Risk-Minimizing Tube Current Modulation (riskTCM) for CT – Potential Dose Reduction Across Different Tube Voltages

Laura Klein[1,2], Chang Liu[3], Jörg Steidel[1,2], Lucia Enzmann[1,2], Stefan Sawall[1,2] , Joscha Maier[1,] Andreas Maier[3], Michael Lell[4], and Marc Kachelrieß[1,2]

[1]German Cancer Research Center (DKFZ), Heidelberg, Germany
[2]University of Heidelberg, Germany
[3]University of Erlangen-Nürnberg, Germany
[4]Klinikum Nürnberg, Germany

DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

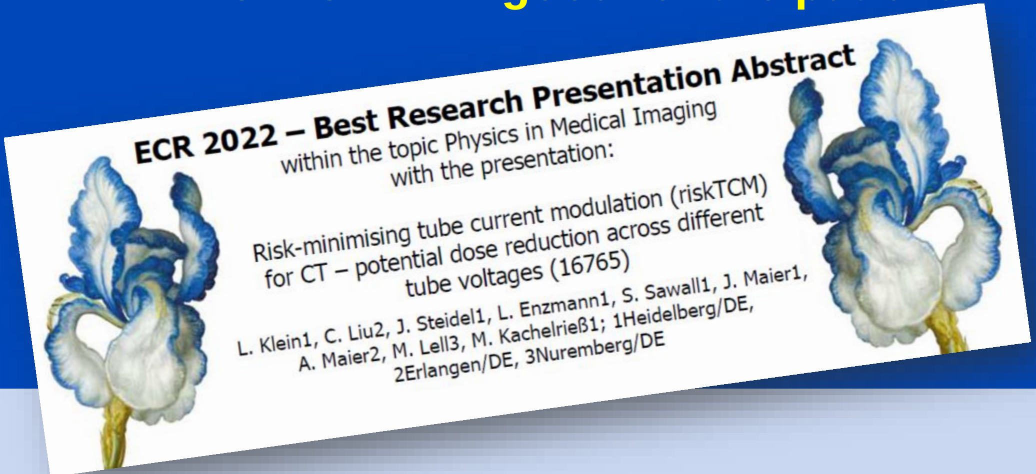
Aim

Today's state-of-art tube current modulation (mAsTCM) minimizes the mAs-product rather than the actual patient risk.

Therefore, we propose a patient risk minimizing TCM (riskTCM) and estimate the potential dose reduction compared to mAsTCM as function of tube voltage.

mAsTCM = good for the x-ray tube

riskTCM = good for the patient



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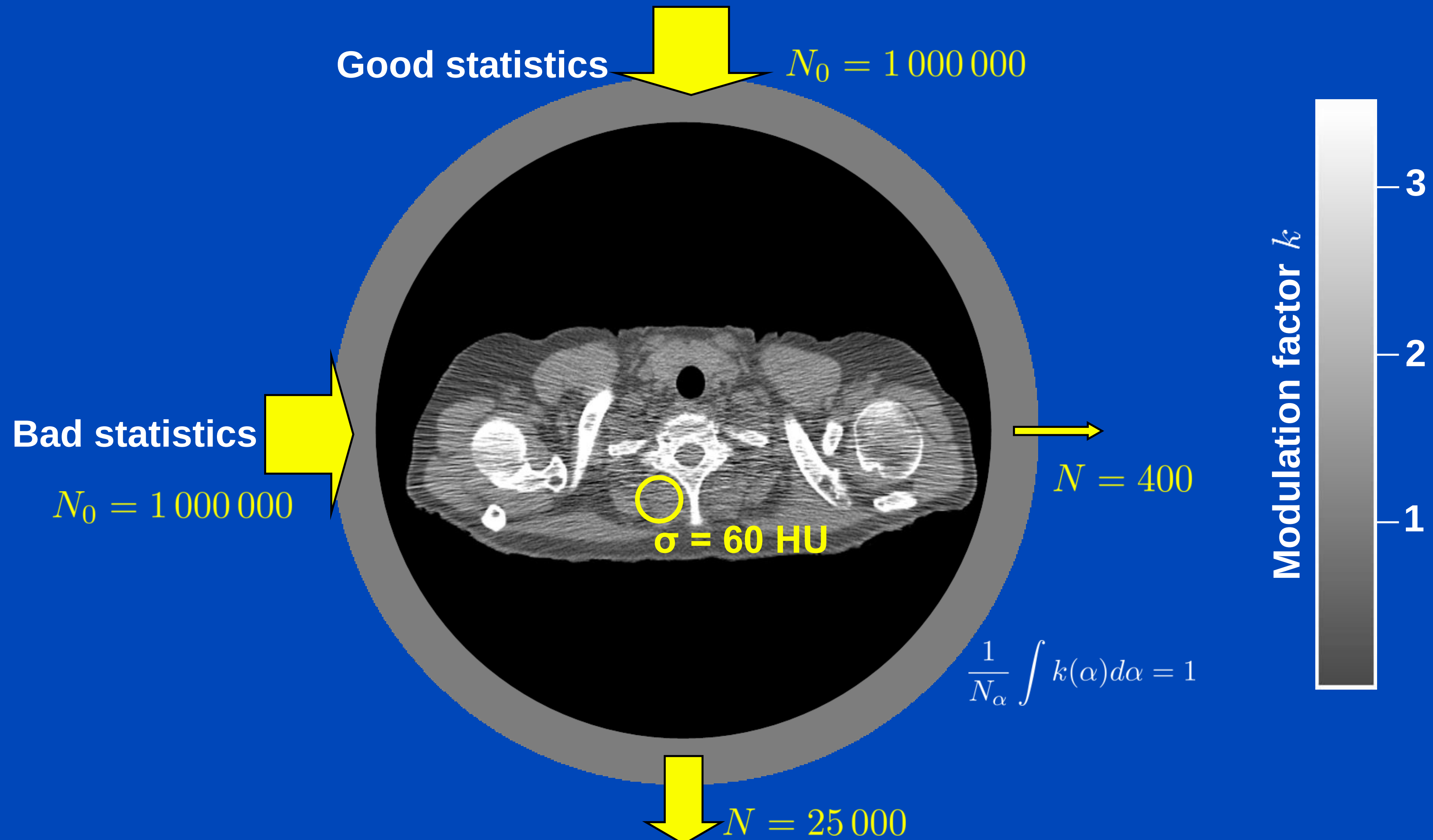
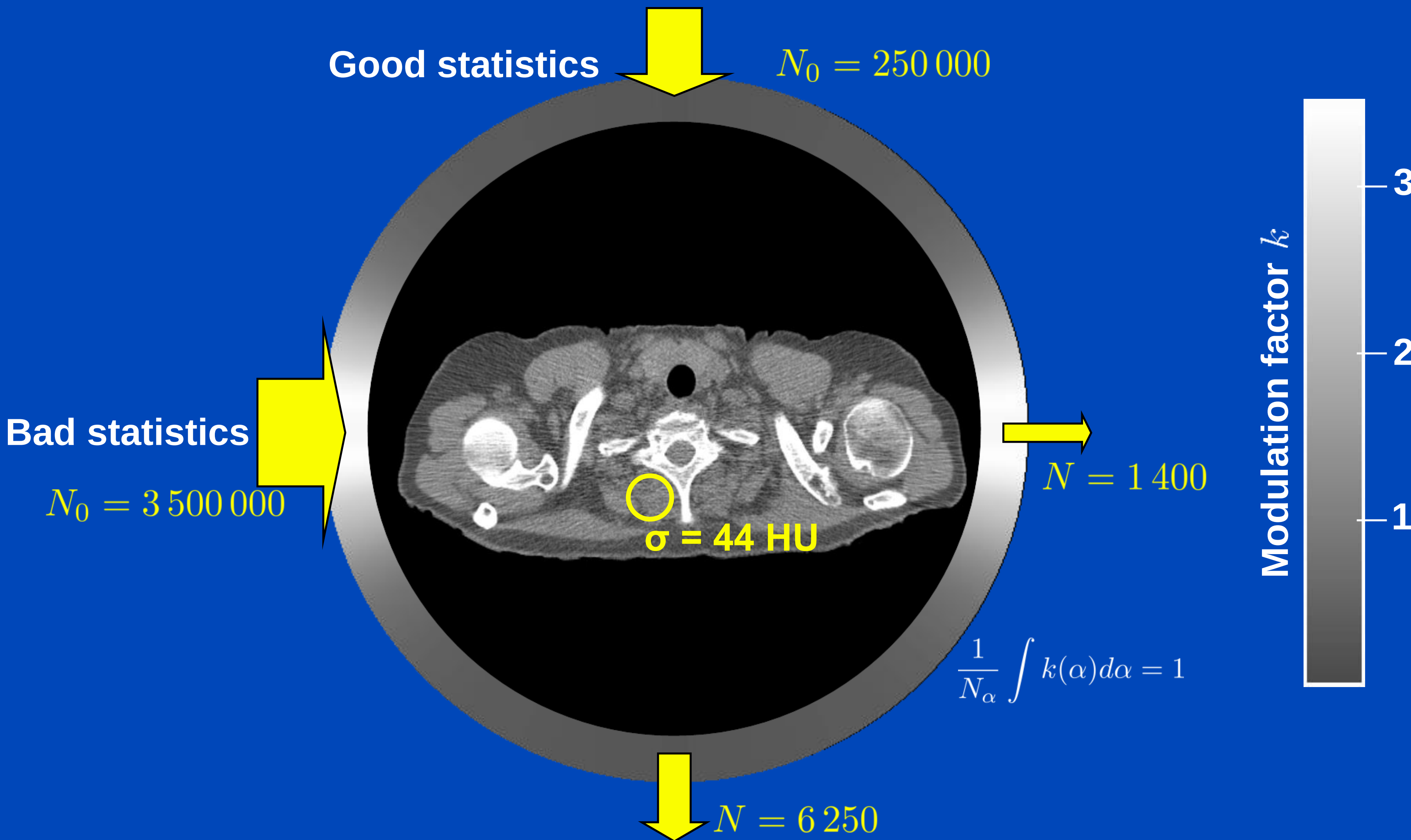
Tube Current Modulation



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.

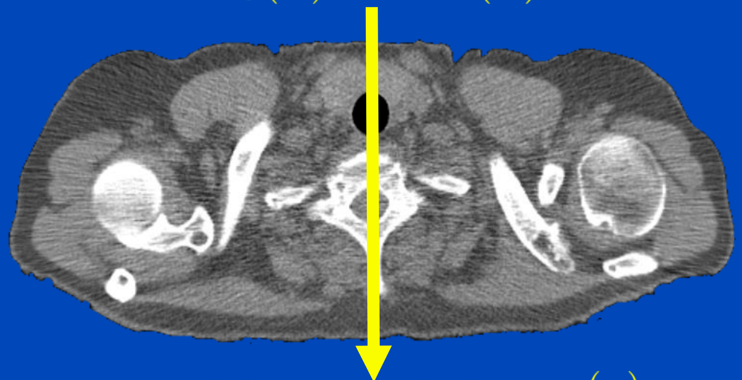
M. Gies, W. A. Kalender, H. Wolf, C. Suess, M. T. Madsen, “Dose reduction in CT by anatomically adapted tube current modulation. I. Simulation studies”, Medical Physics 26 (11): 2235–2247 (1999).

Tube Current Modulation

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

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

- **Cost function:**

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

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

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

Cost Function

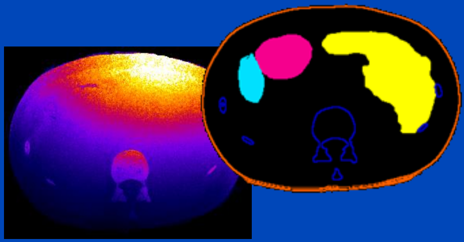


Table 3. Recommended tissue weighting factors.

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

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

Image variance

- For riskTCM, the equation is of the form

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

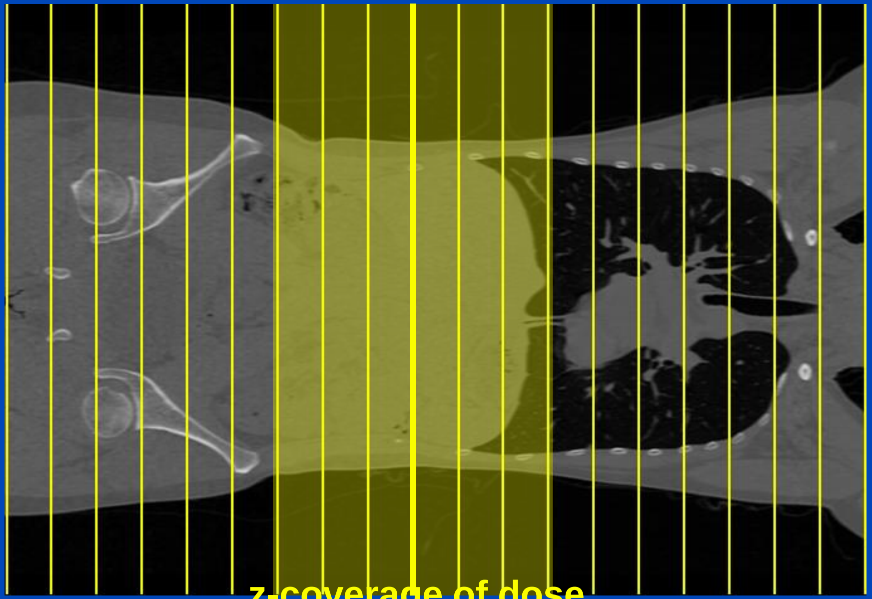
- The cost function for riskTCM also takes into account that the effective dose is dependent on the direction and is therefore not the same for two complementary (180°) rays, i.e. $D_{\mathrm{eff}}(\alpha_{\mathrm{D}}) \neq D_{\mathrm{eff}}(\alpha_{\mathrm{C}})$.

Retrospective Study

- Simulation of CT scans covering different anatomies at 70 kV, 100 kV, 120 kV, and 150 kV (6 mm Al prefiltration).
- Simulation of consecutive circle scans (38.4 mm apart), each with a z-collimation of 38.4 mm.

Axial view

Coronal view



Effective Dose at Same Image Noise Relative to mAsTCM

Average over all patients

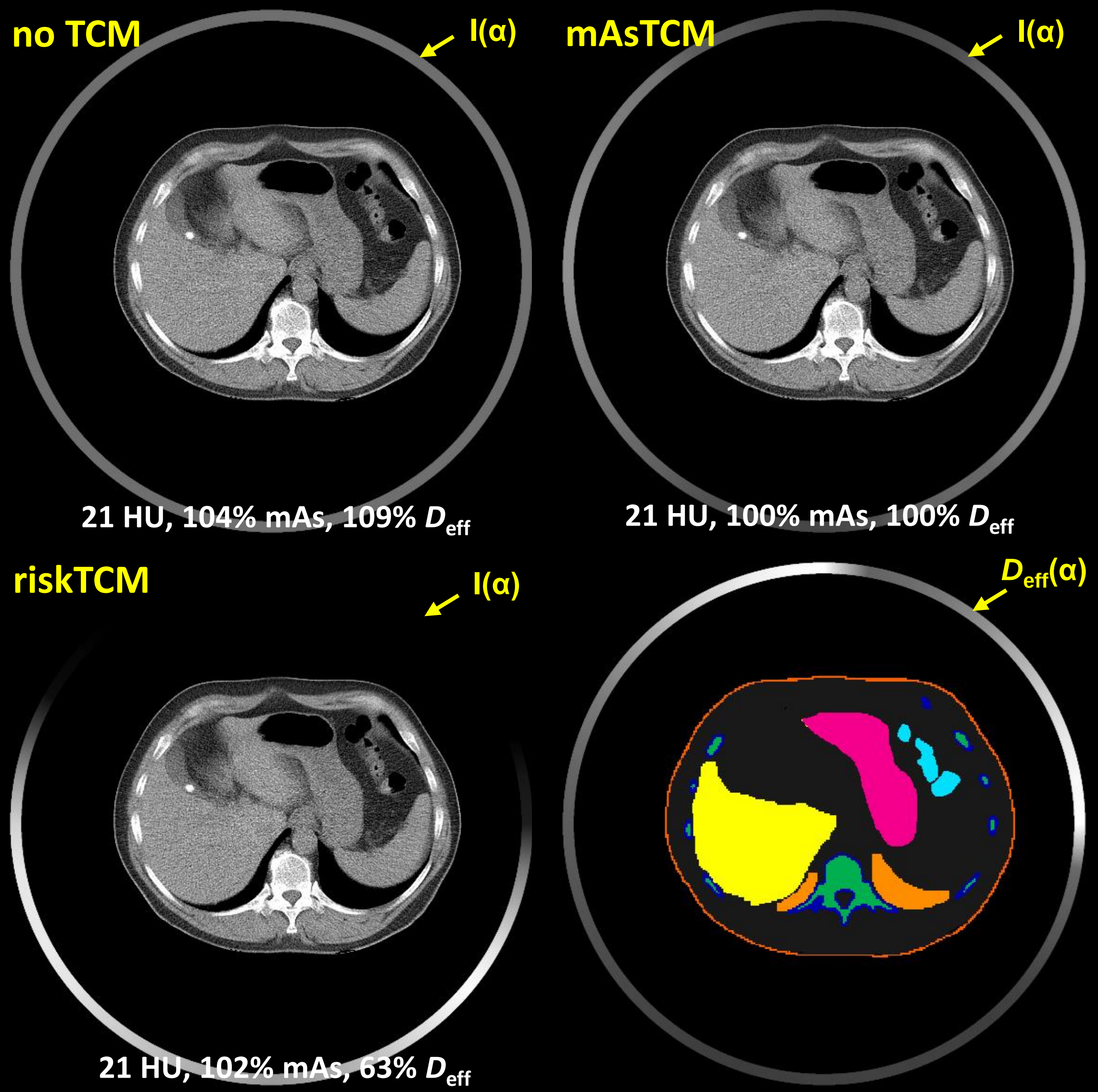
Abdomen

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%

Head+Arms

Tube Voltage	noTCM	mAsTCM	riskTCM
70 kV	**163%** from 145% to 178%	100%	**87%** from 84% to 91%
100 kV	**158%** from 139% to 186%	100%	**87%** from 83% to 91%
120 kV	**160%** from 142% to 183%	100%	**88%** from 84% to 94%
150 kV	**161%** from 144% to 183%	100%	**88%** from 82% to 95%

Modulation Curves for 70 kV



C = 25 HU, *W* = 400 HU

Conclusions

- All considered anatomical regions benefit from riskTCM.
- The highest potential D_{eff} reduction is seen for the abdomen, i.e. about 31% compared to mAsTCM, on average, for 70 kV.
- In case of head examinations, the proposed method achieves a D_{eff} reduction of about 13% compared to mAsTCM, for 70 kV.
- The proposed riskTCM method can be easily adapted to risk measures other than D_{eff}.
- This applies particular since other risk measures typically also account for organ doses.

Thank You!

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

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