

# Risk-Minimizing Tube Current Modulation Compared to Clinical Protocols

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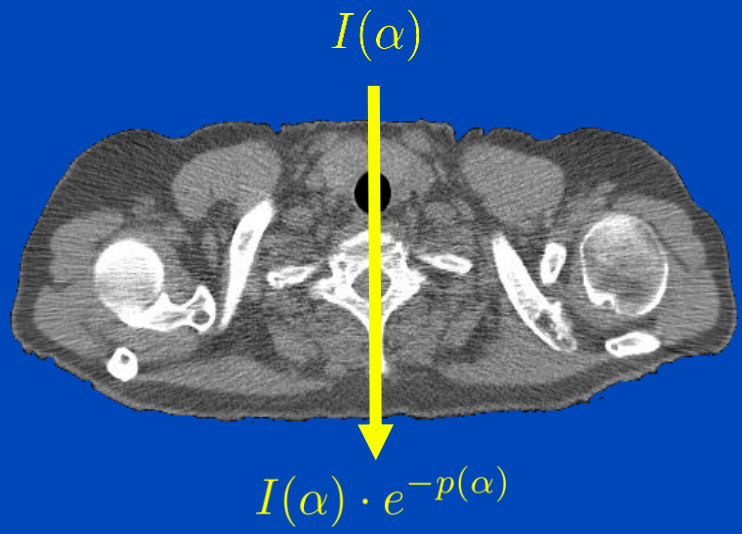
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# Tube Current Modulation



– X-rays reaching the detector follow Poisson statistics:

$$\text{Var}(I(\alpha)) = I(\alpha)e^{-p(\alpha)}$$

– Variance propagation to log domain yields:

$$\text{Var}(p(\alpha)) = \frac{1}{I(\alpha)e^{-p(\alpha)}}$$

– Variance propagation to image domain  $f$  yields:

$$\text{Var}(f) = \sum_{\alpha} \frac{1}{I(\alpha)e^{-p(\alpha)}}$$

• Cost function:

$$C = \underbrace{\sum_{\alpha} \frac{1}{I(\alpha)e^{-p(\alpha)}}}_{\text{Image Variance}} + \lambda \left( \sum_{\alpha} I(\alpha) - \text{const} \right)$$

← Constant tube current time product, hence the name *mAsTCM*

• Minimization yields for the tube current:  $I(\alpha) \propto e^{\frac{1}{2} \cdot p(\alpha)}$

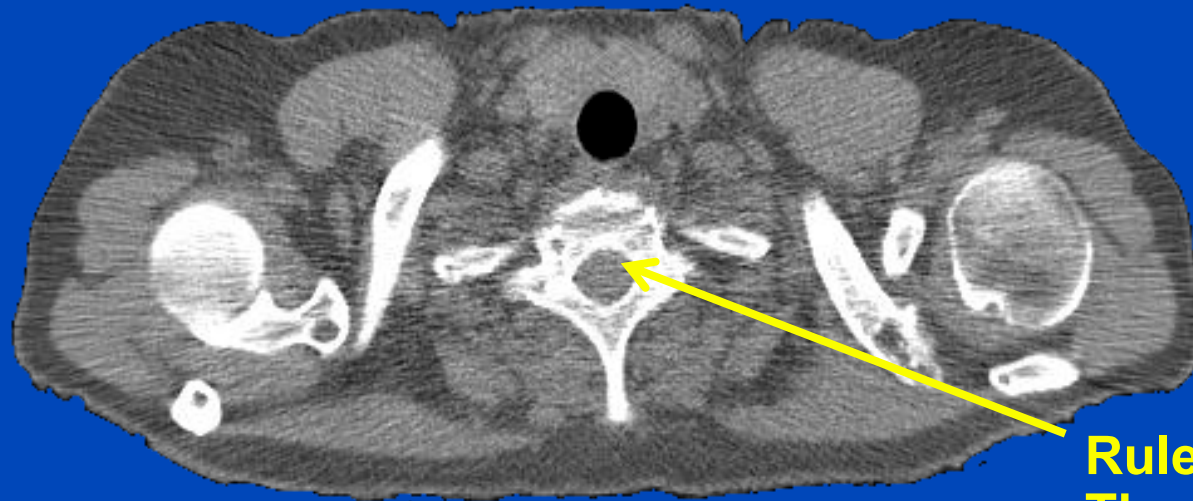
# Tube Current Modulation

## Interpretation

Tube current:  $I(\alpha) \propto e^{\frac{1}{2} \cdot p(\alpha)}$

Photons in center of patient:  $I(\alpha) e^{-\frac{1}{2} p(\alpha)} = \text{const}$

Photons reaching the detector:  $I(\alpha) e^{-p(\alpha)} \propto e^{-\frac{1}{2} p(\alpha)}$



**Rule of thumb:**  
The number of quanta reaching the center of the patient should be constant for all view angles.

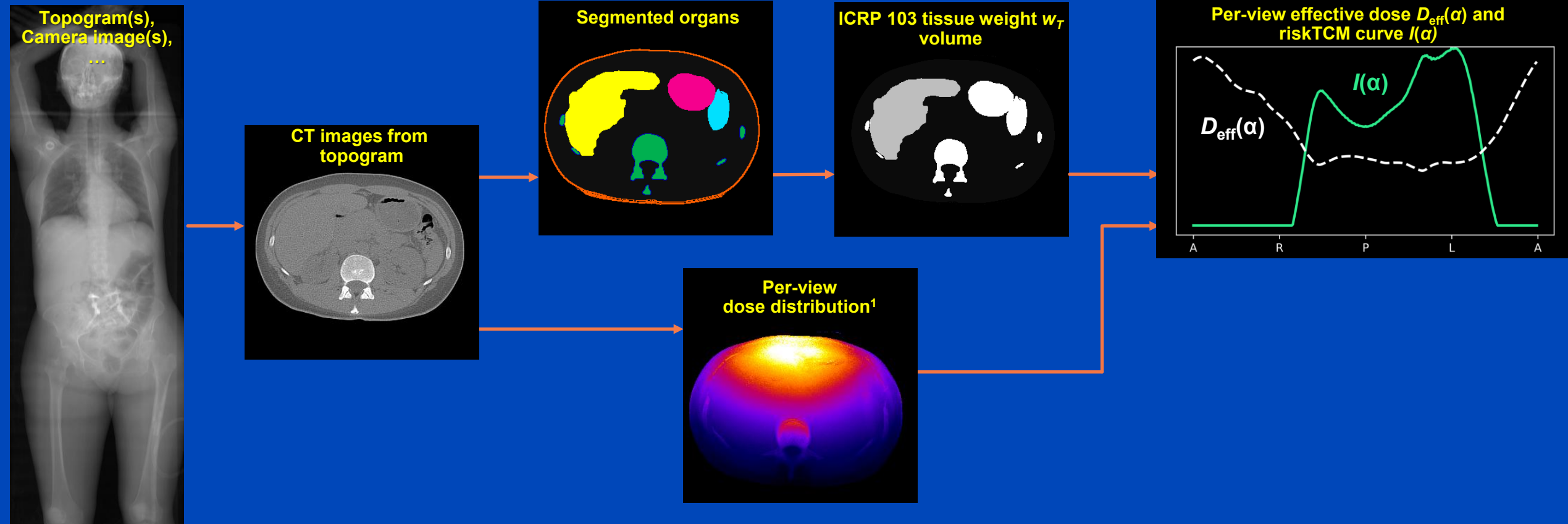
# RiskTCM

- Takes into account organ-specific risk  $\rightarrow$  effective dose  $D_{\text{eff}}(\alpha)$
- Reduces noise with constant effective dose

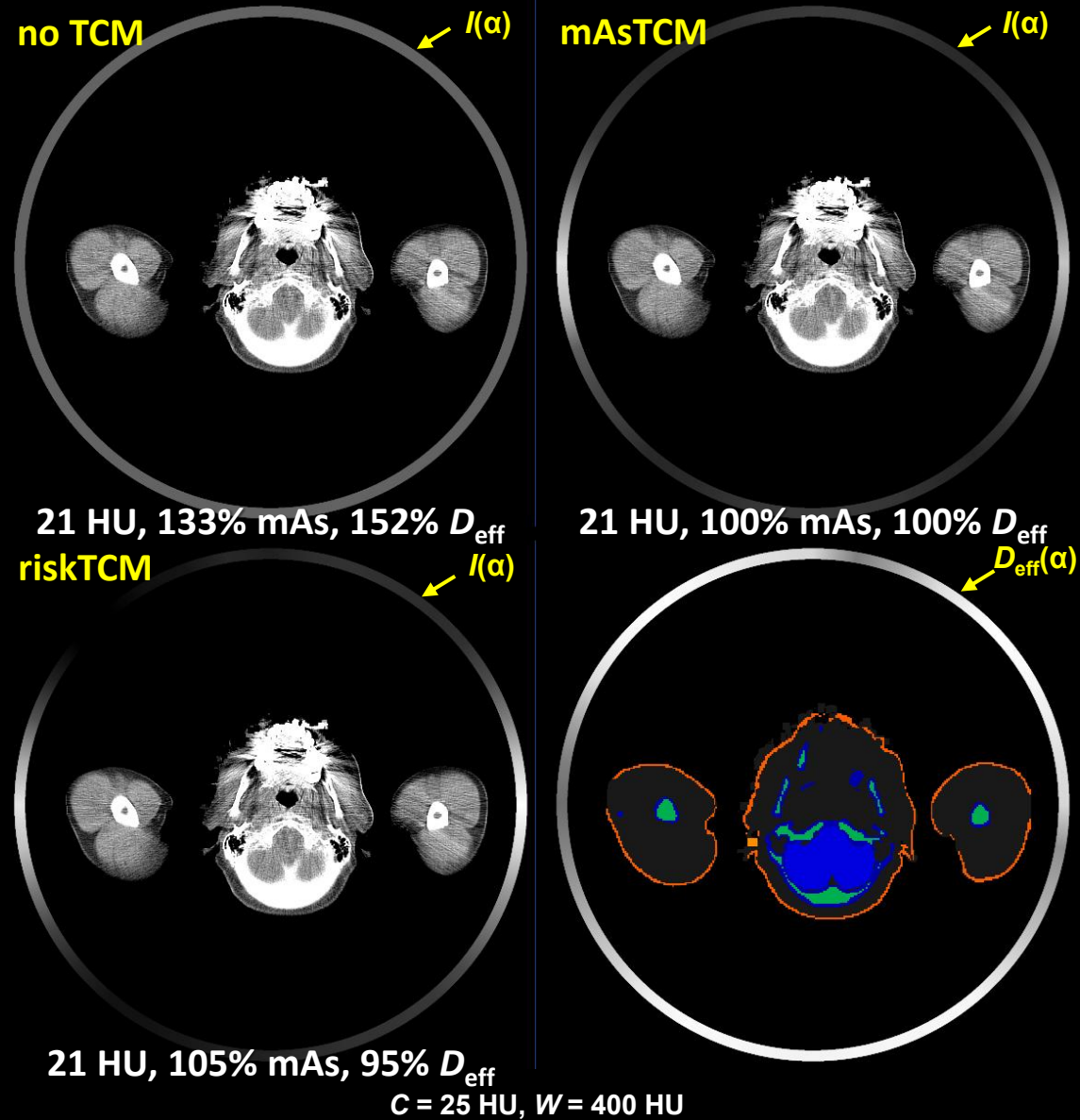
- **mAsTCM:** 
$$C = \sum_{\alpha} \frac{1}{I(\alpha)e^{-p(\alpha)}} + \lambda \left( \sum_{\alpha} I(\alpha) - \text{const} \right)$$

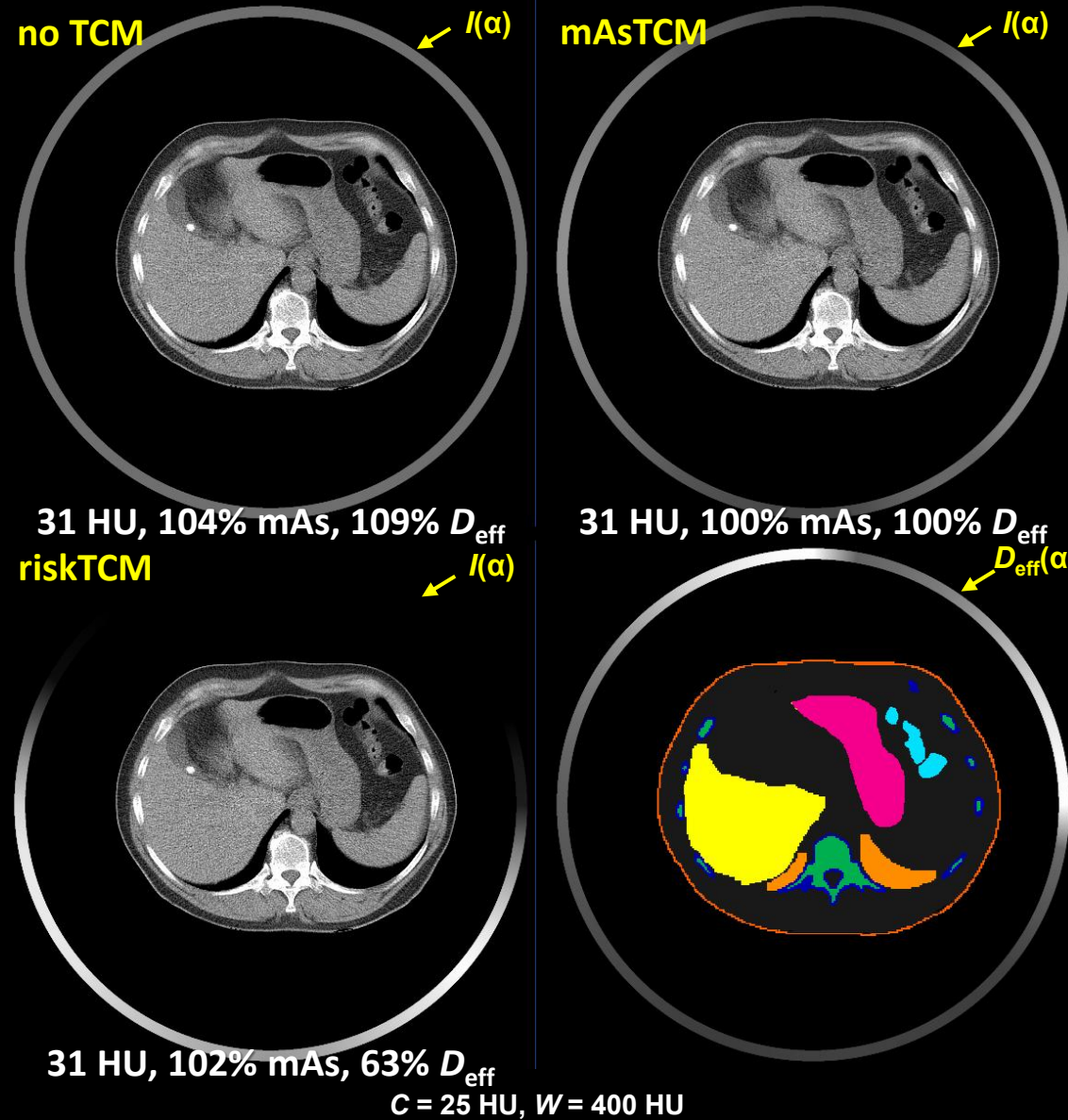
- **riskTCM:** 
$$C = \sum_{\alpha} \frac{1}{I(\alpha)e^{-p(\alpha)}} + \lambda \left( \sum_{\alpha} I(\alpha)D_{\text{eff}}(\alpha) - \text{const} \right)$$

# Ideal riskTCM - Workflow



<sup>1</sup>Maier, J., Klein, L., Eulig, E., Sawall, S., & Kachelrieß, M. (2022). Real-time estimation of patient-specific dose distributions for medical CT using the deep dose estimation. *Med. Phys.*, 49(4), 2259–2269





# Effective Dose at Same Image Noise after Klein et al.

Anatomical region	noTCM	mAsTCM	riskTCM
Head + arms	159%	100%	87%
Head	110%	100%	91%
Neck	217%	100%	78%
Thorax	114%	100%	82%
Abdomen	114%	100%	72%
Pelvis	152%	100%	80%

**riskTCM can reduce the effective dose of the patient by 10 to 30% depending on the anatomical region**

# Motivation

- **Comparison of riskTCM with clinical tube current modulation (CARE Dose) instead of simulated mAsTCM**
- **Evaluation of riskTCM with radiologist upcoming. Therefore reconstructions need to be identical to the clinic**
  - i.e. reconstruction kernels
  - noise texture
- **Reconstruction methods need to be exactly identical**
- **Noise addition for realistic low dose images**

# ReconCT<sup>1</sup>

The screenshot displays the ReconCT software interface. At the top, there is a menu bar with 'General', 'Reconstruction', and 'Settings' tabs. Below the menu bar is a toolbar with various icons for file operations, windowing, and job management. The main workspace is divided into two panels, each showing a CT scan reconstruction of a human torso. The left panel shows a coronal view, and the right panel shows a sagittal view. Both panels have technical data at the bottom: '-1000 C 0.00 / W 100.00 1024 x 1024 X: 00842 Y: 00886' for the left and '-1000 C 0.00 / W 100.00 1024 x 1024 X: 00036 Y: 00531' for the right. Below the workspace is a settings panel with the following sections:

- Patient Name:** PatientID
- Study:** riskTCM
- Series:** riskTCM
- Version:** SomX VA40A
- Reconstruction Mode:** Standard - WFBP
- Resolution:** Integrator
- Algorithm:** WFBP
- Post Processing:** Matrix Size: 512
- 16bit DICOM CT-Scale:**
- Anonymize Images:**
- Simulate Noise:**
- Position Increment:** 1.00
- Number of Images:** 620
- Kernel:** Br40
- IBHC:** Off
- Window:** Abdomen
- Cupping Correction:** GE
- FoV:** 500
- Center X:** 0
- Center Y:** 0
- Begin Position:** -944.2
- End Position:** -1,563.9
- Recon Groups:** All
- Transfer to:** File System
- Image Comment:**

At the bottom left, there are four circular buttons: 'Create Test' (green), 'Open' (green), 'Recon' (blue), and 'Cancel' (red). At the bottom center, there are five tabs: 'Recon', 'Scan', 'Advanced' (highlighted in green), 'Recon Log', and 'Info Log'.

**Not for clinical use!**  
18.0.0.861-PRERELEASE+eef037832

# ReconCT<sup>1</sup>

The screenshot displays the ReconCT software interface with the following parameters and settings:

- Patient Name:** PatientID
- Study:** riskTCM
- Series:** riskTCM
- Version:** SomX VA40A
- Reconstruction Mode:** Standard - WFBP
- Resolution:** Integrator
- Algorithm:** WFBP
- Post Processing:** (empty)
- Matrix Size:** 512
- 16bit DICOM CT-Scale:**
- Anonymize Images:**
- Simulate Noise:**
- Slice:** 2.00
- Position Increment:** 1.00
- Number of Images:** 620
- Kernel:** Br40
- IBHC:** Off
- Window:** Abdomen
- Cupping Correction:** GE
- FoV:** 500
- Center X:** 0
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- End Position:** -1,563.9
- Recon Groups:** all
- Transfer to:** File System
- Image Comment:** (empty)

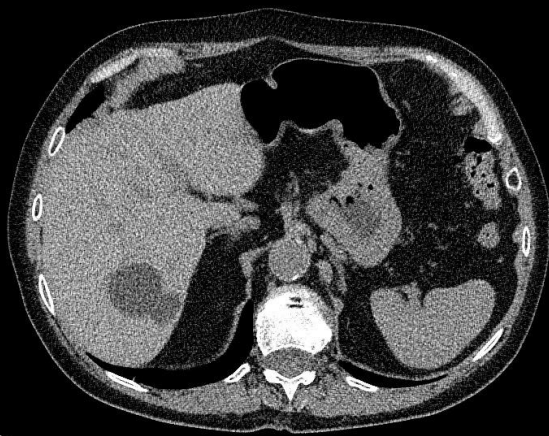
Additional settings at the bottom of the interface:

- Preset:** P60A\_ExFactory\_w30
- Dose Reduction [%]:** 100.0
- SDF:**
- El.Noise:**
- Random Seed:** -1
- Load Tube Current:** (highlighted)

The interface includes a navigation bar at the bottom with tabs: Recon, Scan, **Advanced**, Recon Log, and Info Log. A patient icon and a large downward arrow are also visible on the right side of the main panel.

# Comparison of Reconstructions

DKFZ Reconstruction



Scanner Reconstruction



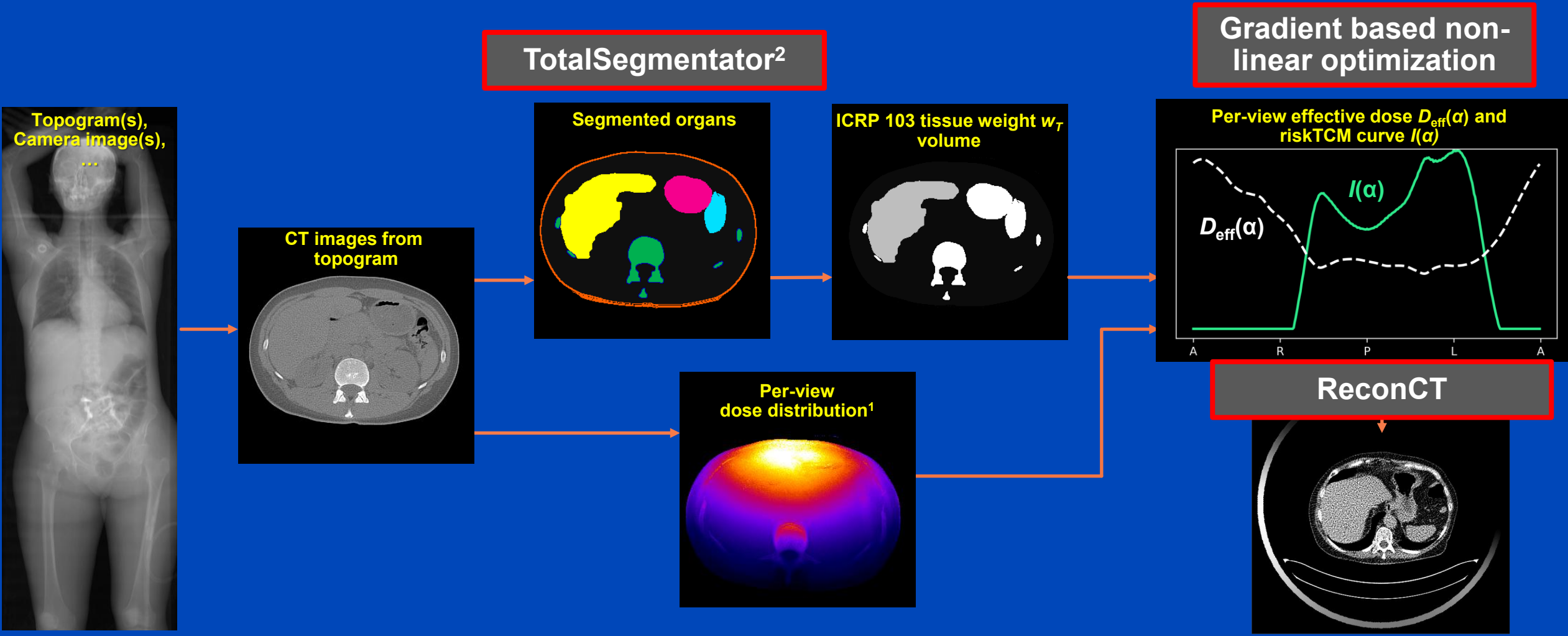
ReconCT Reconstruction



C = 40 HU, W = 300 HU

# riskTCM Reconstruction with ReconCT

## Ideal riskTCM - Workflow

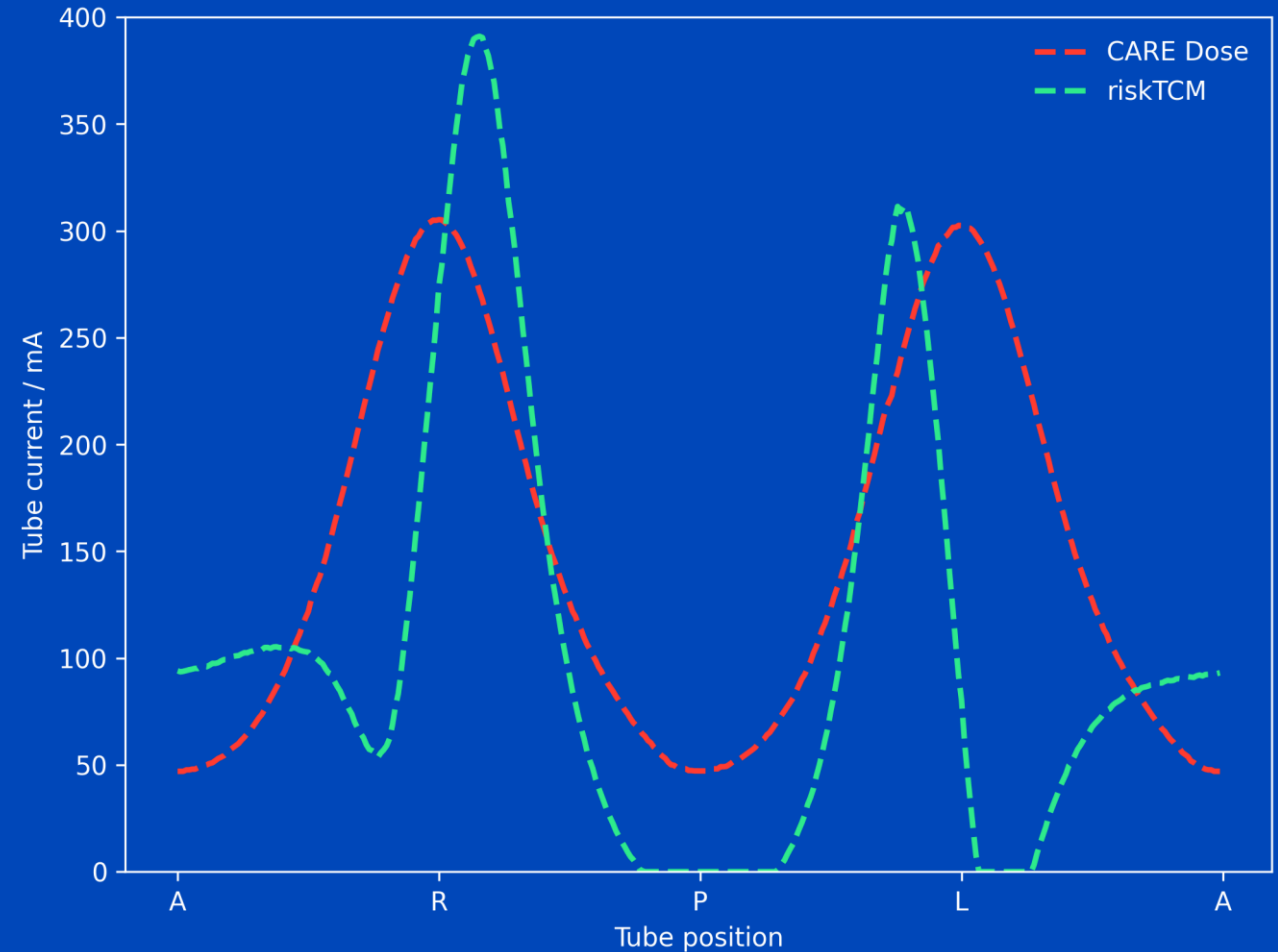


<sup>1</sup>Maier, J., Klein, L., Eulig, E., Sawall, S., & Kachelrieß, M. (2022). Real-time estimation of patient-specific dose distributions for medical CT using the deep dose estimation. *Med. Phys.*, 49(4), 2259–2269

<sup>2</sup>Wasserthal, Jakob et al. (2023). "TotalSegmentator: Robust segmentation of 104 anatomic structures in CT images". In: *Radiology: Artificial Intelligence* 5.5, e230024.

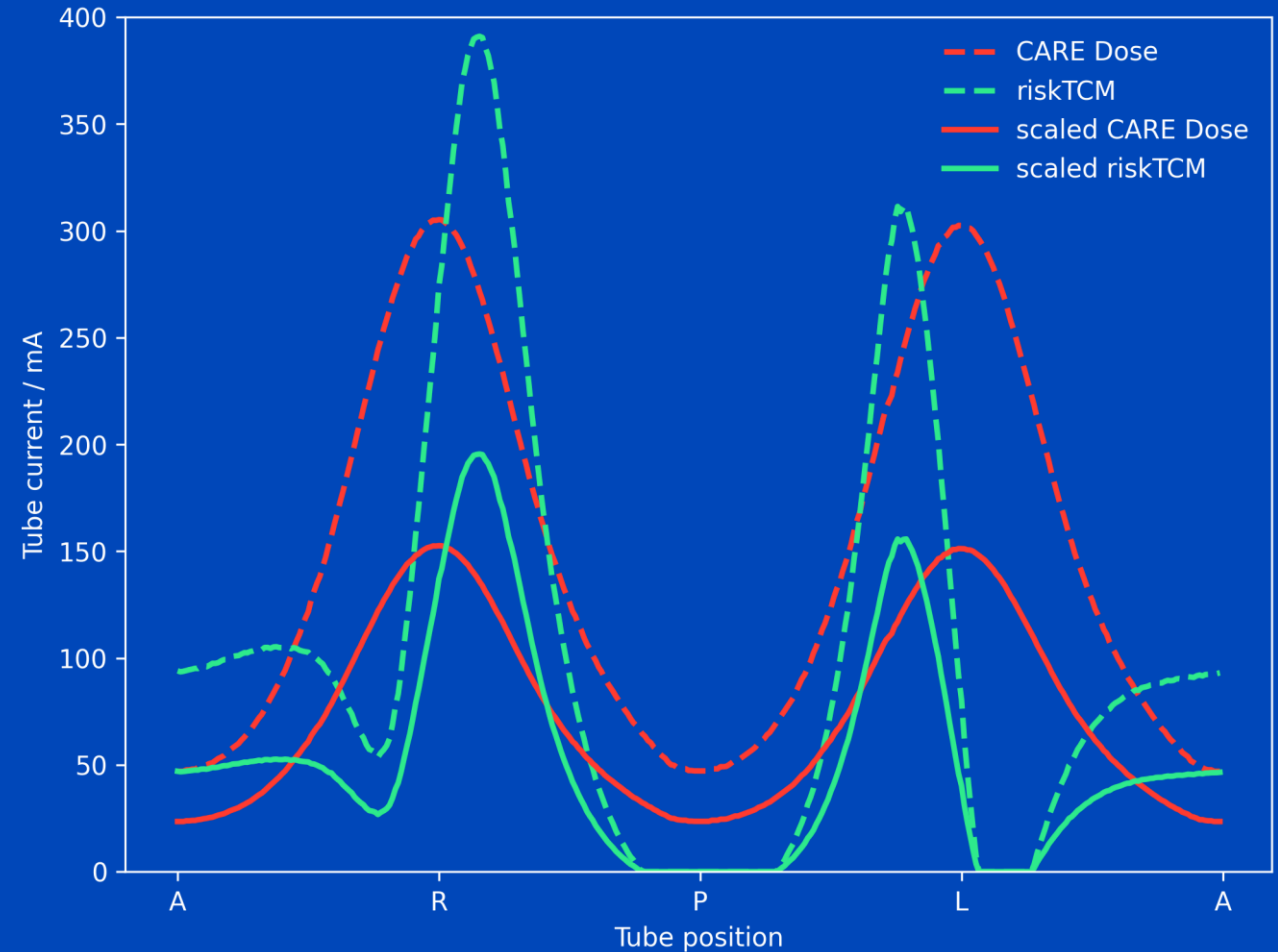
# ReconCT Reconstructions

- **Allows for reconstructions that are identical to the ones from the scanner**
- **Option to add noise during reconstruction:**
  - as const. linear factor
  - as given tube current profile (i.e. riskTCM curve)

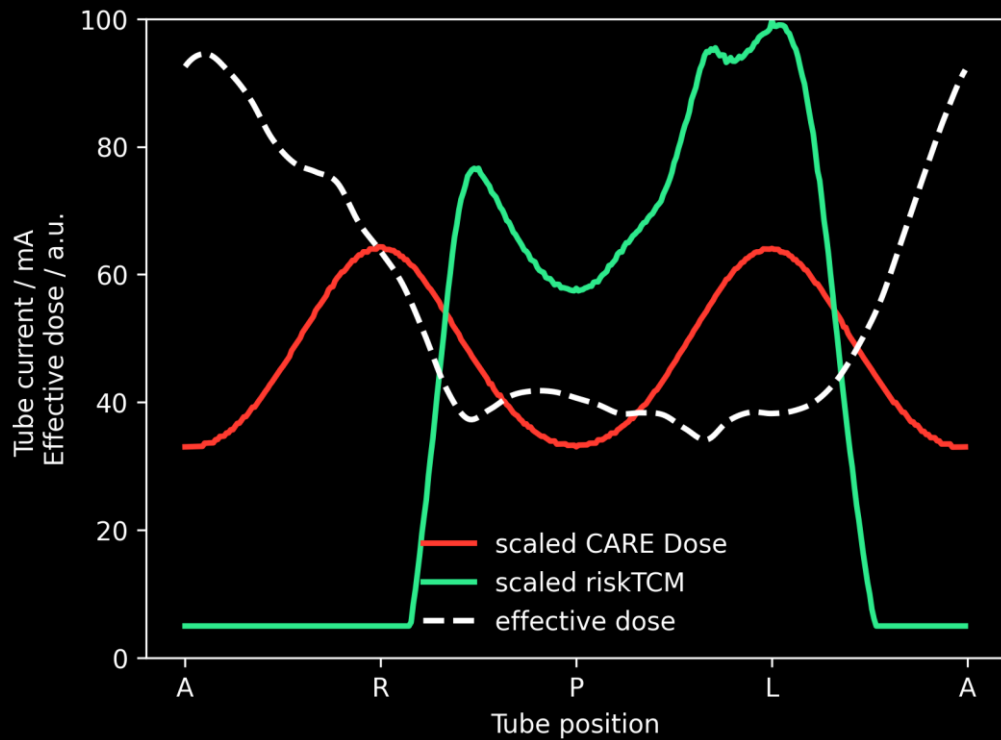


# ReconCT Reconstructions

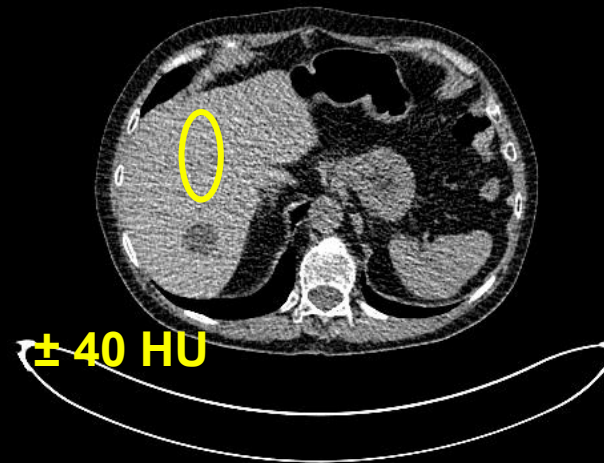
- Allows for reconstructions that are identical to the ones from the scanner
- Option to add noise during reconstruction:
  - as const. linear factor
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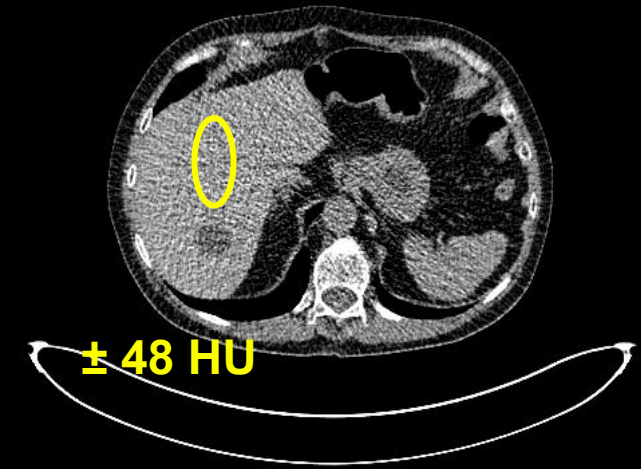
# Quantity Comparison of riskTCM and CARE Dose with Added Noise at Equal Dose Level



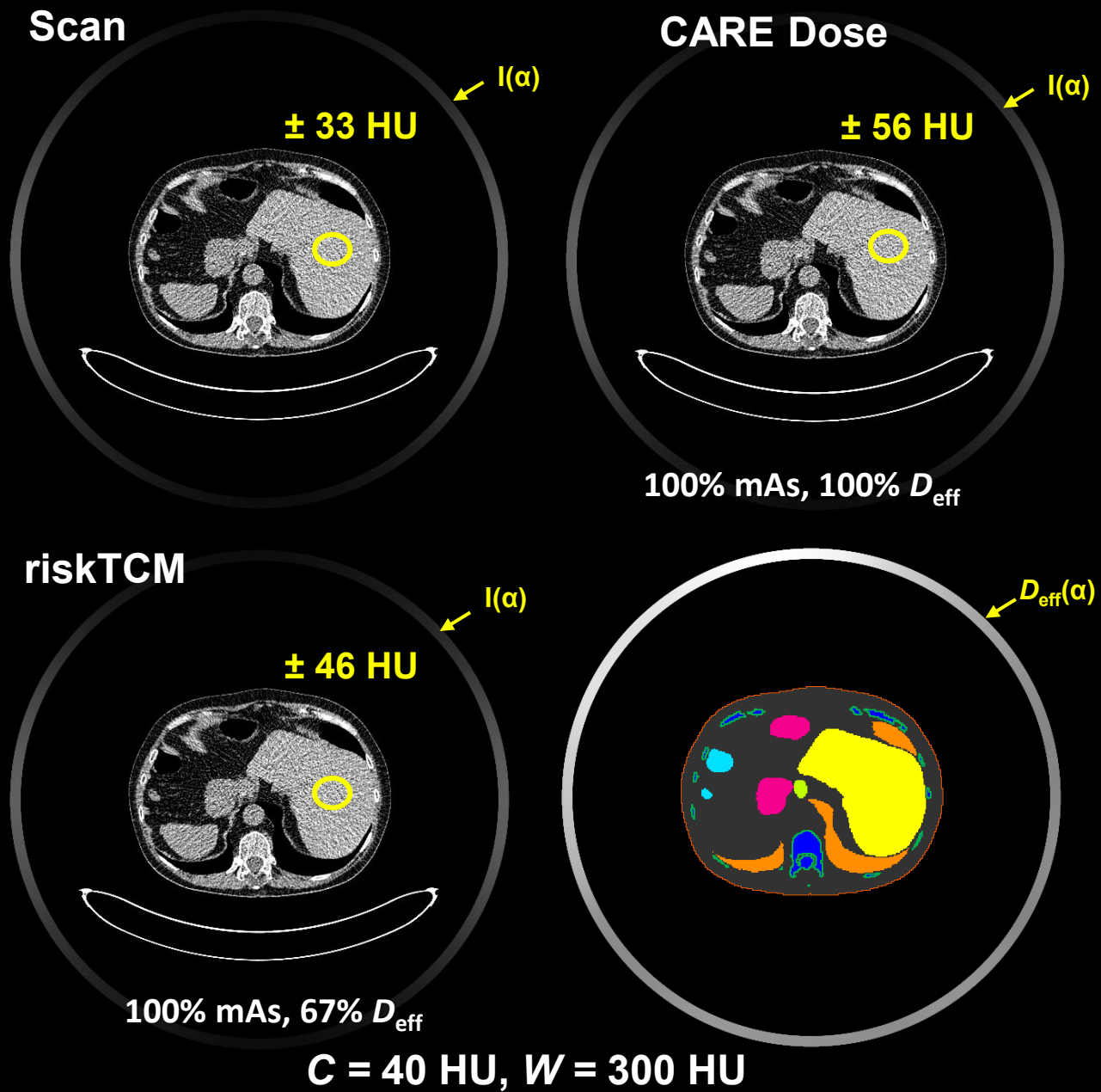
riskTCM



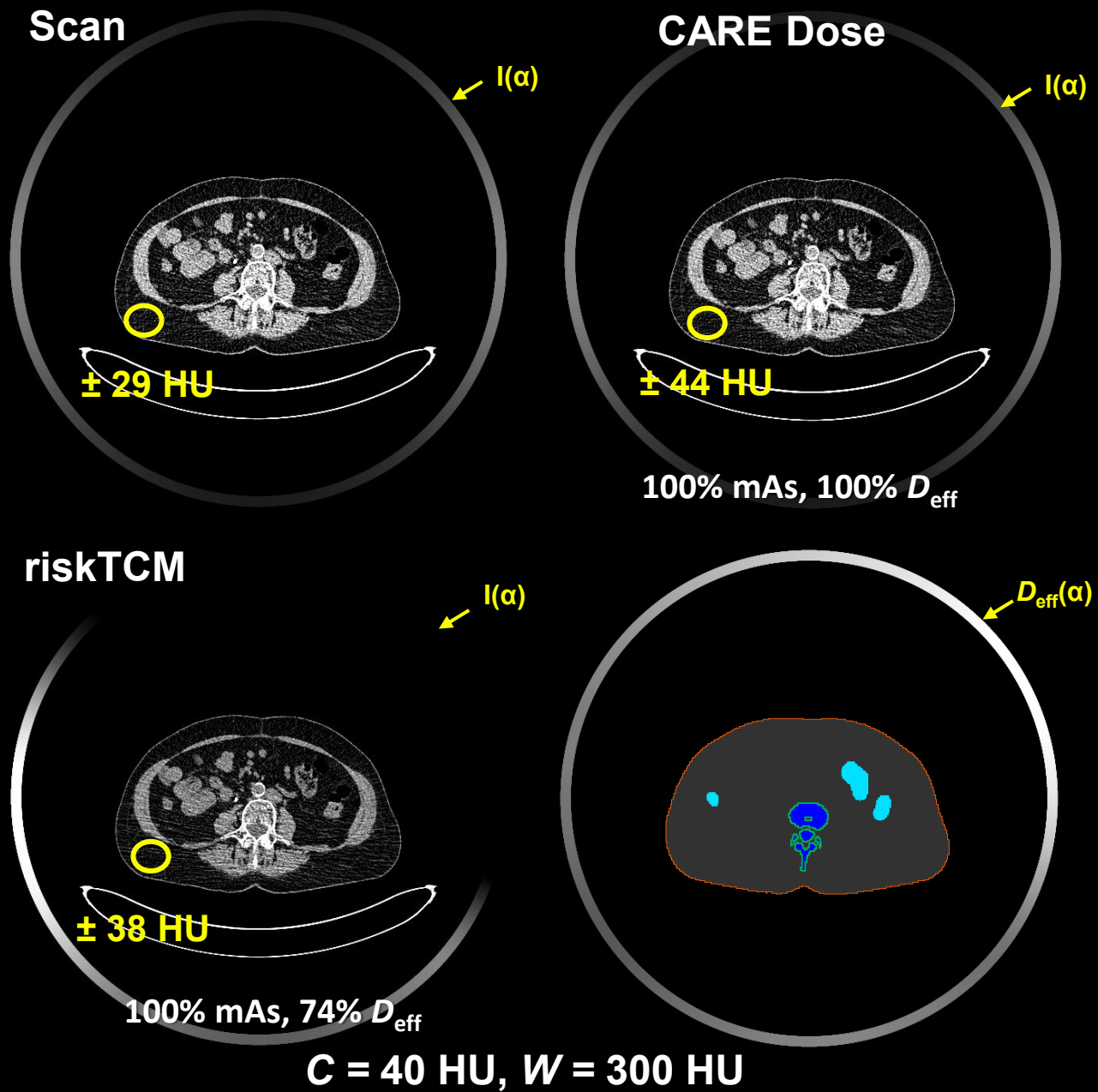
CARE Dose



C = 40 HU, W = 300 HU

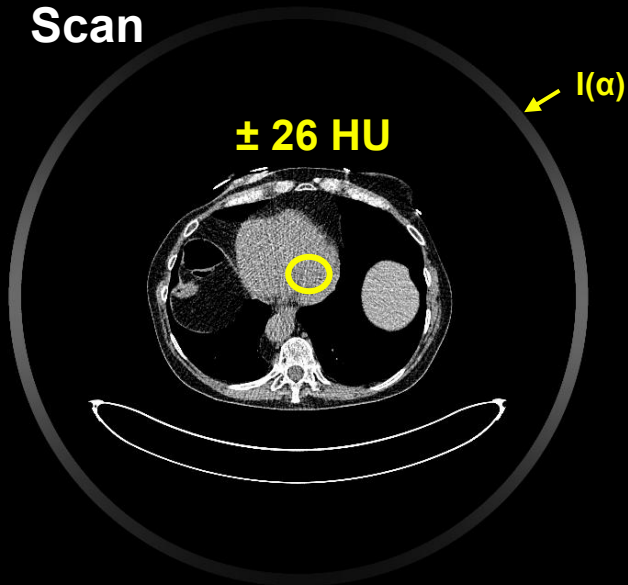


CARE Dose and riskTCM images are displayed at the same dose level

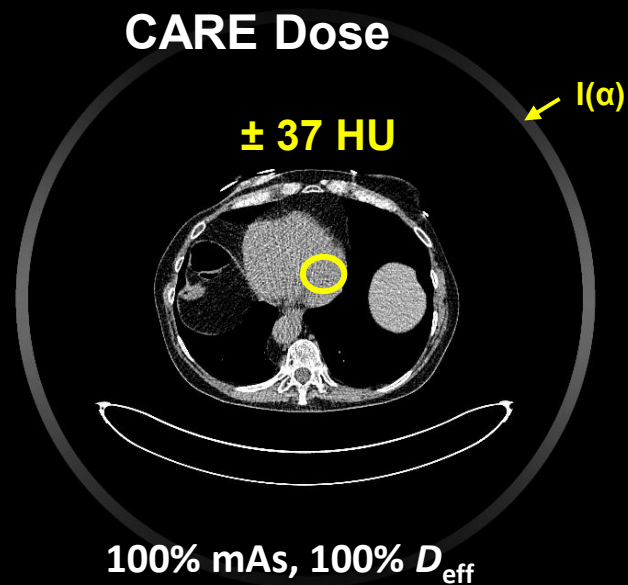


CARE Dose and riskTCM images are displayed at the same dose level

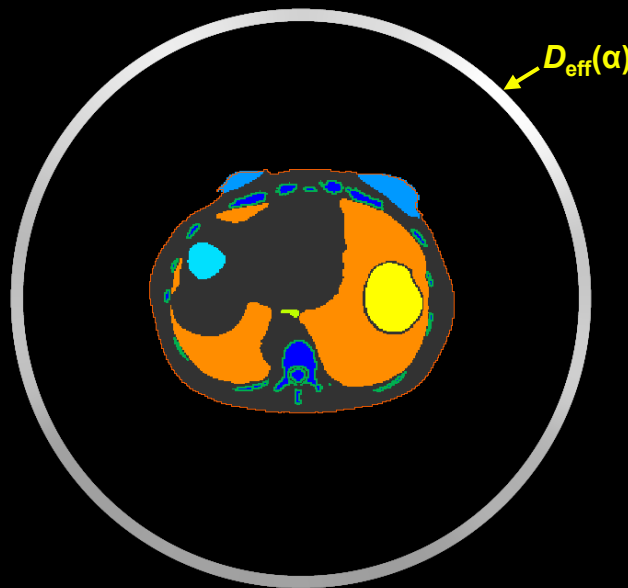
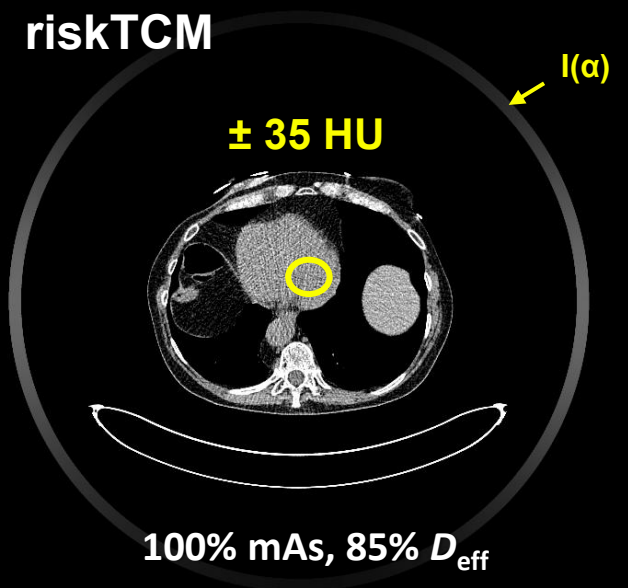
Scan



CARE Dose



riskTCM



$C = 40 \text{ HU}, W = 300 \text{ HU}$

CARE Dose and riskTCM images are displayed at the same dose level

# Results

	<b>CARE Dose</b>	<b>riskTCM</b>	<b>Dose reduction</b>
Pelvis	44 HU	38 HU	26 %
Abdomen	56 HU	46 HU	37 %
Thorax	35 HU	38 HU	15 %

# Conclusion & Outlook

## Conclusion:

- We showed that riskTCM can provide patient dose reduction, but the dose reduction with ReconCT achieved by riskTCM are similar to than the previous simulation study.
- Reconstructions are limited to the tube current used in the original scan.

## Outlook:

- Reader study with radiologist
- Phantom scan with riskTCM curve

# Thank You!

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Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs ([marc.kachelriess@dkfz.de](mailto:marc.kachelriess@dkfz.de)).

Parts of the simulation software were provided by RayConStruct<sup>®</sup> GmbH, Nürnberg, Germany.

ReconCT was provided by Siemens Healthineers, Forchheim, Germany.