Patient Risk-Minimizing Tube Current Modulation in CT (riskTCM)

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DEUTSCHES KREBSFORSCHUNGSZENTRUM
IN DER HELMHOLTZ-GEMEINSCHAFT

Aim

- Today's tube current modulation minimizes the mAs-product (mAsTCM).
- We propose a patient risk minimizing TCM (riskTCM).
- We compare its potential dose reduction to mAsTCM.
  - mAsTCM = good for the x-ray tube
  - riskTCM = good for the patient

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Patient-specific radiation risk-based tube cu
diagnostic CT

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Michael Lell, Joscha Maier, Marc Kachelrieß

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AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

Congratulations

This paper received the Sylvia&Moses Greenfield Award for the best scientific paper on imaging in Medical Physics in 2022.

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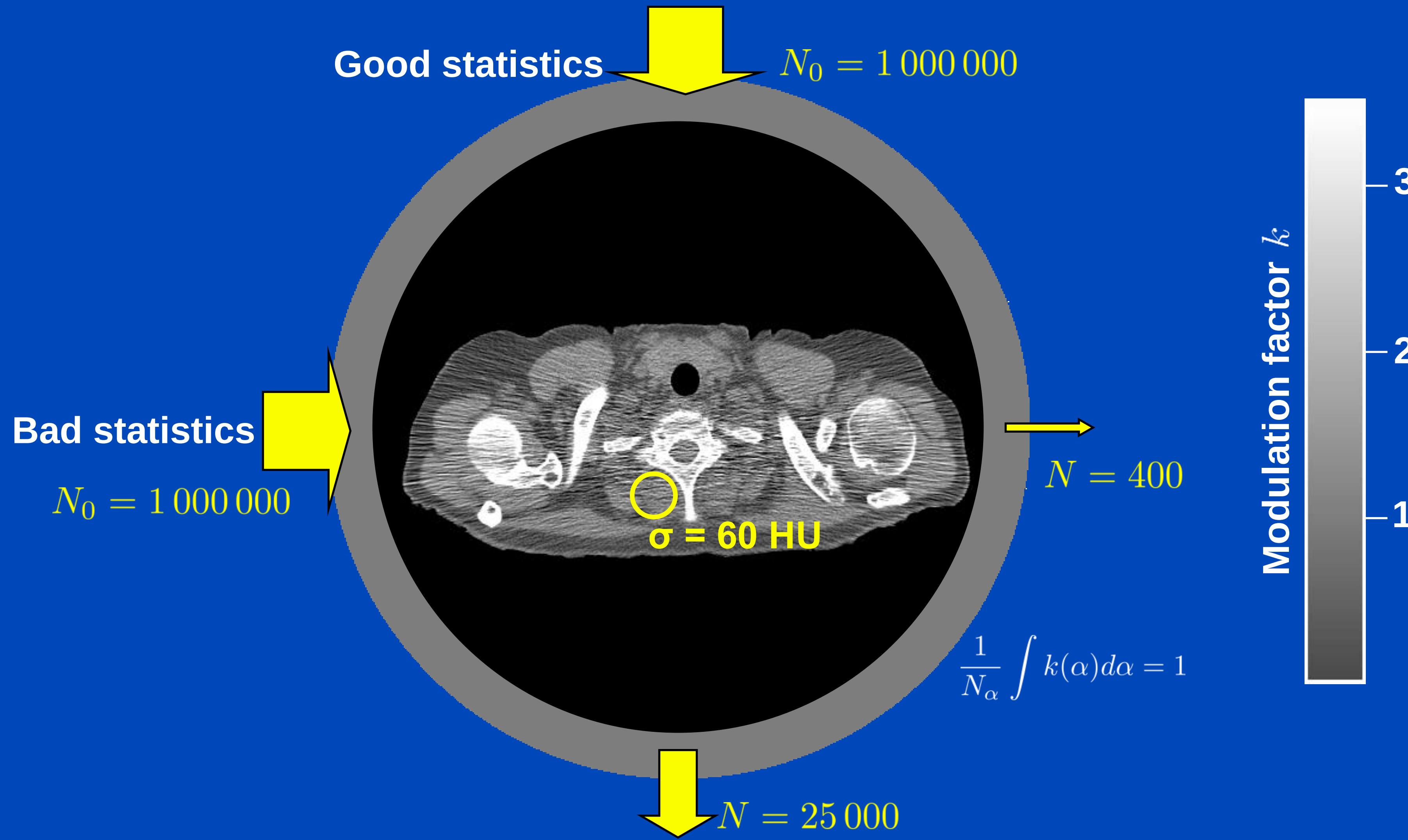
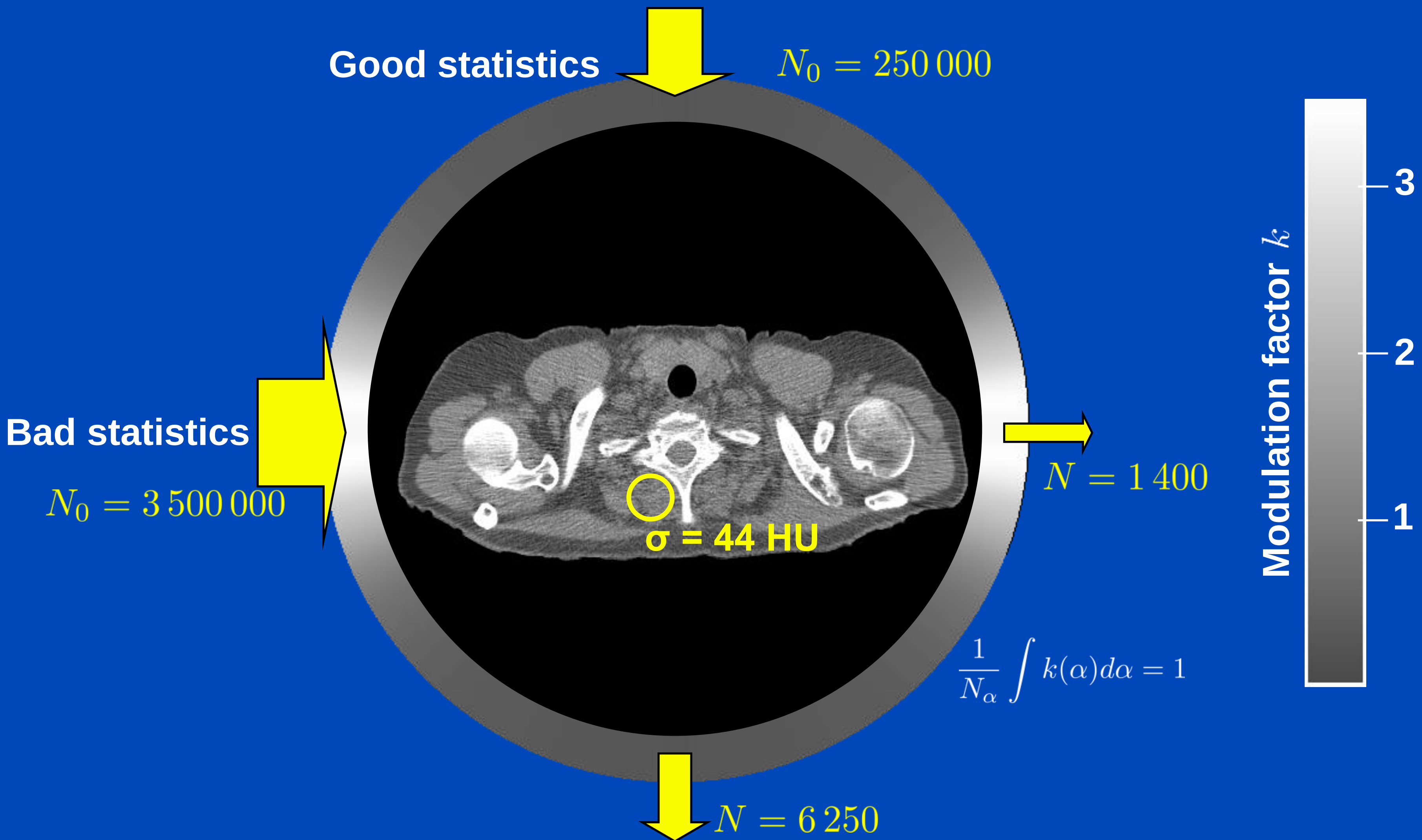
Tube Current Modulation



Constant tube current: High, inhomogeneous noise.

M. Gies, W. A. Kalender, H. Wolf, C. Suess, M. T. Madsen, "Dose reduction in CT by anatomically adapted tube current modulation. I. Simulation studies", Medical Physics 26 (11): 2235–2247 (1999).

Tube Current Modulation



Modulated tube current: Lower, more homogeneous noise.

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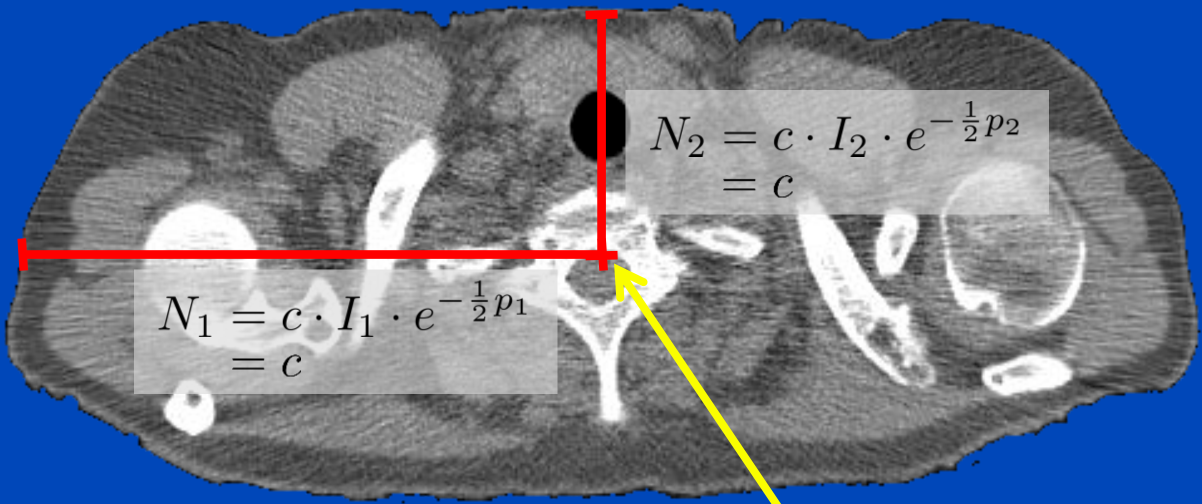
Tube Current Modulation

Interpretation

- **Tube current:** $I(\alpha) \propto e^{\frac{1}{2}\cdot p(\alpha)}$
- **Photon numbers:** $N(\alpha) = c \cdot I(\alpha) \cdot e^{-p(\alpha)}$



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

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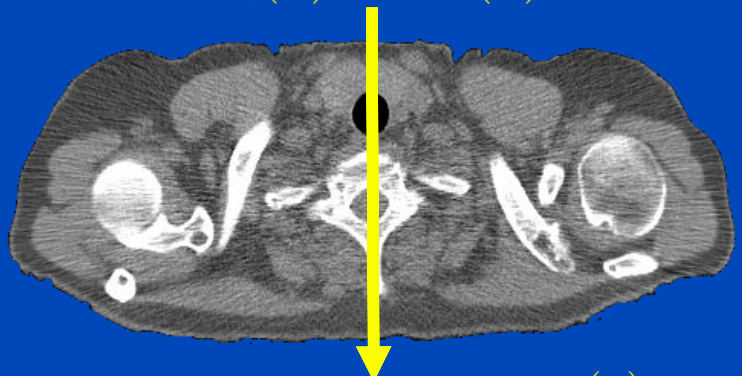
Tube Current Modulation

From a mathematical perspective

- The tube current modulation curve $I(\alpha)$ is chosen such that the variance in the CT reconstruction is minimal

$$N_0(\alpha) = c \cdot I(\alpha)$$



$$N(\alpha) = c \cdot I(\alpha) \cdot e^{-p(\alpha)}$$

  – X-rays reaching the detector follow Poisson statistics: $\sigma^2_{N(\alpha)} = N(\alpha) = c \cdot I(\alpha) \cdot e^{-p(\alpha)}$

  – Variance propagation to projection domain yields: $$\sigma^2_{p(\alpha)} = \frac{1}{c \cdot I(\alpha) \cdot e^{-p(\alpha)}}$$

  – Variance propagation to image domain yields:

$$\sigma^2_f = \sum_\alpha \frac{1}{c \cdot I(\alpha) \cdot e^{-p(\alpha)}}$$

- Cost function:

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

For riskTCM, we also account for the effective dose $D_{\text{eff}}(\alpha)$ here.

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

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Cost Function

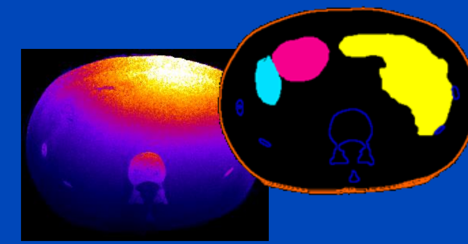

Table 3. Recommended tissue weighting factors.

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	Total	1.00

$$D_{\mathrm{eff}}(\alpha) = \sum_T w_T \cdot D_T(\alpha)$$

- **For mAsTCM, the cost function is**

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

- **For riskTCM, the equation is of the form**

$$C = \sum_\alpha \mathrm{Image\ variance}(\alpha) + \lambda \left(\sum_\alpha I(\alpha) \cdot D_{\mathrm{eff}}(\alpha) - \mathrm{const} \right)$$

- **The cost function for riskTCM also takes into account that the effective dose is dependent on the direction and is therefore not the same for two complementary (180°) rays, i.e., $D_{\mathrm{eff}}(\alpha_{\mathrm{D}}) \neq D_{\mathrm{eff}}(\alpha_{\mathrm{C}})$.**

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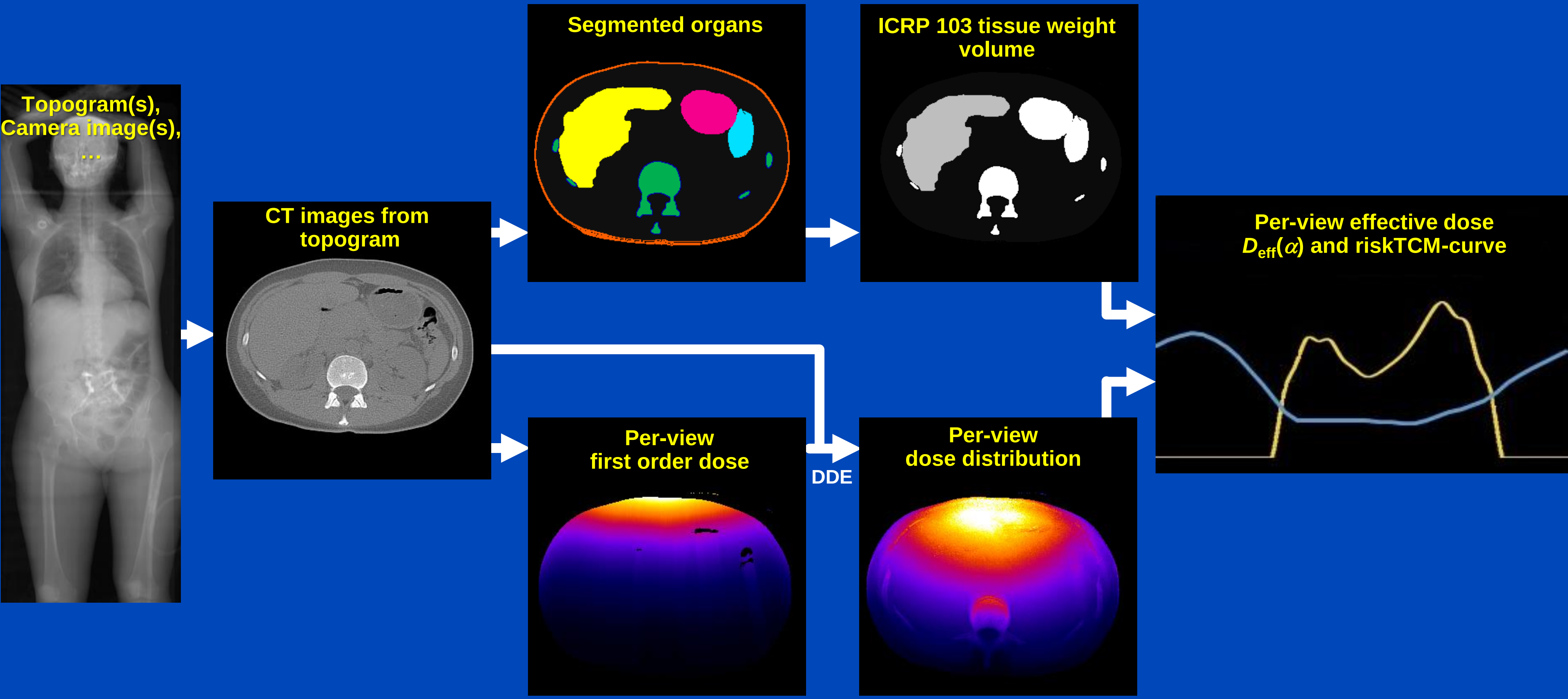
TCM Minimizing the Radiation Risk

Basic workflow



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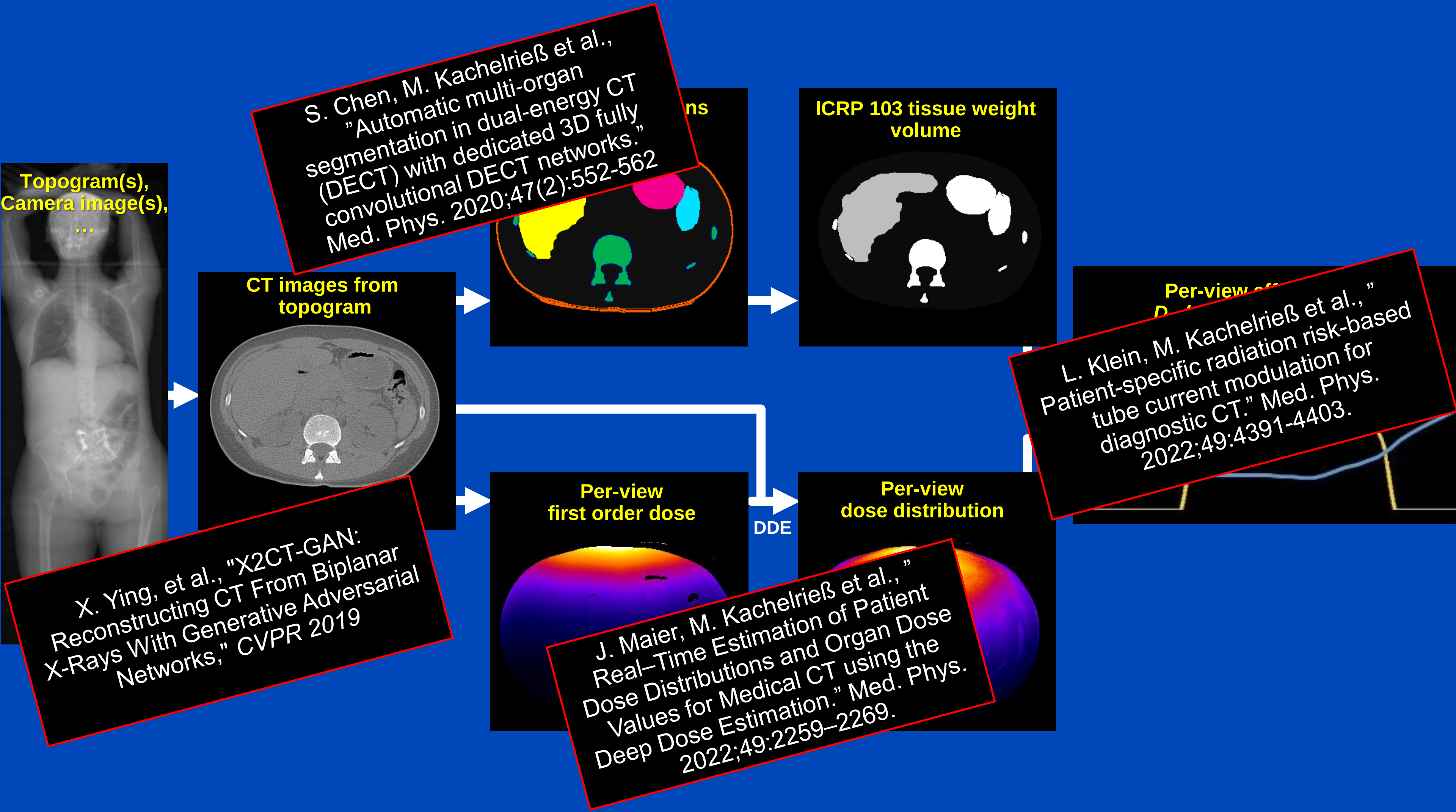
TCM Minimizing the Radiation Risk

Basic workflow



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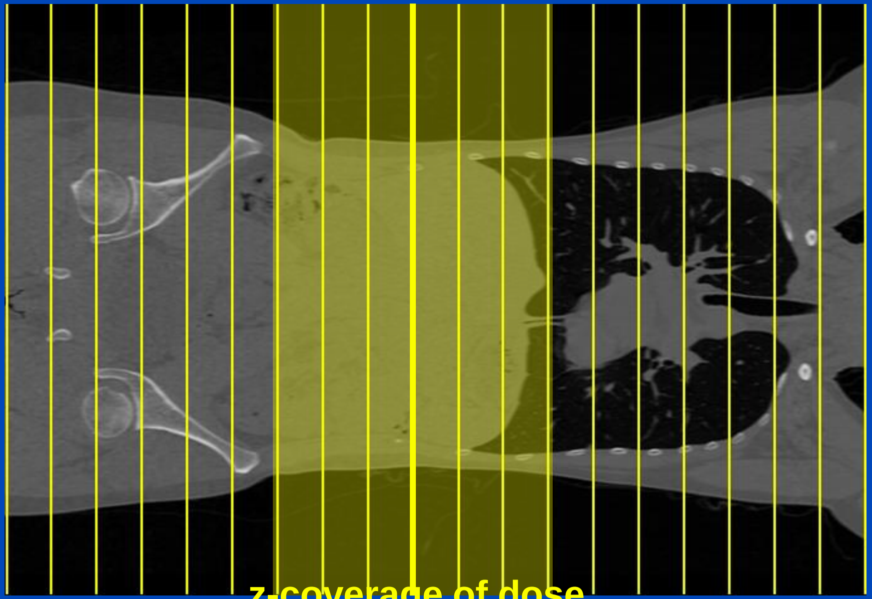
Retrospective Study

- Simulation of CT scans covering different anatomies from 70 kV to 150 kV (6 mm Al prefiltration).
- Simulation of consecutive circle scans each with a z-collimation of 40 mm.

Axial view

Coronal view



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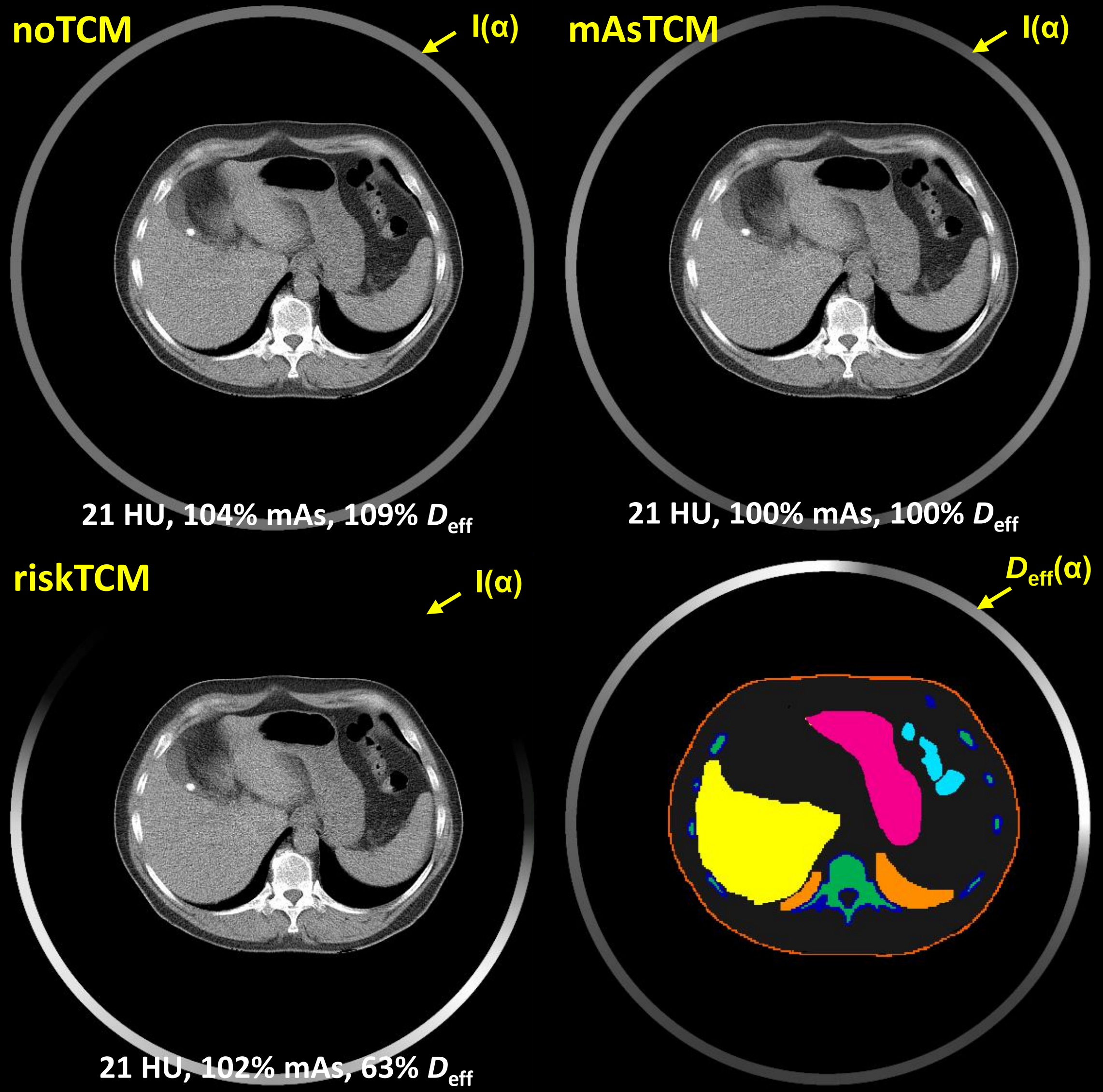
Modulation Curves for 70 kV



Effective Dose at Same Image Noise Relative to mAsTCM

Average over all patients

Abdomen

Tube Voltage	noTCM	mAsTCM	riskTCM
70 kV	**113%** from 105% to 135%	100%	**69%** from 57% to 76%
100 kV	**113%** from 103% to 137%	100%	**71%** from 62% to 79%
120 kV	**114%** from 106% to 135%	100%	**72%** from 64% to 79%
150 kV	**115%** from 106% to 136%	100%	**73%** from 66% to 80%

Thorax

Tube Voltage	noTCM	mAsTCM	riskTCM
70 kV	**113%** from 108% to 118%	100%	**77%** from 67% to 82%
100 kV	**113%** from 107% to 117%	100%	**81%** from 74% to 85%
120 kV	**113%** from 107% to 118%	100%	**82%** from 75% to 86%
150 kV	**113%** from 108% to 118%	100%	**83%** from 76% to 87%

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Extensions of riskTCM

- **Comparison with organ-specific TCM (osTCM)**

  L. Klein, L. Enzmann, A. Byl, C. Liu, S. Sawall, A. Maier, J. Maier, M. Lell, and M. Kachelrieß. “Organ-specific vs. patient risk-specific tube current modulation in thorax CT scans covering the female breast.“ CT Meeting 2022.

- **Additional modulation of the tube voltage (riskTCTVM) and of the prefilter (riskXSM)**

  E. Baader, L. Klein, S. Sawall, J. Maier, and M. Kachelrieß. “CT tube current and tube voltage modulation to minimize the patient's radiation risk.“ ECR 2023.

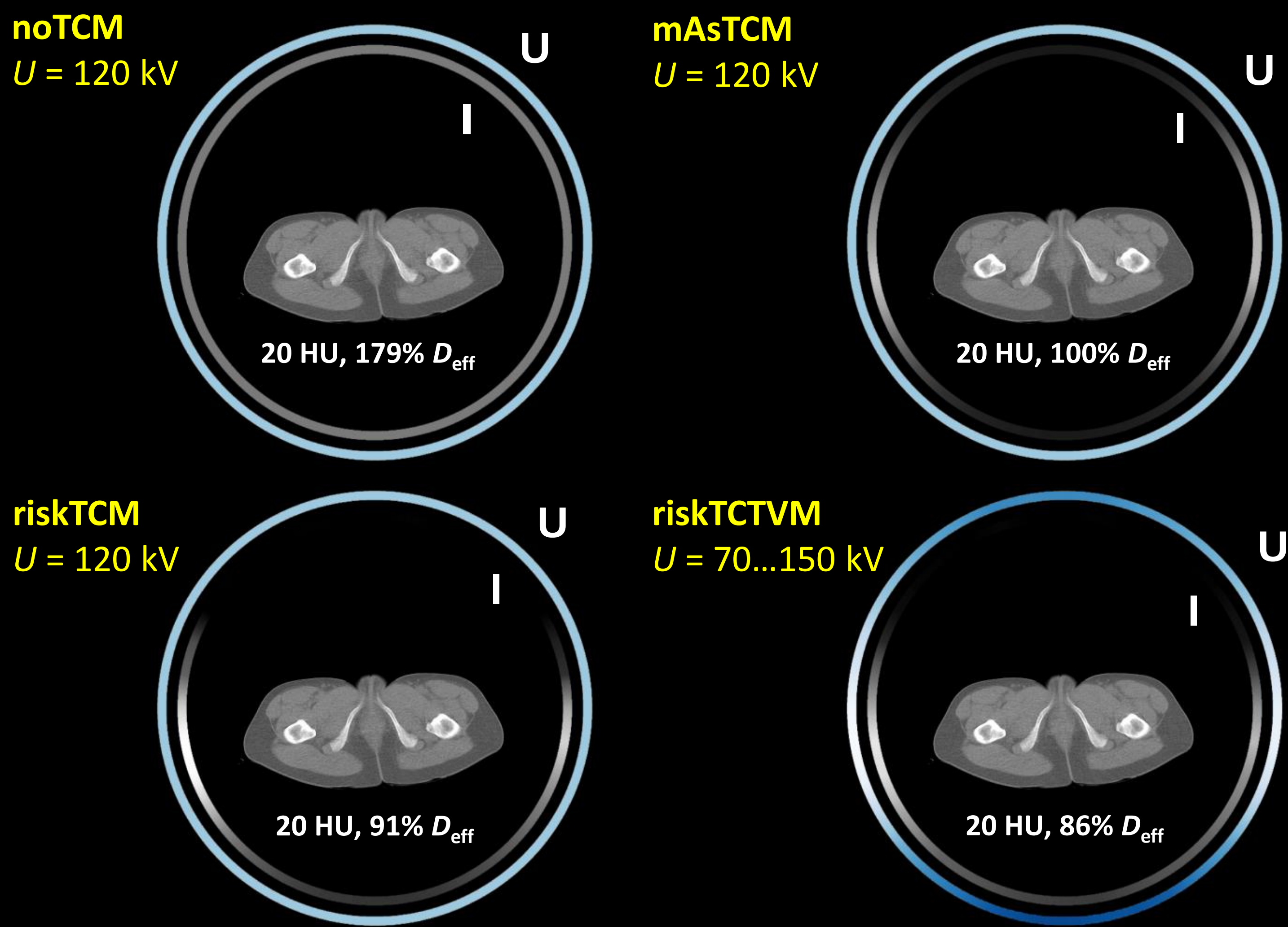
- **Performance of real measurements**

  Cooperation with Siemens Healthineers (Forchheim, Germany)

- **Risk models (upcoming)**

  S. Klubertz

Risk Minimizing Tube Current & Tube Voltage Modulation (riskTCTVM)



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Conclusions

- **All anatomical regions benefit from riskTCM.**
- **The highest D_{eff} reduction compared to mAsTCM is seen for the abdomen (31%) and for the pelvis (25%).**
- **The implementation of riskTCM on a clinical CT only requires software updates.**
- **A further D_{eff} reduction might be possible with riskTCTVM or riskXSM, in particular when contrast agents are used.**

This work received the
Behnken-Berger Award
at the DGMP annual meeting 2023

BEHNKEN-BERGER STIFTUNG

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Thank You!

This presentation will soon be available at www.dkfz.de/ct.

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Job opportunities through DKFZ's international PhD programs or through marc.kachelriess@dkfz.de.

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