Risk-Minimizing Tube Current Modulation Compared to Clinical Protocols

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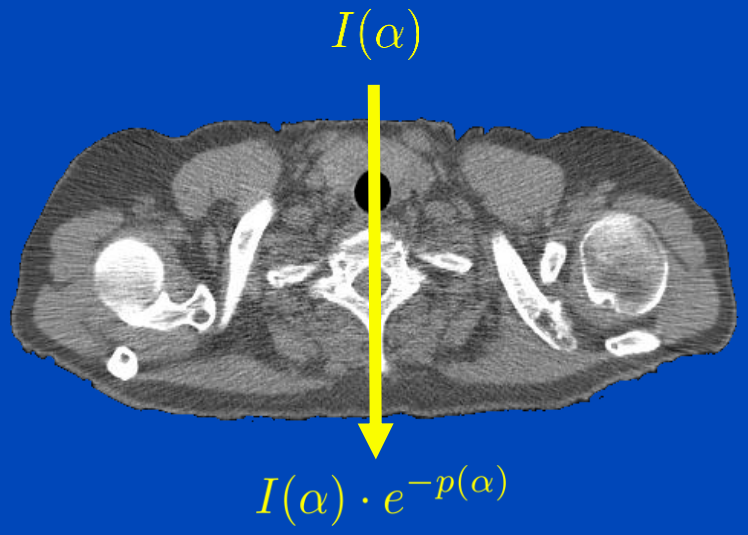
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Tube Current Modulation



- X-rays reaching the detector follow Poisson statistics:

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

- Variance propagation to log domain yields:

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

- Variance propagation to image domain f yields:

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

- **Cost function:**

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

Image Variance

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

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

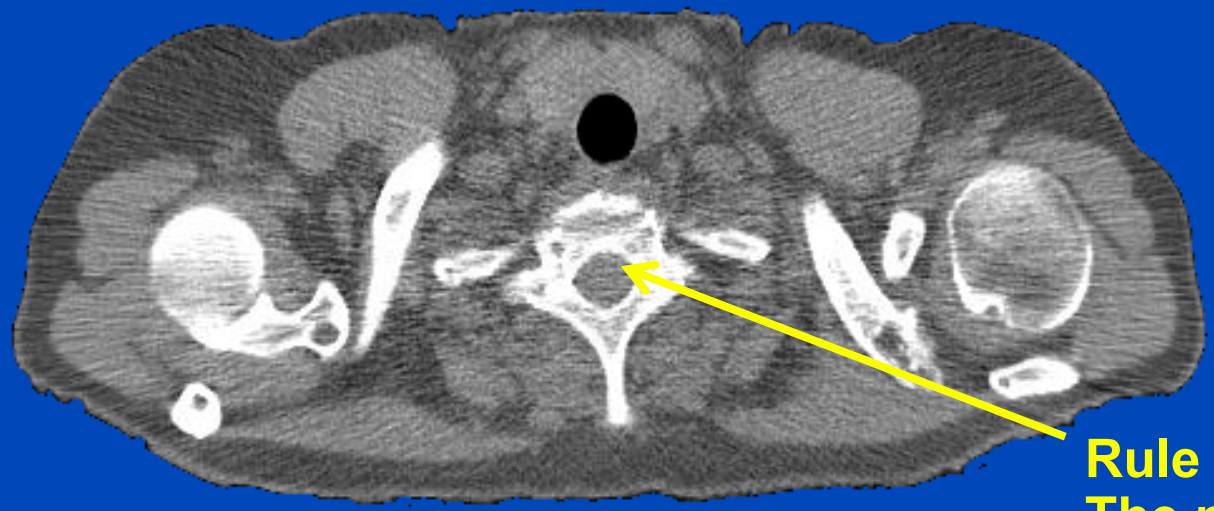
Tube Current Modulation

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



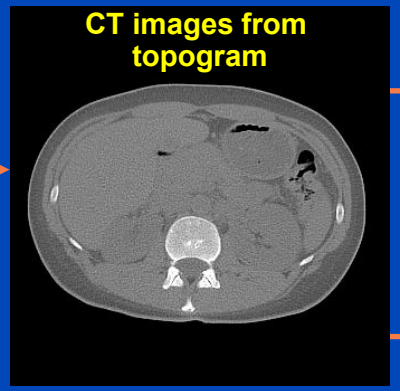
Rule of thumb:
The number of quanta reaching the center of the patient should be constant for all view angles.

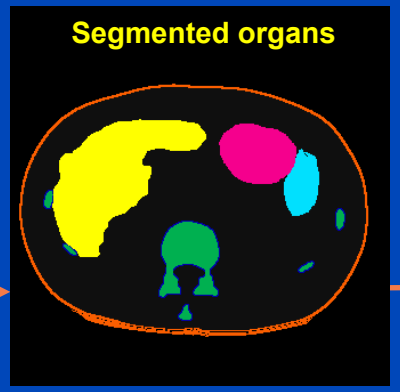
RiskTCM

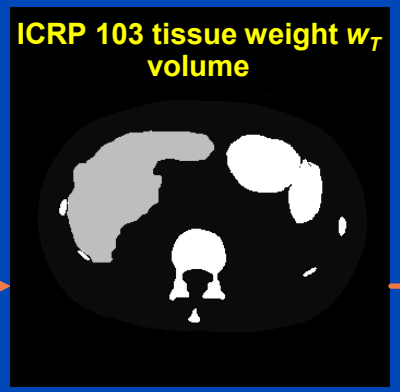
- Takes into account organ-specific risk → effective dose $D_{eff}(\alpha)$
- Reduces noise with constant effective dose
- **mAsTCM:** $$C = \sum_{\alpha} \frac{1}{I(\alpha)e^{-p(\alpha)}} + \lambda \left(\sum_{\alpha} I(\alpha) - \text{const} \right)$$
- **riskTCM:** $$C = \sum_{\alpha} \frac{1}{I(\alpha)e^{-p(\alpha)}} + \lambda \left(\sum_{\alpha} I(\alpha) D_{\text{eff}}(\alpha) - \text{const} \right)$$

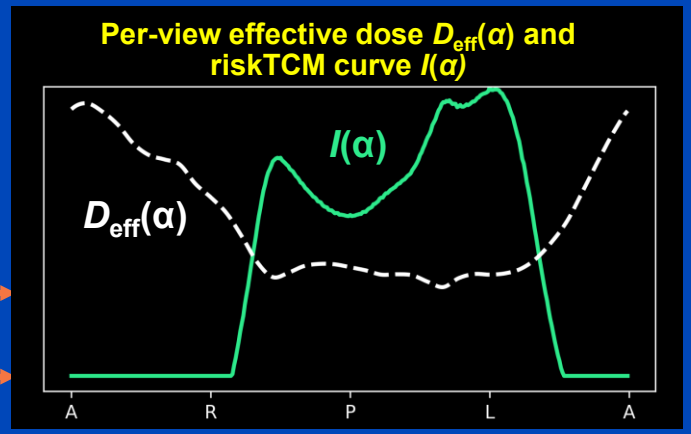
L. Klein, C. Liu, J. Steidel, L. Enzmann, M. Knaup, S. Sawall, A. Maier, M. Lell, J. Maier, and M. Kachelrieß. Patient-specific radiation risk-based tube current modulation for diagnostic CT. Med. Phys. 49(7):4391-4403, July 2022. *This paper received the Sylvia&Moses Greenfield Award for the best scientific paper on imaging in Medical Physics in 2022.*

Ideal riskTCM - Workflow









[1]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

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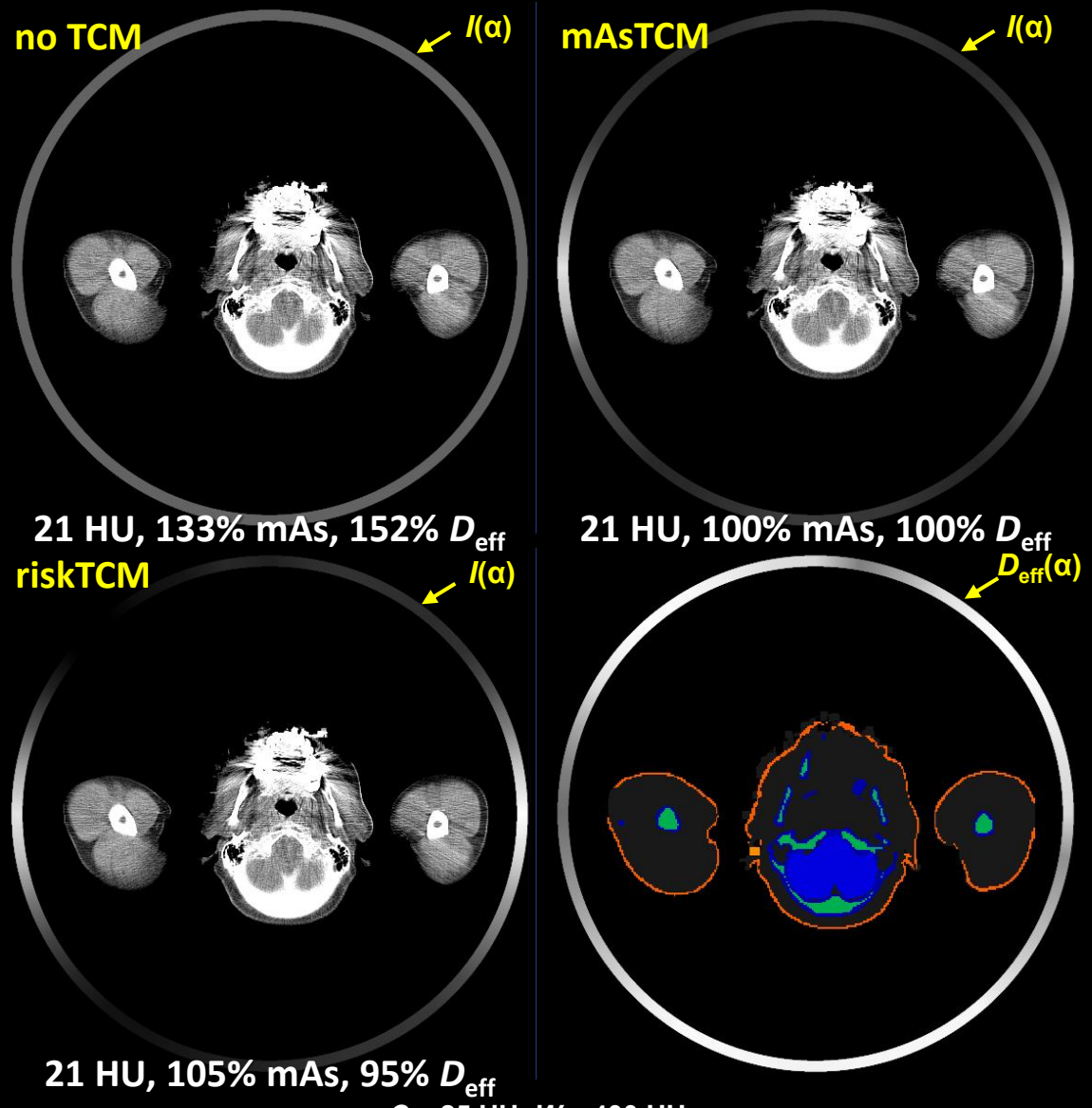

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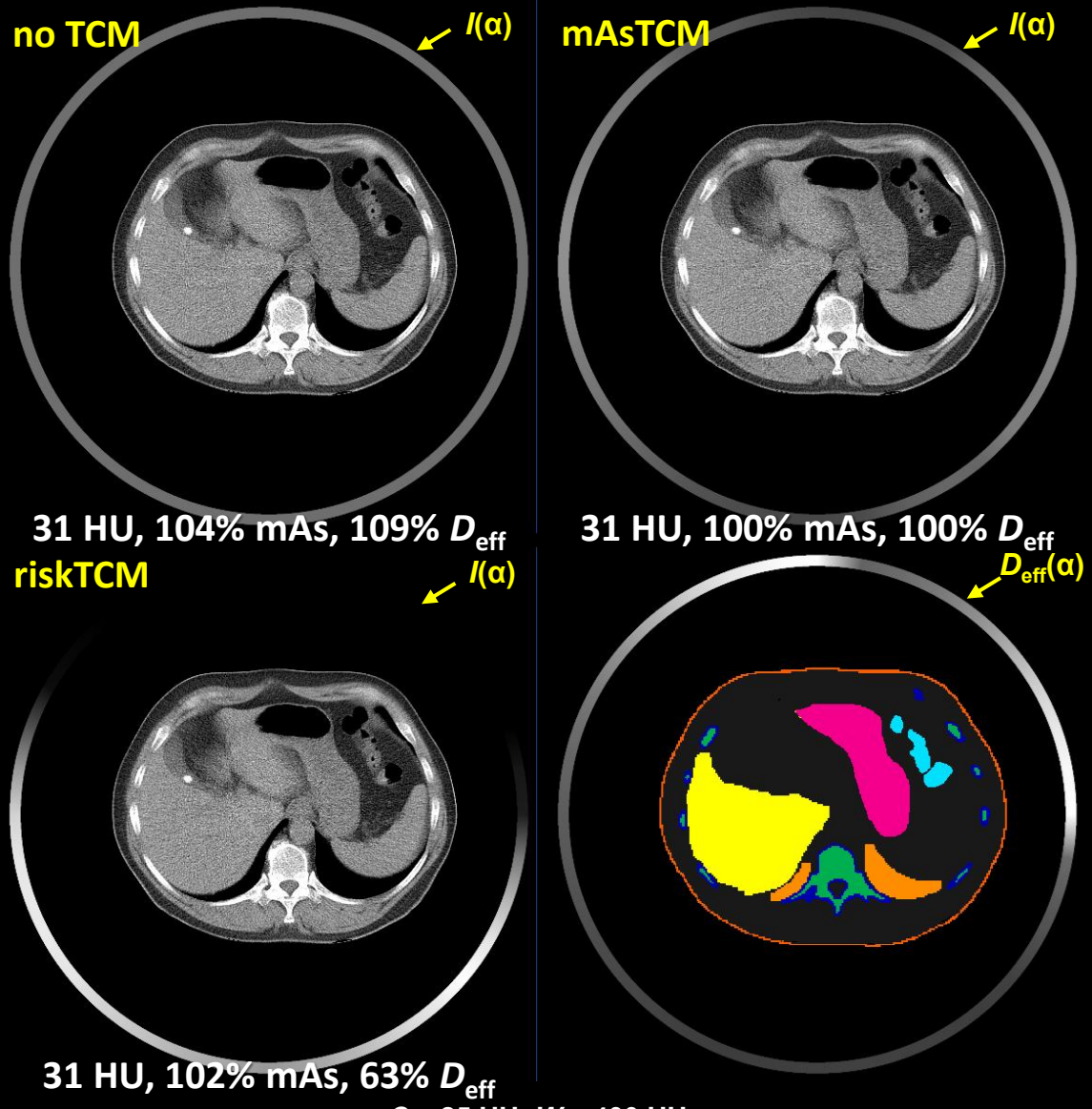

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Effective Dose at Same Image Noise after Klein et al.

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%

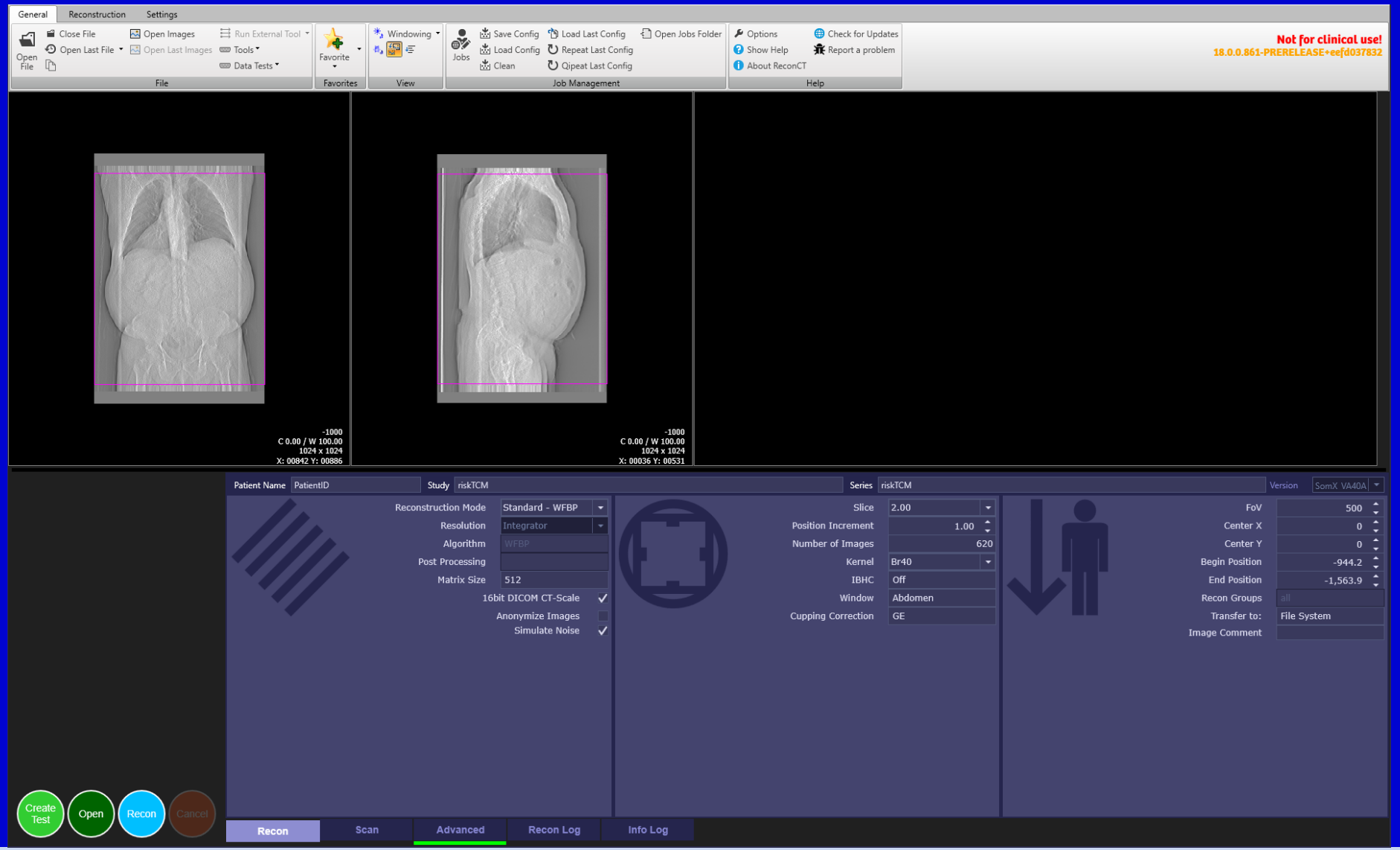
riskTCM can reduce the effective dose of the patient by 10 to 30% depending on the anatomical region

L. Klein, C. Liu, J. Steidel, L. Enzmann, M. Knaup, S. Sawall, A. Maier, M. Lell, J. Maier, and M. Kachelrieß. Patient-specific radiation risk-based tube current modulation for diagnostic CT. Med. Phys. 49(7):4391-4403, July 2022. *This paper received the Sylvia&Moses Greenfield Award for the best scientific paper on imaging in Medical Physics in 2022.*

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[1]



[1]ReconCT – Siemens Healthineers pre-production reconstruction software

ReconCT[1]

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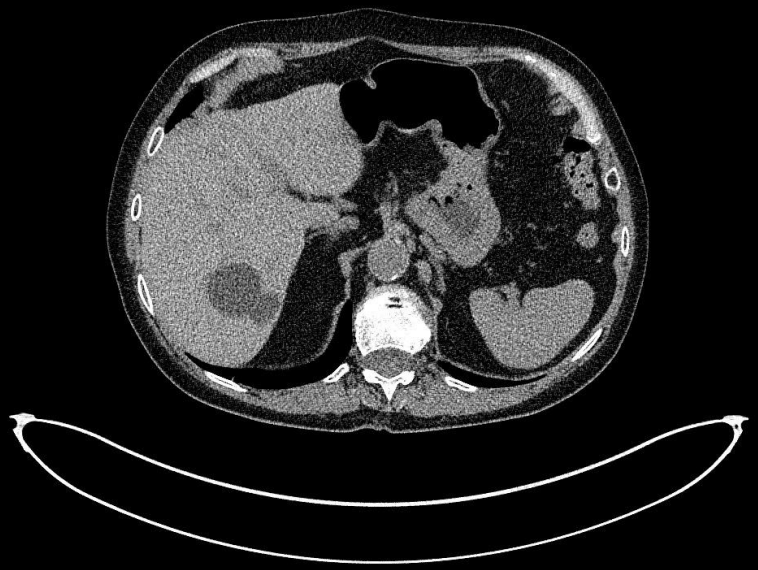
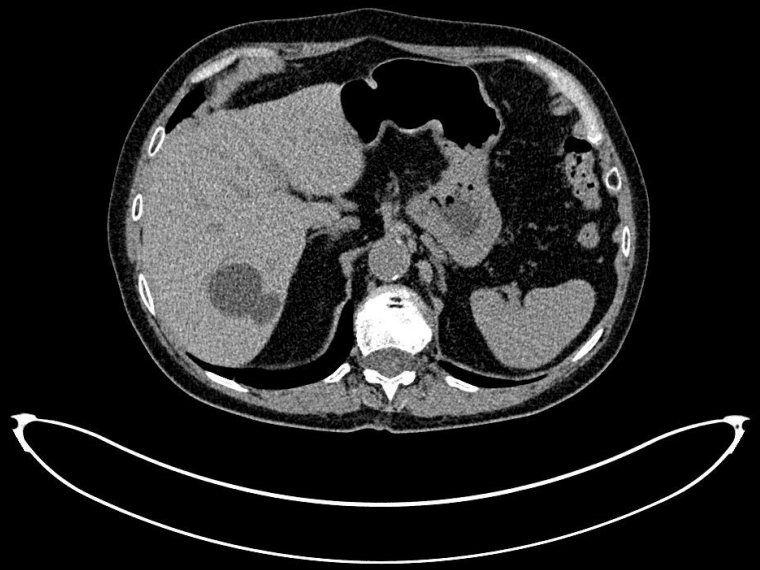
Comparison of Reconstructions

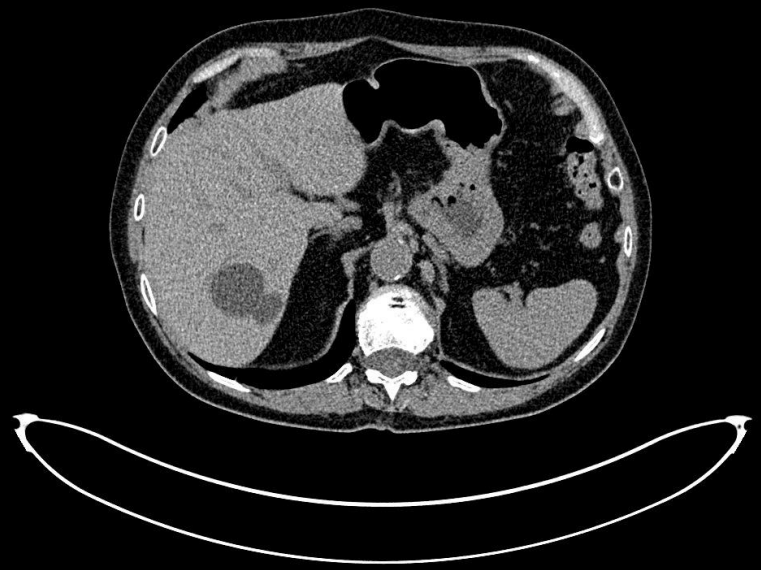
DKFZ Reconstruction



Scanner Reconstruction

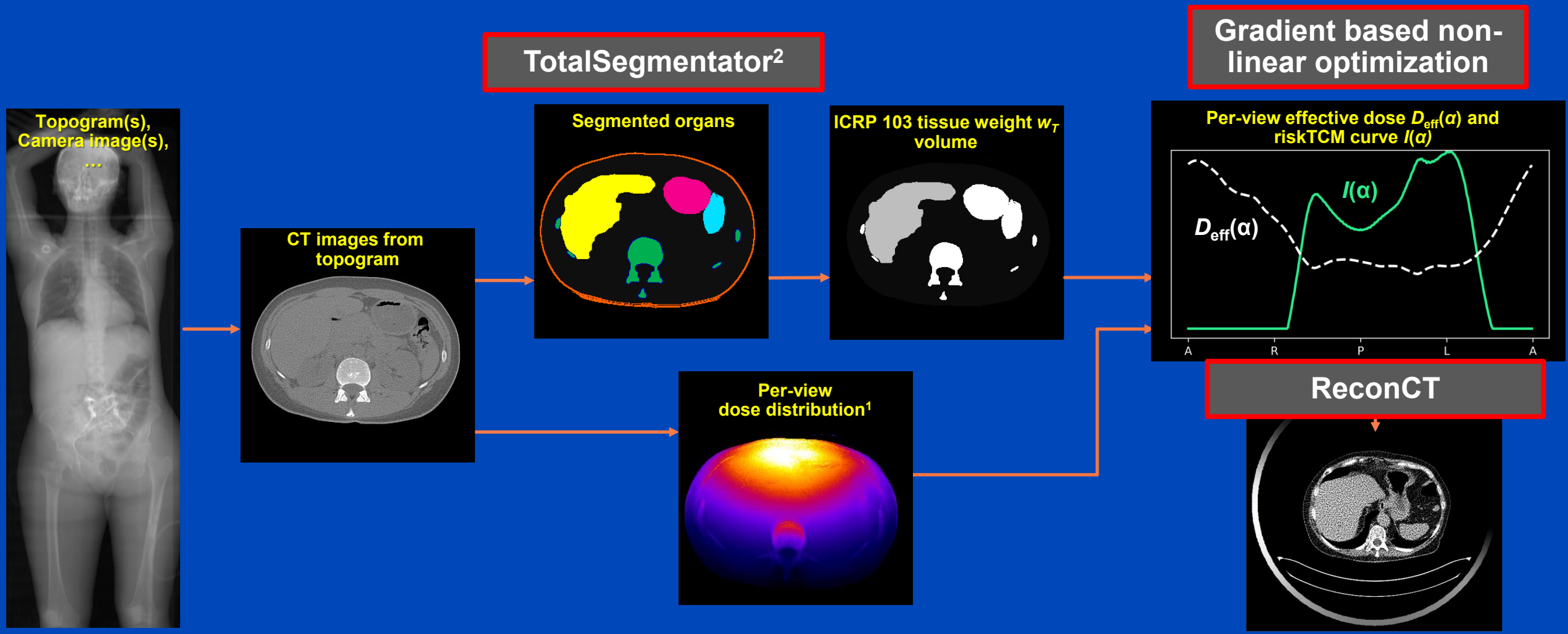


ReconCT Reconstruction



C = 40 HU, *W* = 300 HU

riskTCM Reconstruction with ReconCT
Ideal riskTCM - Workflow



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

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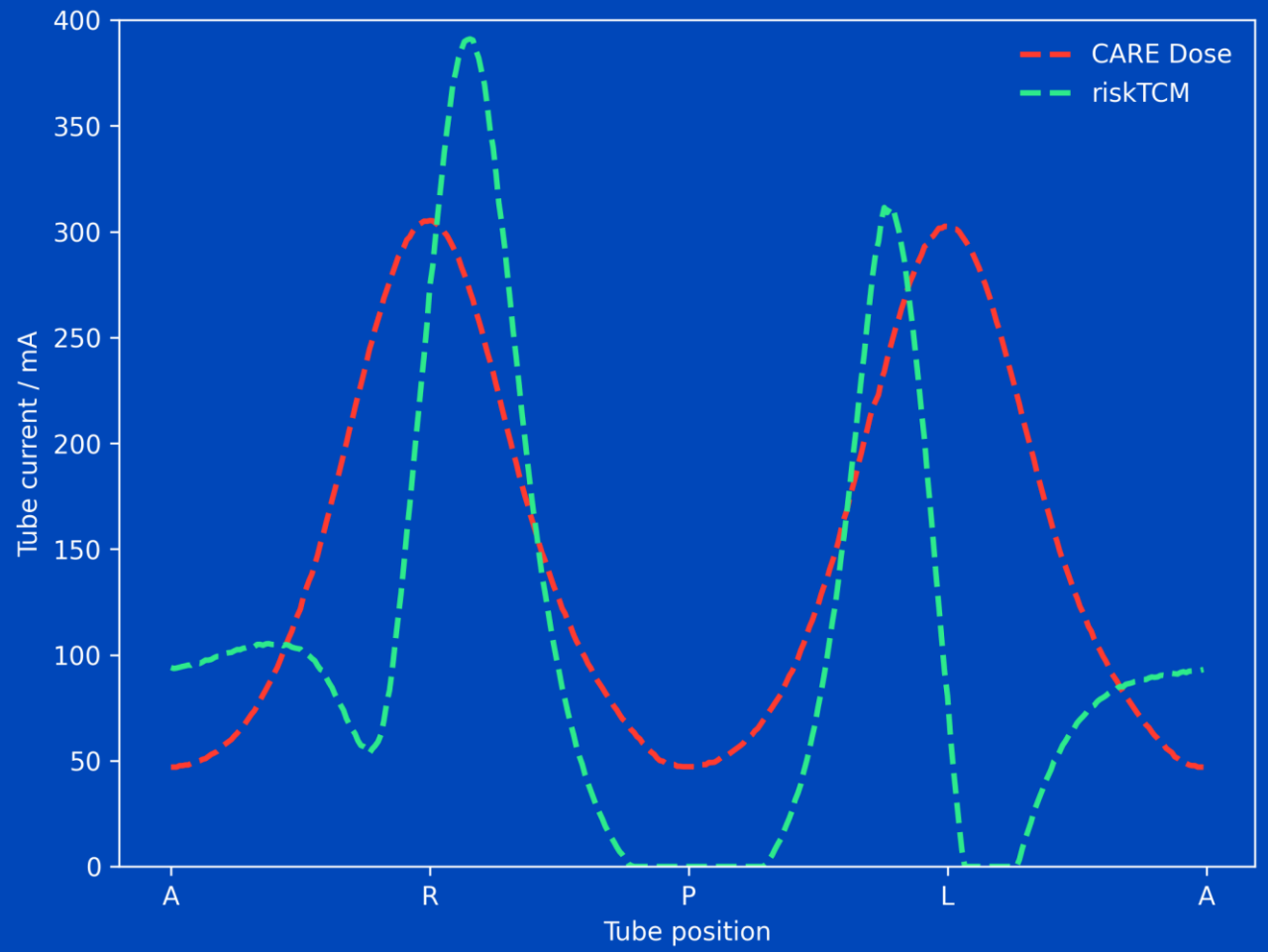
ReconCT Reconstructions

- 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)



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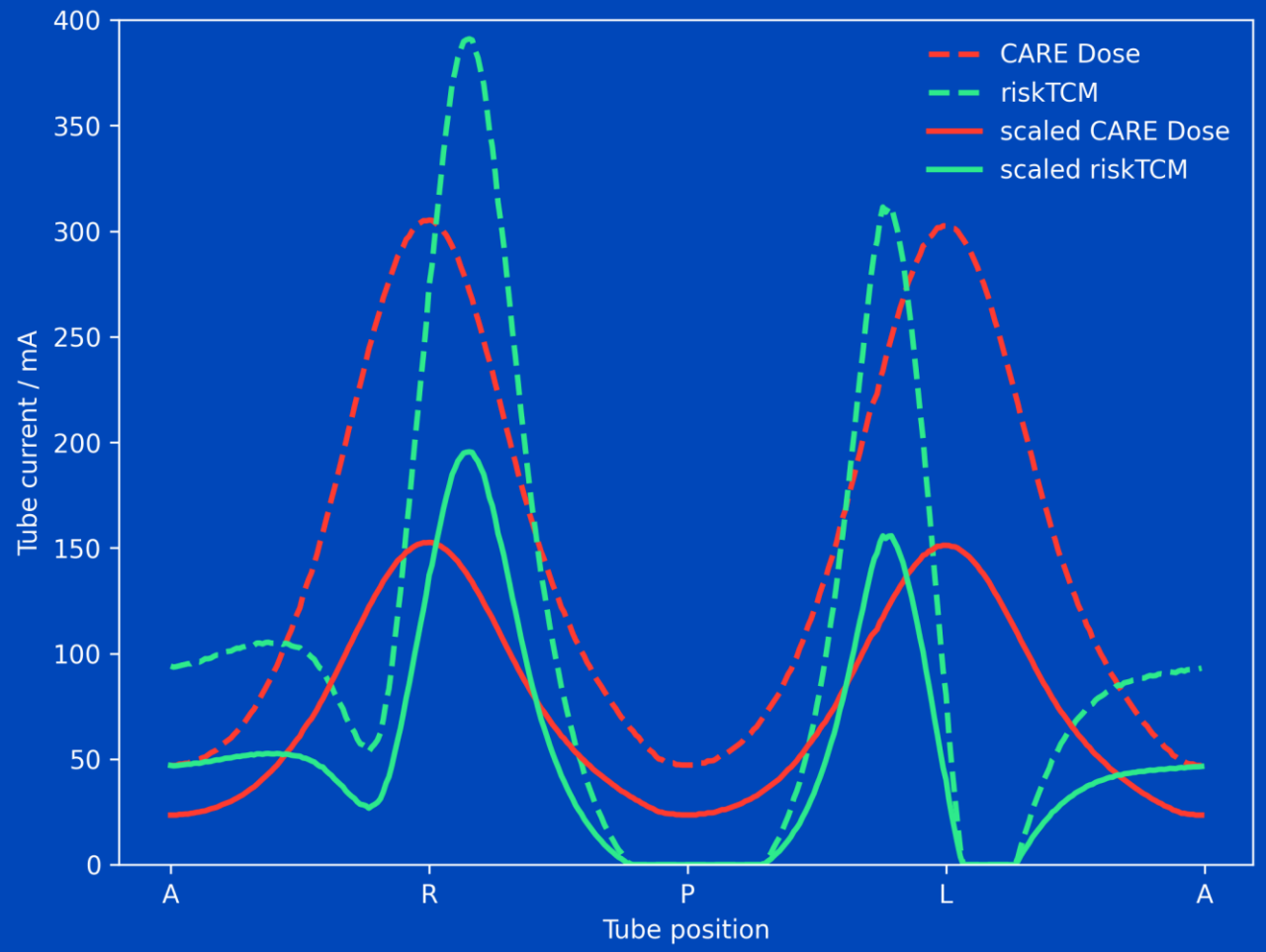
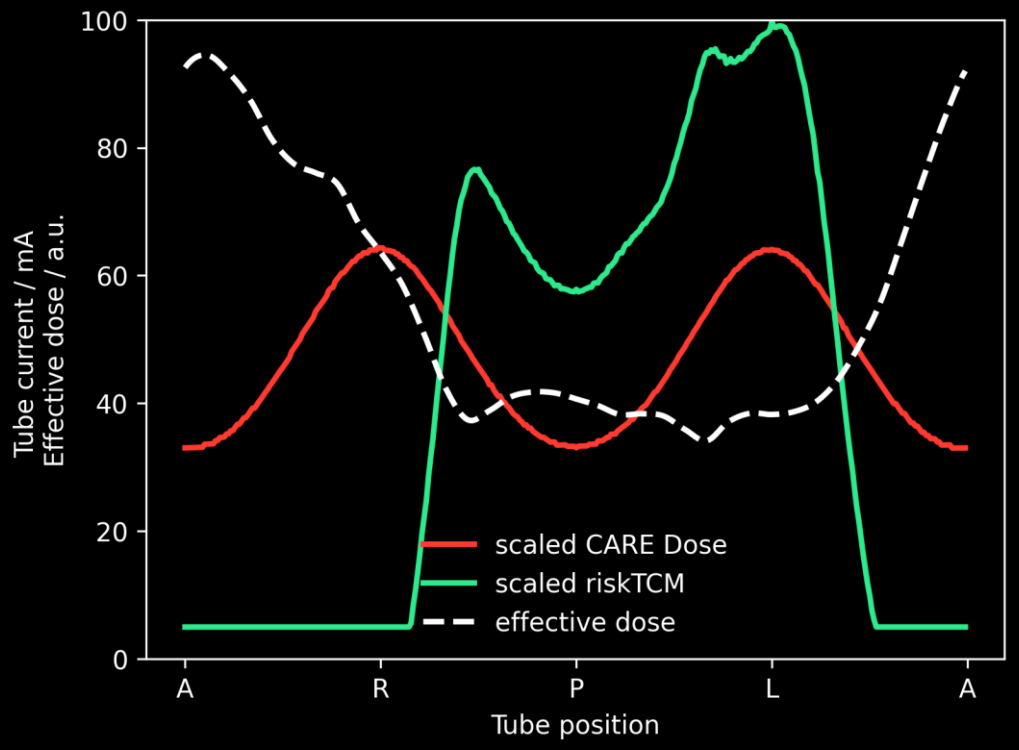


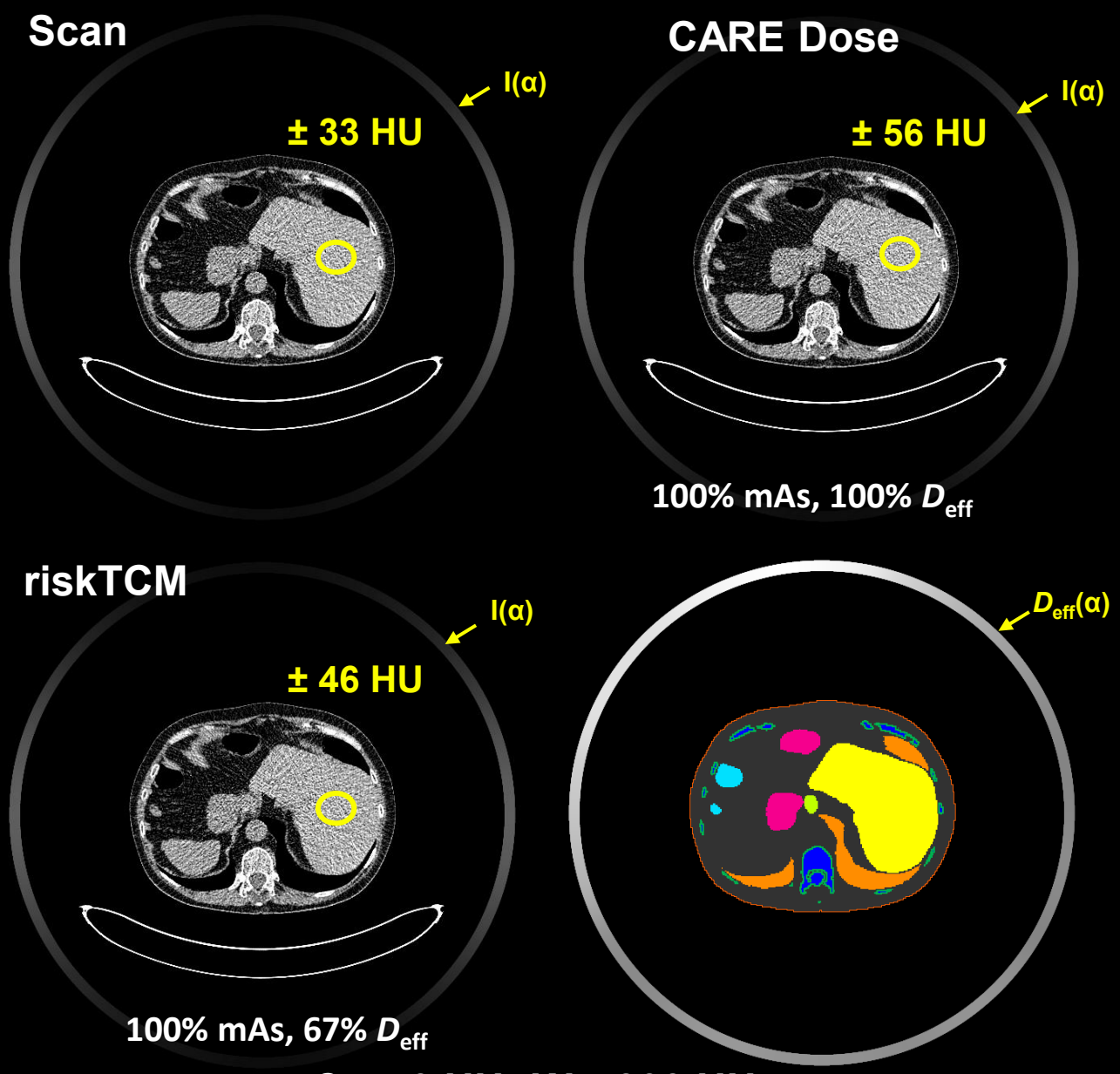
Quantity Comparison of riskTCM and CARE Dose with Added Noise at Equal Dose Level



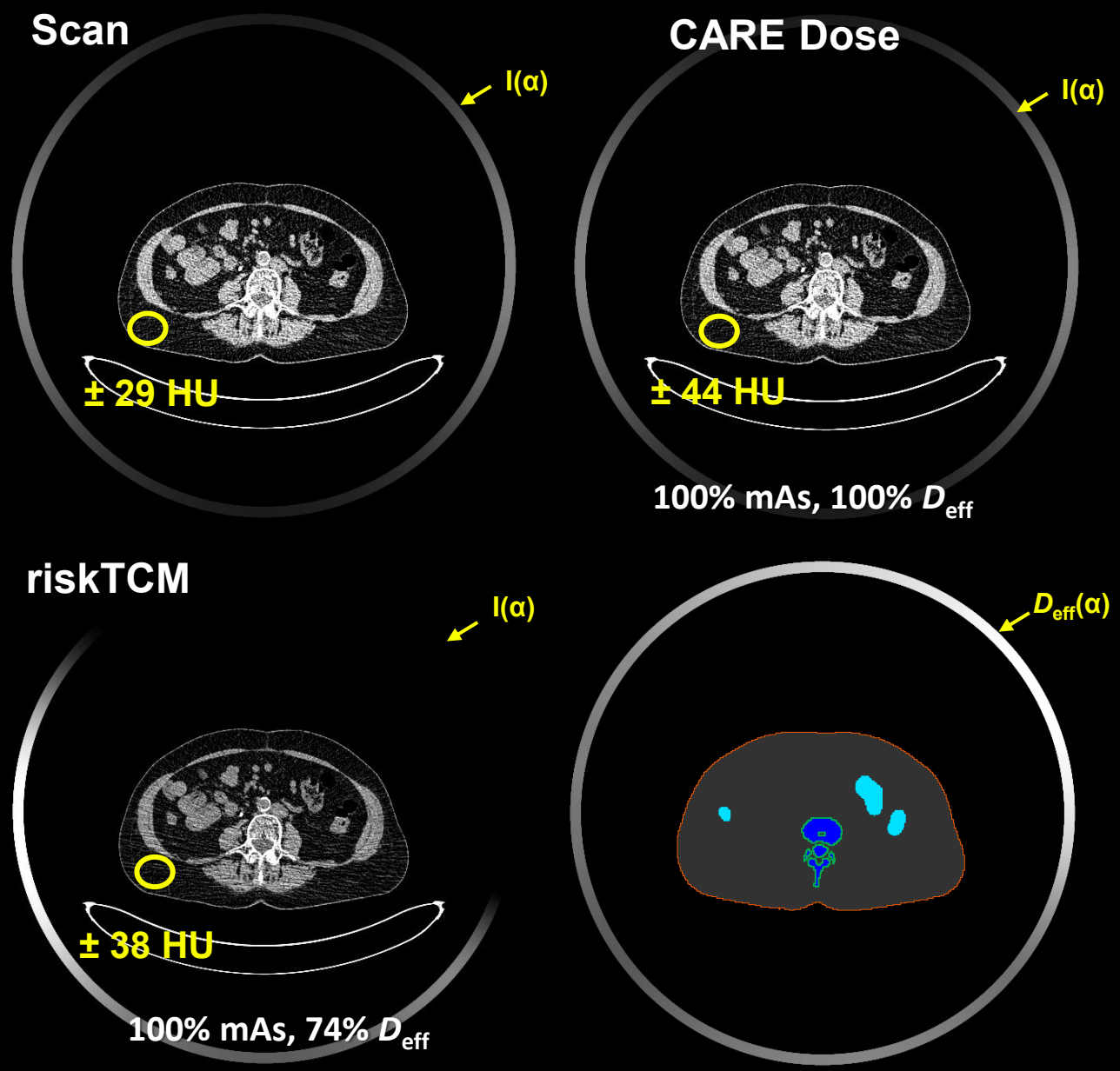
riskTCM

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

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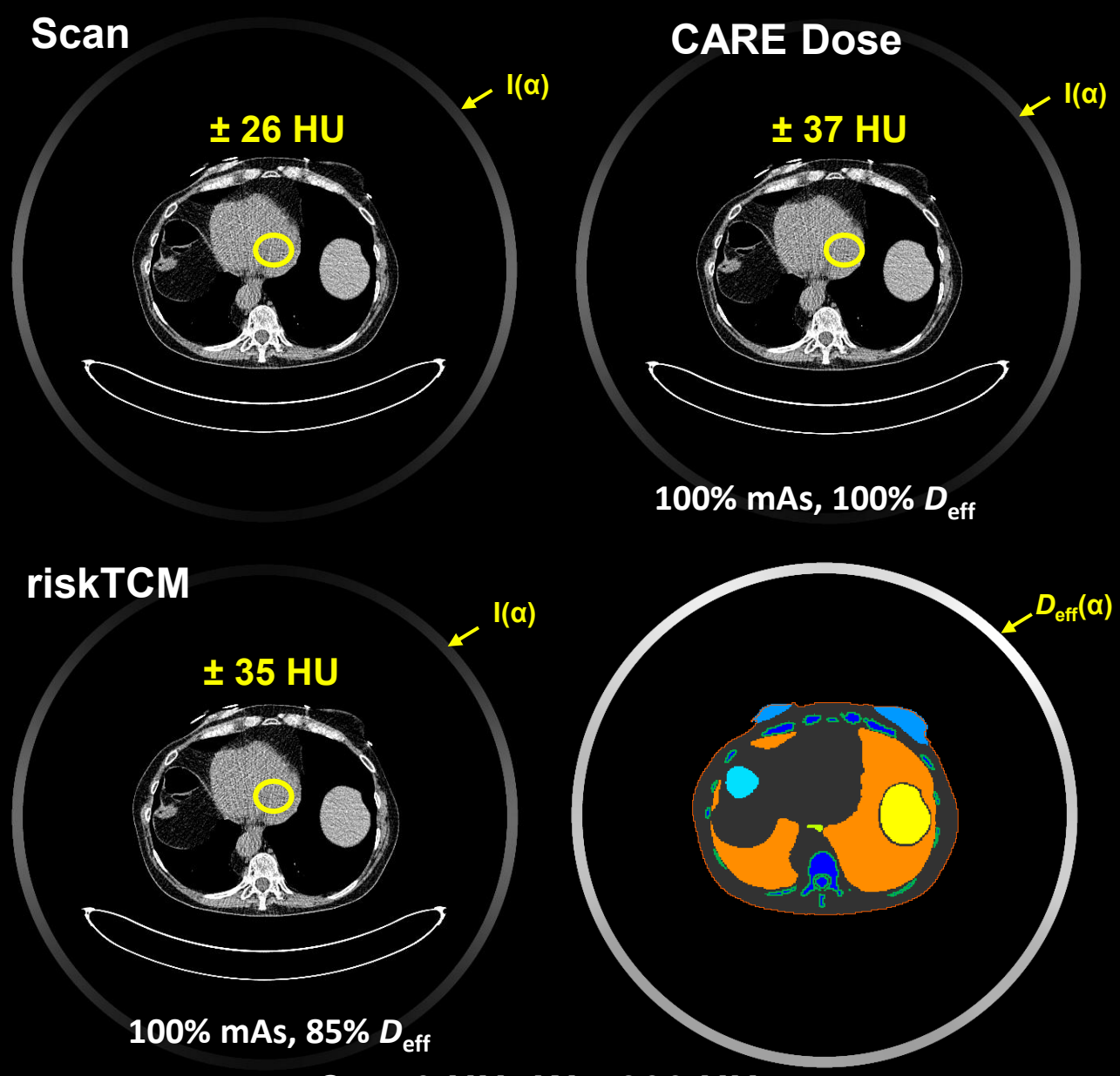

CARE Dose and riskTCM images are displayed at the same dose level

Results

	CARE Dose	riskTCM	Dose reduction
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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ReconCT was provided by Siemens Healthineers, Forchheim, Germany.