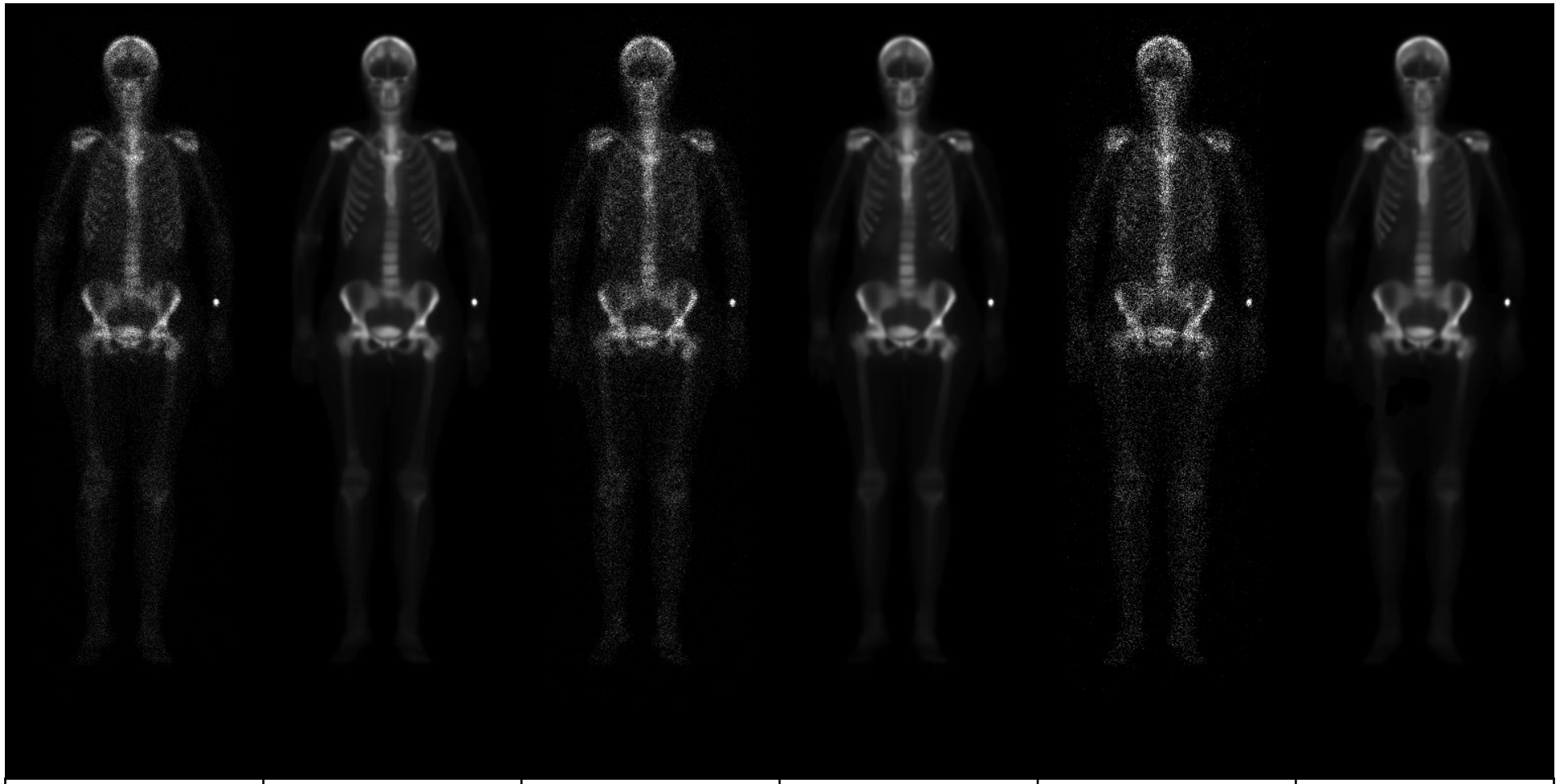
Evaluation — Visual Examples



	unfiltered	filtered	unfiltered	filtered	unfiltered	filtered
Stats:	1/8		1/16		1/32	

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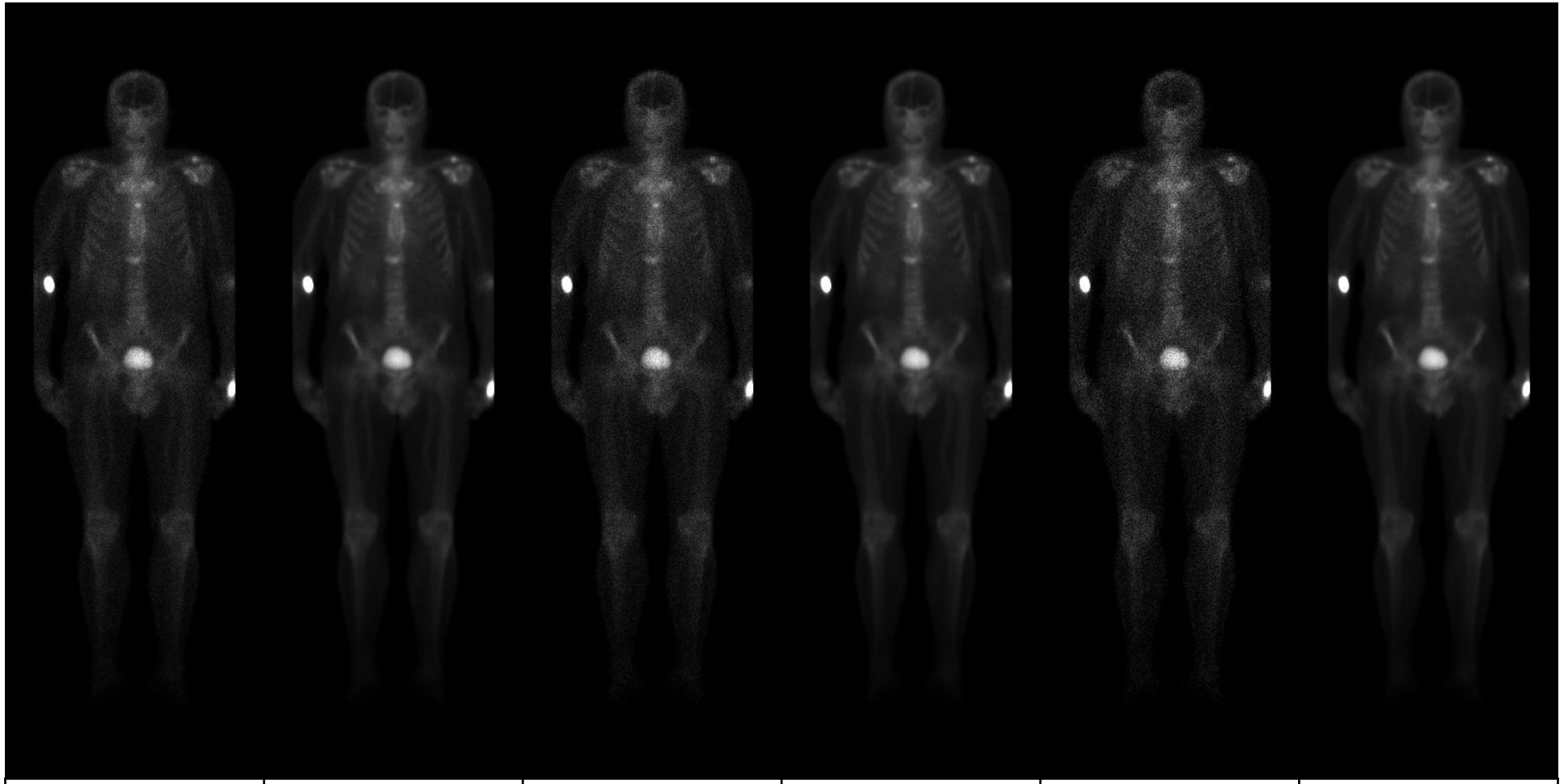
Evaluation — Visual Examples



	unfiltered	filtered	unfiltered	filtered	unfiltered	filtered
Stats:	original		1/2		1/4	

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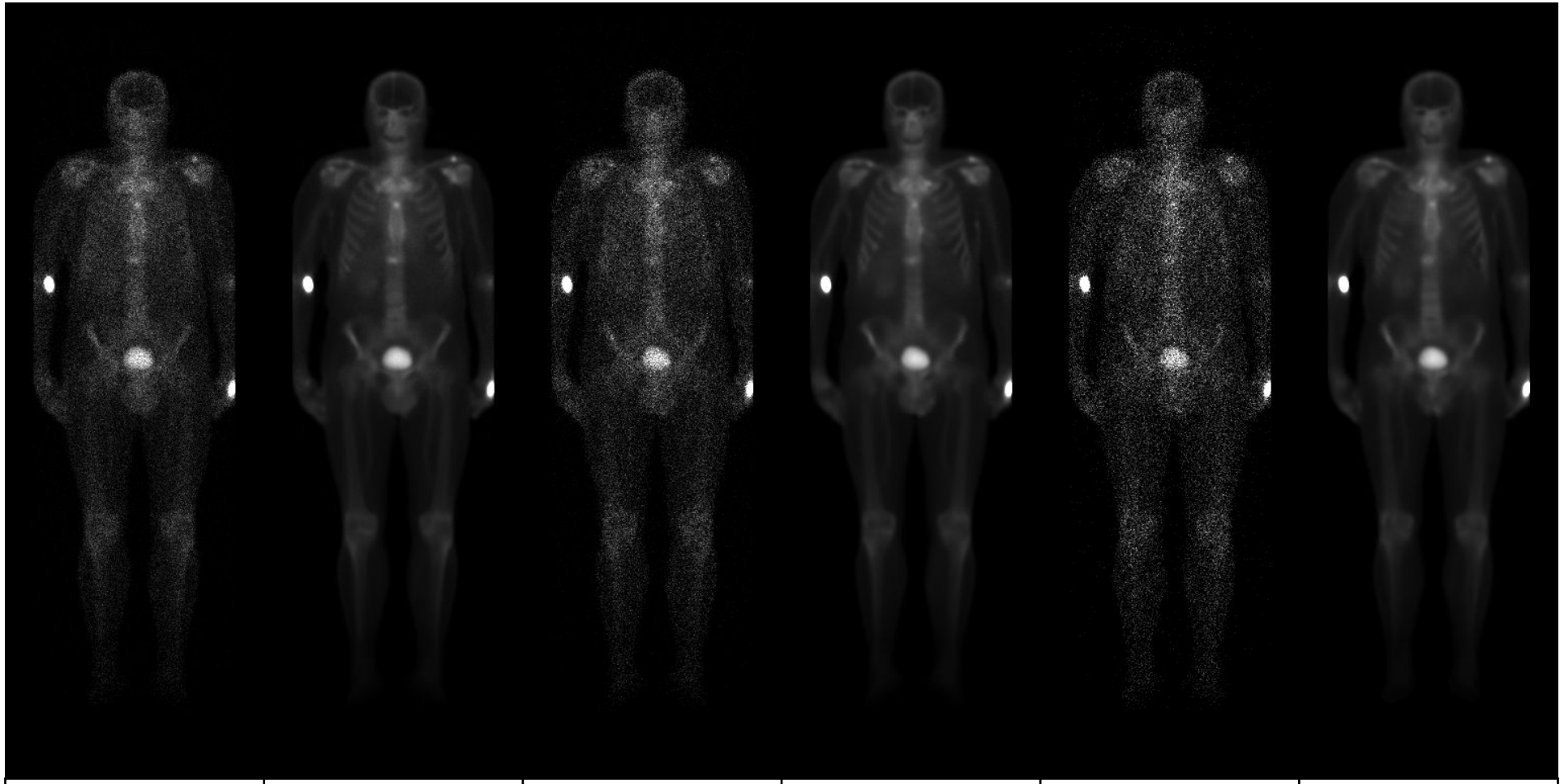
Evaluation — Visual Examples



	unfiltered	filtered	unfiltered	filtered	unfiltered	filtered
stats:	1/8		1/16		1/32	

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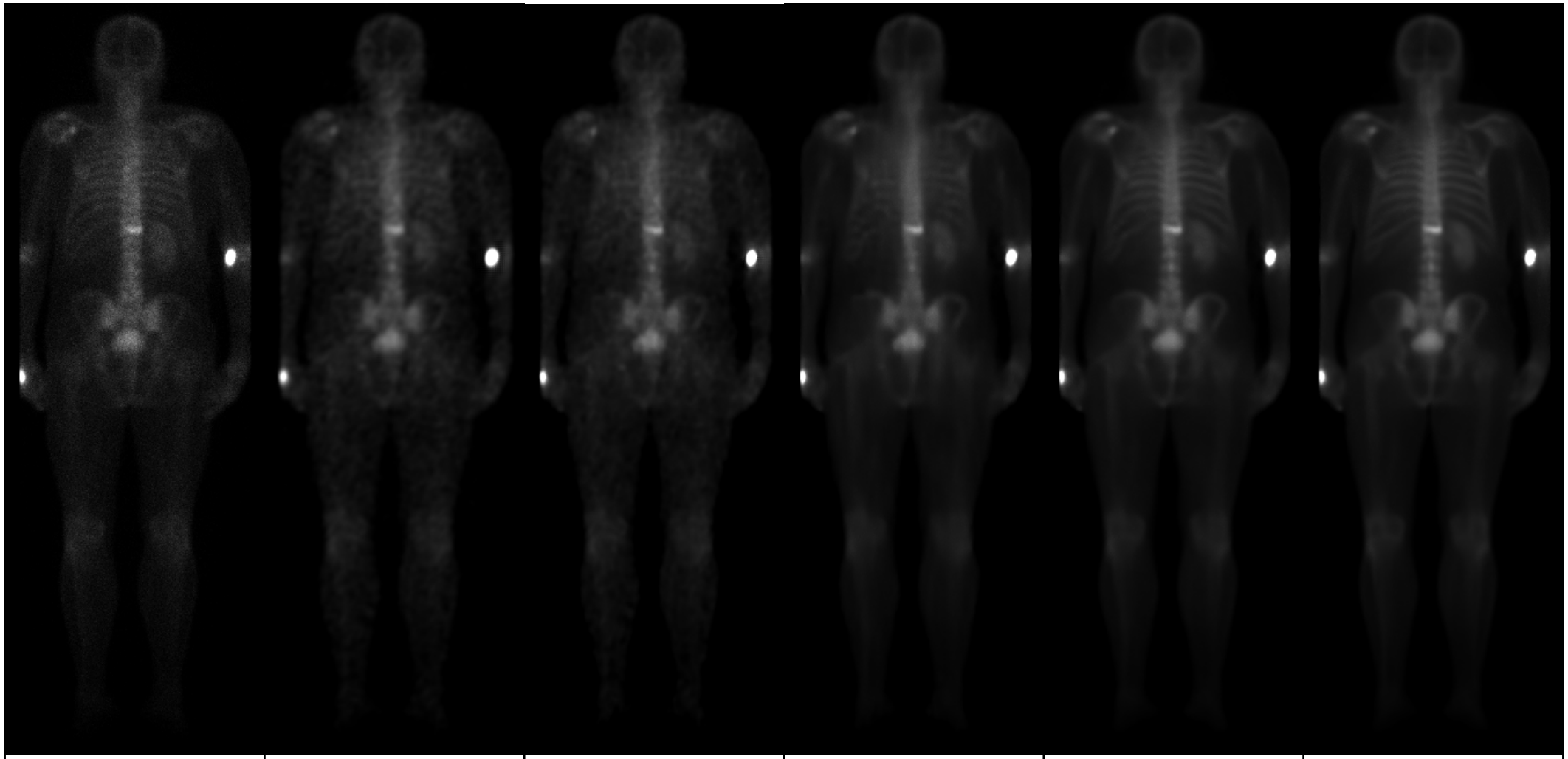
Evaluation — Epochs

Quality of filtered images degraded to 1/16 statistics as a function of epochs



Original	Epoch 1	Epoch 5	Epoch 20	Epoch 100	Epoch 1200

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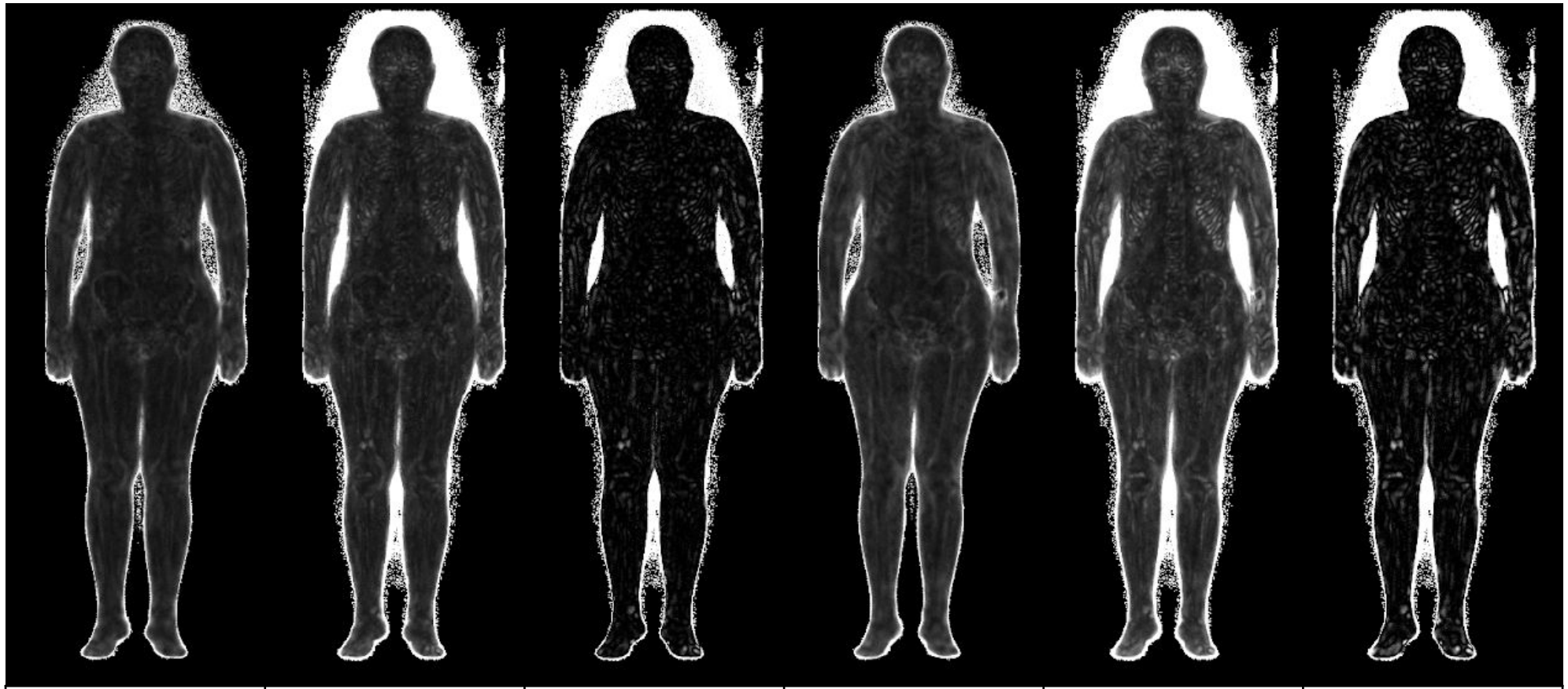
Evaluation — Distance Metrics

Difference images between the inferred images and the original



Difference:	std	rms	rms - std	std	rms	rms - std
Stats:	1/8			1/16		

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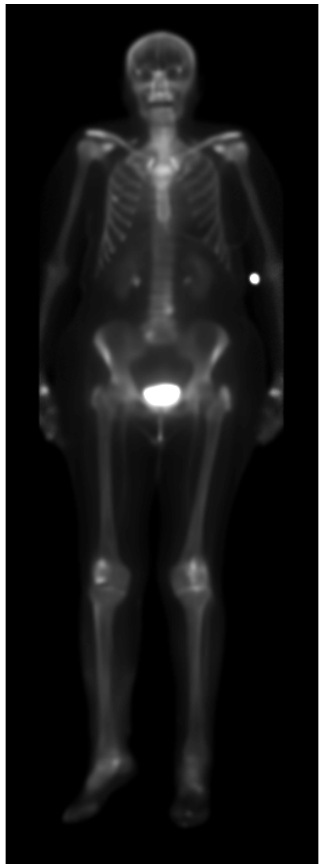
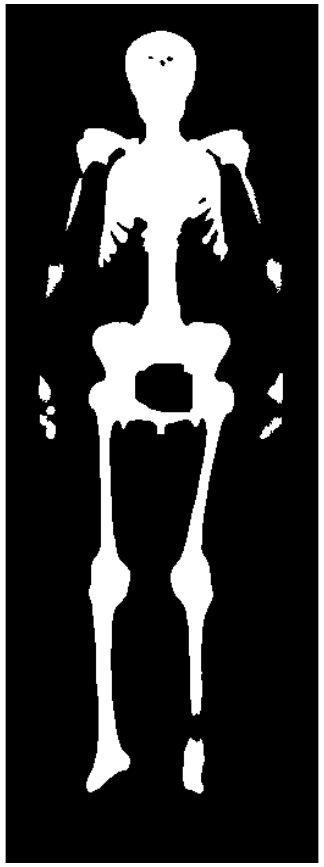
Evaluation — Lesion Generation

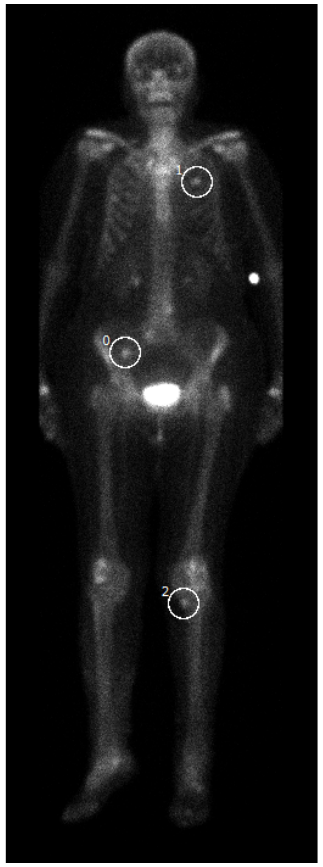
Difference images between the inferred images and the original



Original image

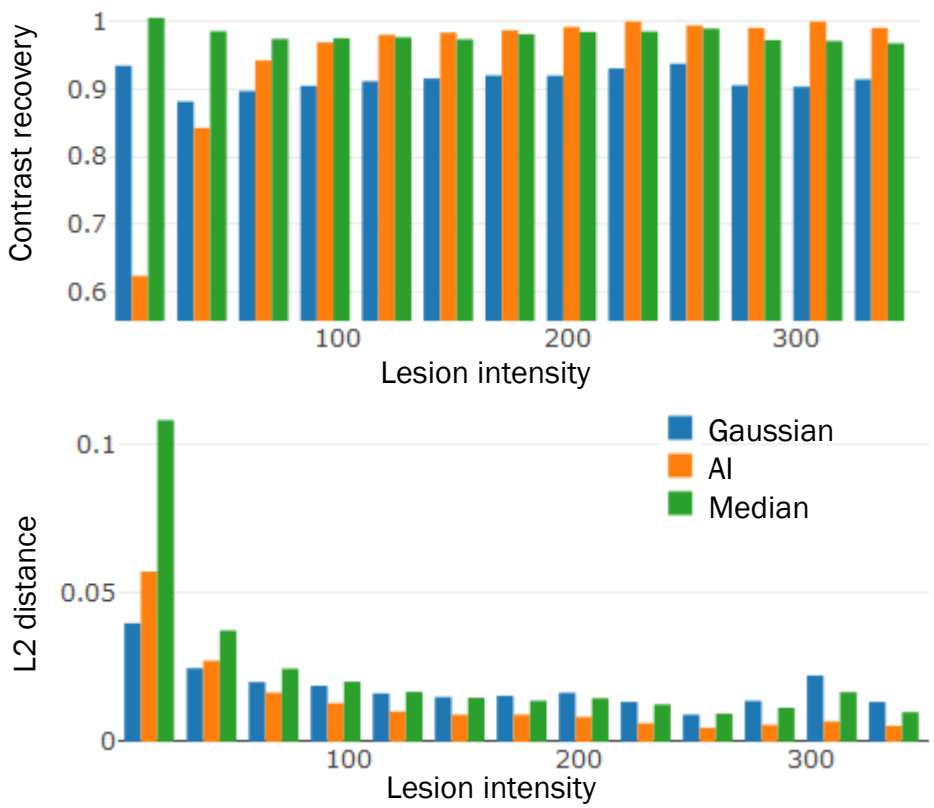


Bone mask



Generated lesions

Various quantitative results, e.g.:



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Evaluation — Preliminary Clinical Test

Preliminary clinical test was performed on 30 patient acquisitions (retrospective study).

From each original image, three additional images were generated with the following steps:

1. Degrade image to { 1 / 2 ; 1 / 4 ; 1 / 8 } ⇨ 2. Filter images with NN ⇨ 3. Increase noise level according to original image

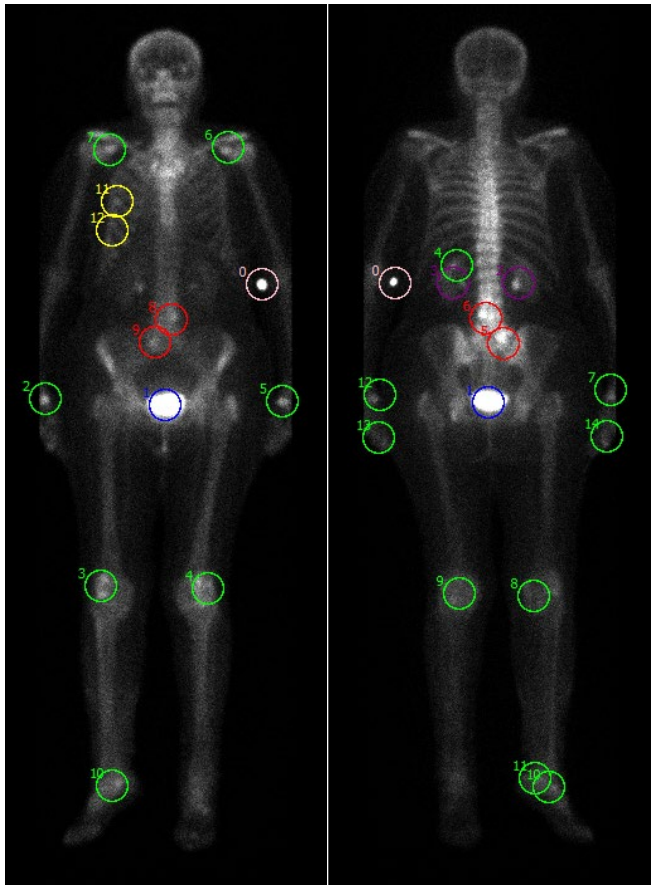
Noise level of the resulting images are indistinguishable
Source of a given image cannot be easily guessed

Images were evaluated with a blind test

Lesions were localized and labeled into 6 categories
injection point / bladder / kidney / low risk / medium risk / high risk

Labels from the degraded images were compared with
the labels from the original patient scan

False / True positives and negatives were counted on
each image



Anterior Posterior

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Evaluation — Preliminary Clinical Test

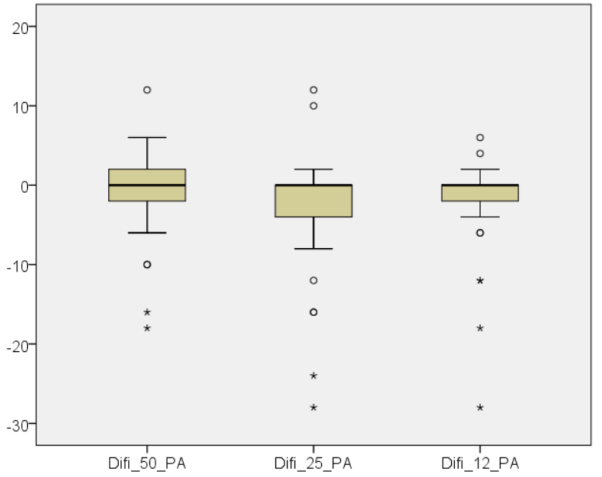
A statistical analysis was performed on the lesions found on the different image types.

Test Statistics[a]

	PA_12.5 - PA_100	PA_50 - PA_100	PA_25 - PA_100
Z	-2,033[b]	-,853[b]	-1,754[b]
Asymp. Sig. (2-tailed)	,042	,393	,079
Exact Sig. (2-tailed)	,044	,408	,082
Exact Sig. (1-tailed)	,022	,204	,041
Point Probability	,003	,007	,002

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.



No significant difference was found between the original, the ½ and the ¼ statistics.

1/8 statistics show significant difference in lesion detection.

“Usual” challenges of clinical evaluation: intra/inter-operator variability

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