Radiation Risk Minimizing Tube Current Modulation (rmTCM) for X-Ray Computed Tomography

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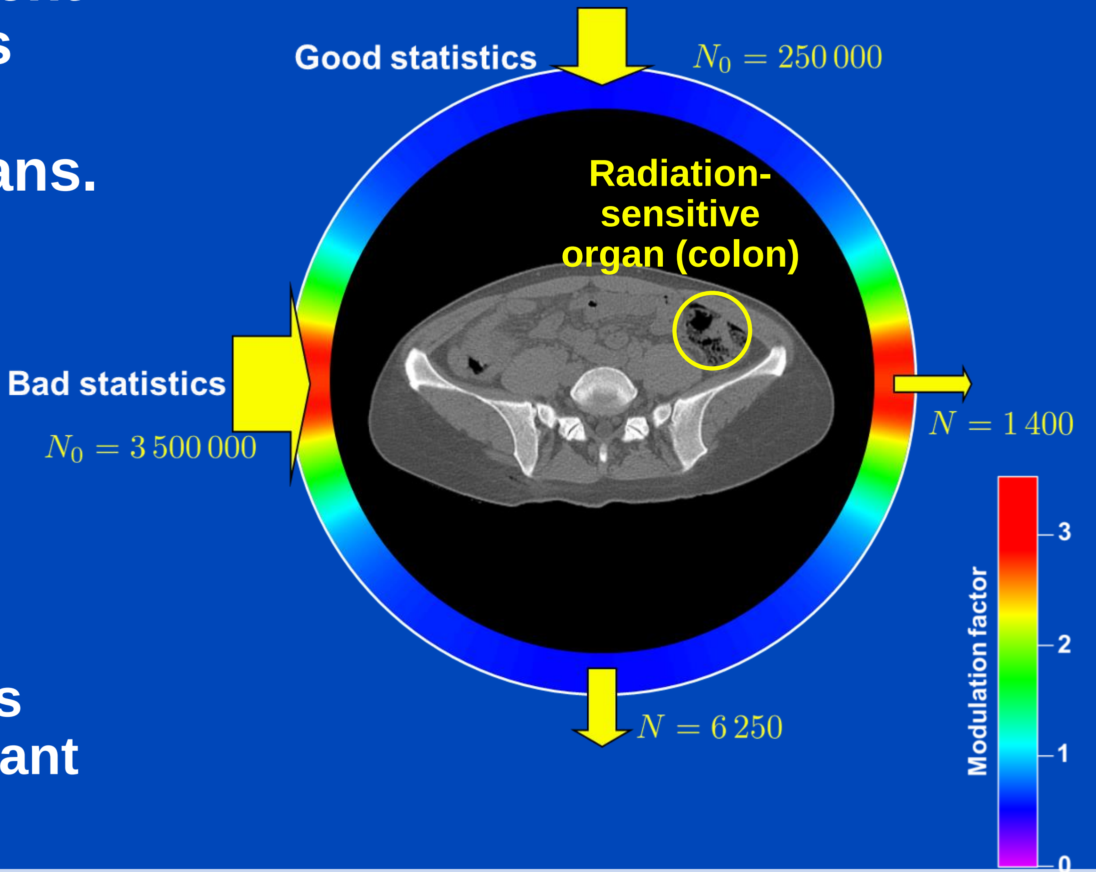
IN DER HELMHOLTZ-GEMEINSCHAFT

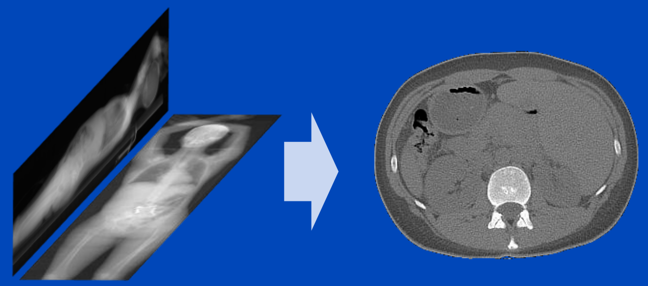
Motivation

- Tube current modulation (TCM) is a well-established tool to minimize x-ray dose while maintaining image quality.
- Conventional tube current modulation approaches do not account for (all) radiation-sensitive organs.
- Additional prior knowledge may enable more sophisticated approaches.
- Here: Use deep learning-based prior knowledge to perform a tube current modulation that minimizes the radiation risk at constant image quality.

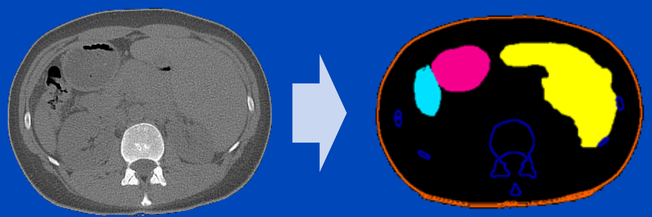


Radiation Risk Minimizing Tube Current Modulation (rmTCM) – Basic Workflow

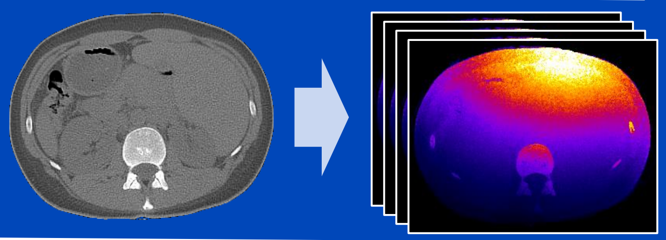
1. Coarse reconstruction from two scout views



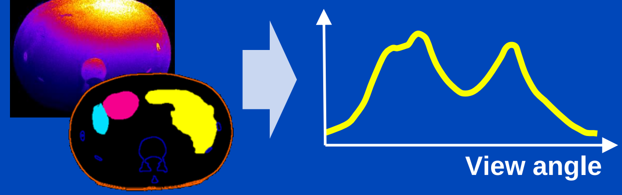
2. Segmentation of radiation-sensitive organs



3. Calculation of the effective dose per view using the deep dose estimation (DDE)



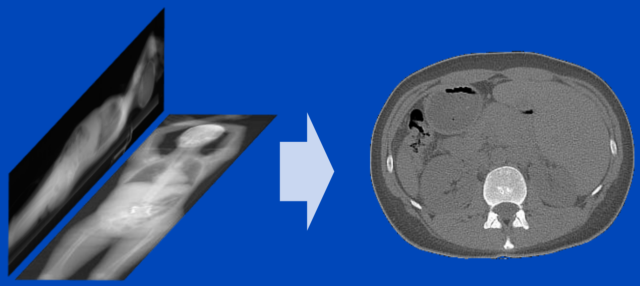
4. Determination of the tube current modulation curve that minimizes the radiation risk



Radiation Risk Minimizing Tube Current Modulation (rmTCM) – Basic Workflow

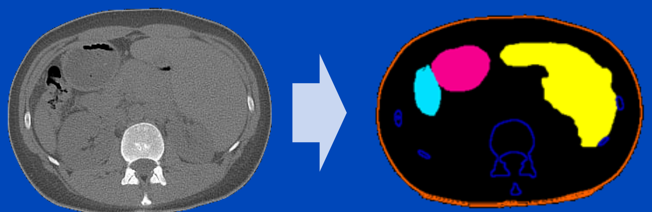
1. **Coarse reconstruction from two scout views**

   X. Ying, et al., "X2CT-GAN: Reconstructing CT From Biplanar X-Rays With Generative Adversarial Networks," *CVPR 2019*

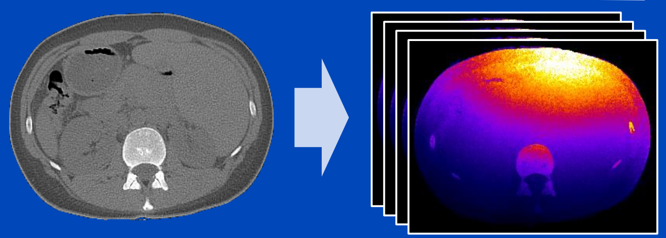


2. **Segmentation of radiation-sensitive organs**

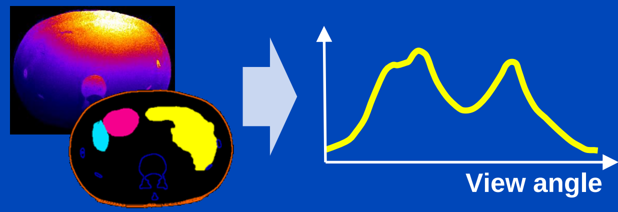
   S. Chen, M. Kachelrieß et al., "Automatic multi-organ segmentation in dual-energy CT (DECT) with dedicated 3D fully convolutional DECT networks." Med. Phys. 2019



3. **Calculation of the effective dose per view using the deep dose estimation (DDE)**



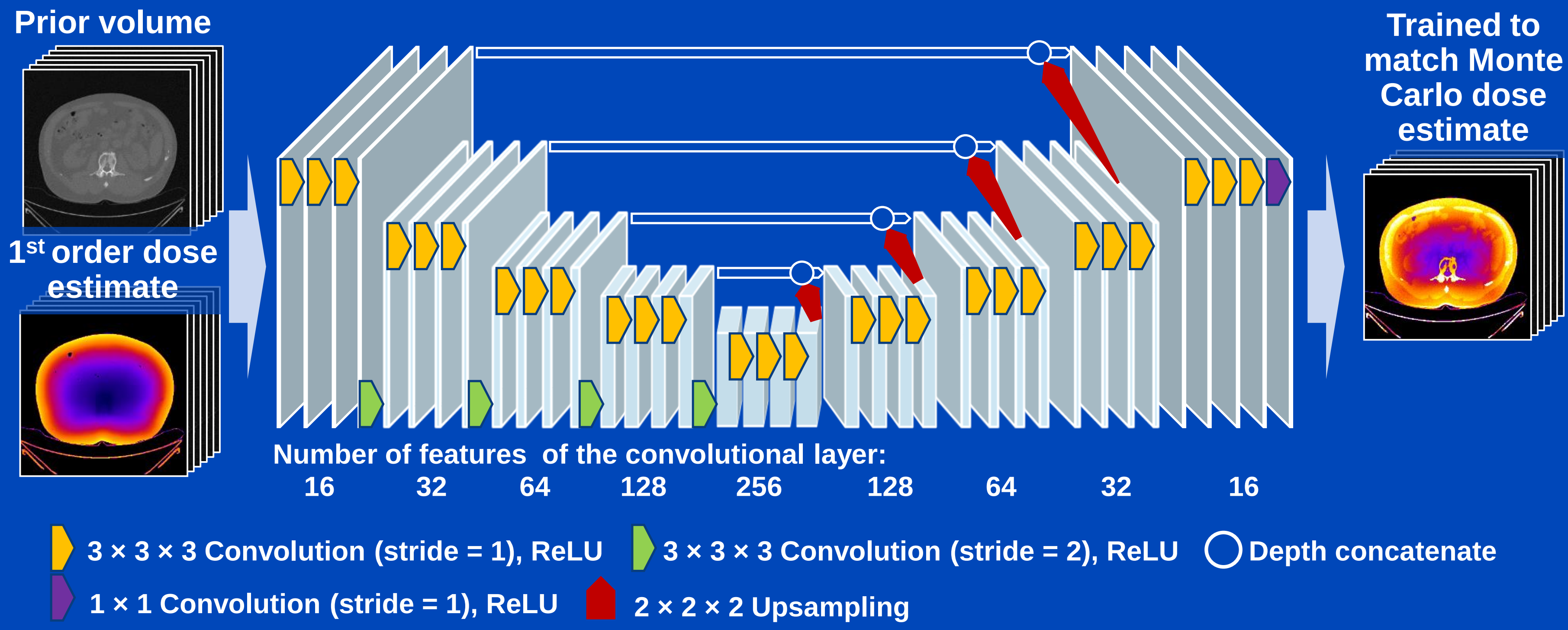
4. **Determination of the tube current modulation curve that minimizes the radiation risk**



Deep Dose Estimation (DDE)

- Monte Carlo (MC) simulation is the gold standard for patient-specific dose estimation, but too slow to be applied routinely.

➡ Training of a deep convolution to reproduce MC simulations given only the CT image and a 1st order dose estimate as input.



J. Maier, E. Eulig, S. Dorn, S. Sawall, M. Kachelrieß, in *Proceedings of the IEEE Nuclear Science Symposium and Medical Imaging Conference* (2018).

TCM Minimizing the Radiation Risk

Determination of the modulation curve

- Calculation of dose estimates $D_T(\alpha)$ for every view angle α using the deep dose estimation.
- Calculation of the effective dose according to the ICRP weighting factors w_T .

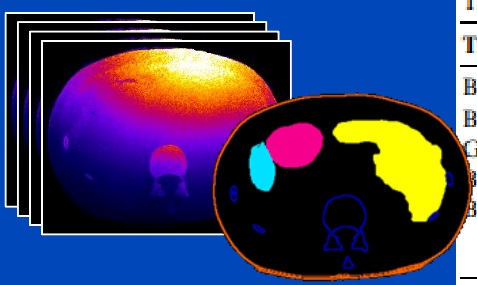


Table 3. Recommended tissue weighting factors.

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

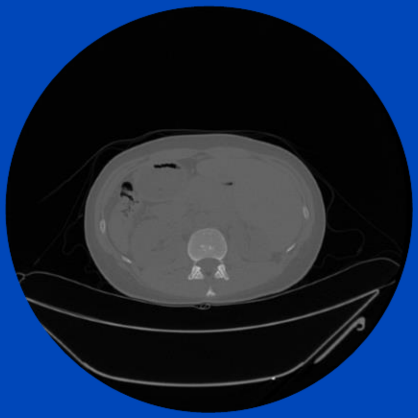
- Total effective dose: $D_{\text{eff}}(I(\alpha)) \propto \sum_{\alpha} I(\alpha) \cdot \left(\sum_T w_T \cdot D_T(\alpha) \right)$
- Choose tube current modulation curve $I(\alpha)$ such that effective dose is minimal at constant image quality.

Results – TCM at 70 kV

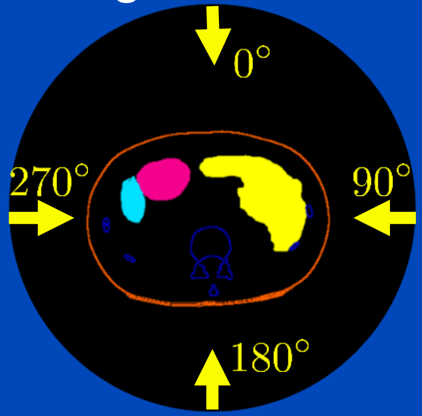
Angular modulation, abdomen

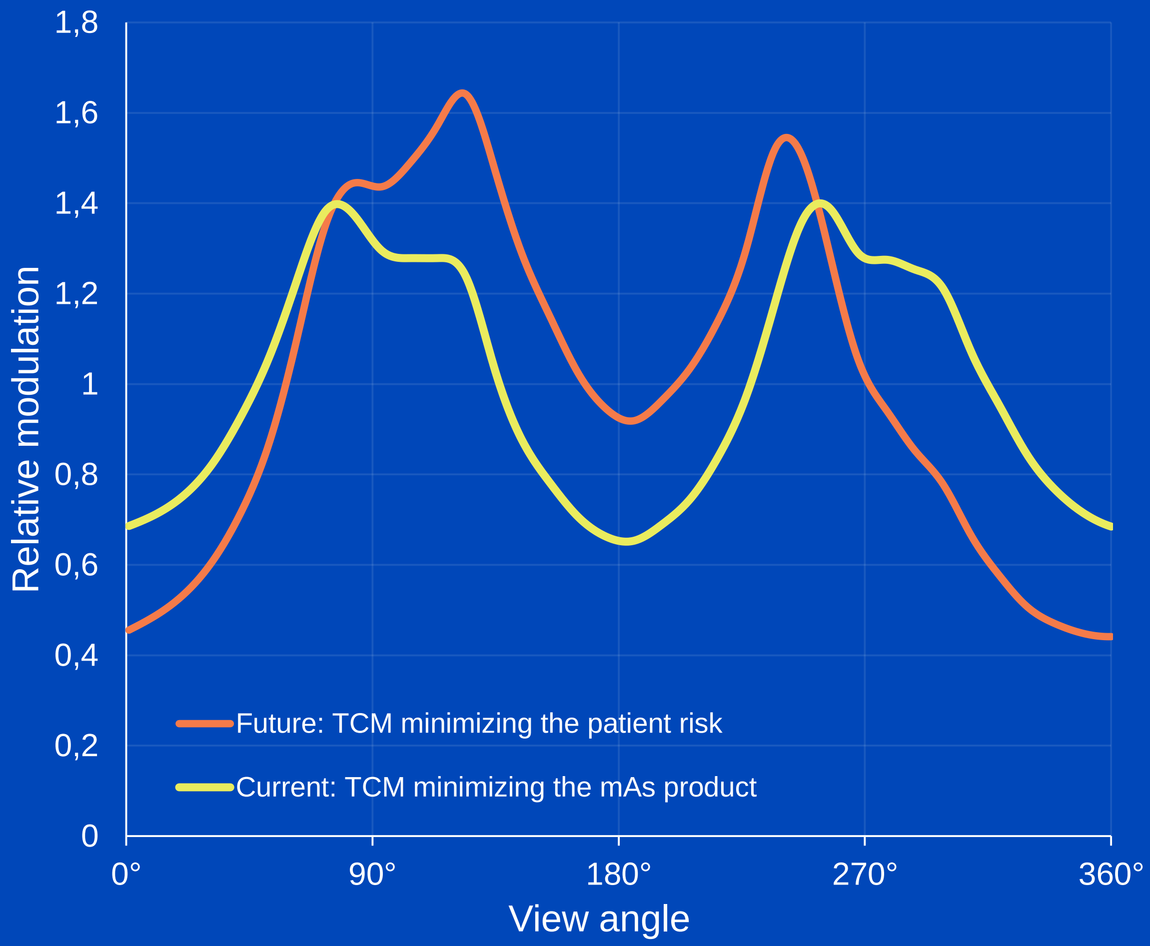
Organ / weight
Remainder 0.12
Bone surface 0.01
Brain 0.01
Breast 0.12
Colon 0.12
Esophagus 0.04
Liver 0.04
Lung 0.12
Skin 0.01
Stomach 0.12
Thyroid 0.04
Bladder 0.04

CT image



Segmentation





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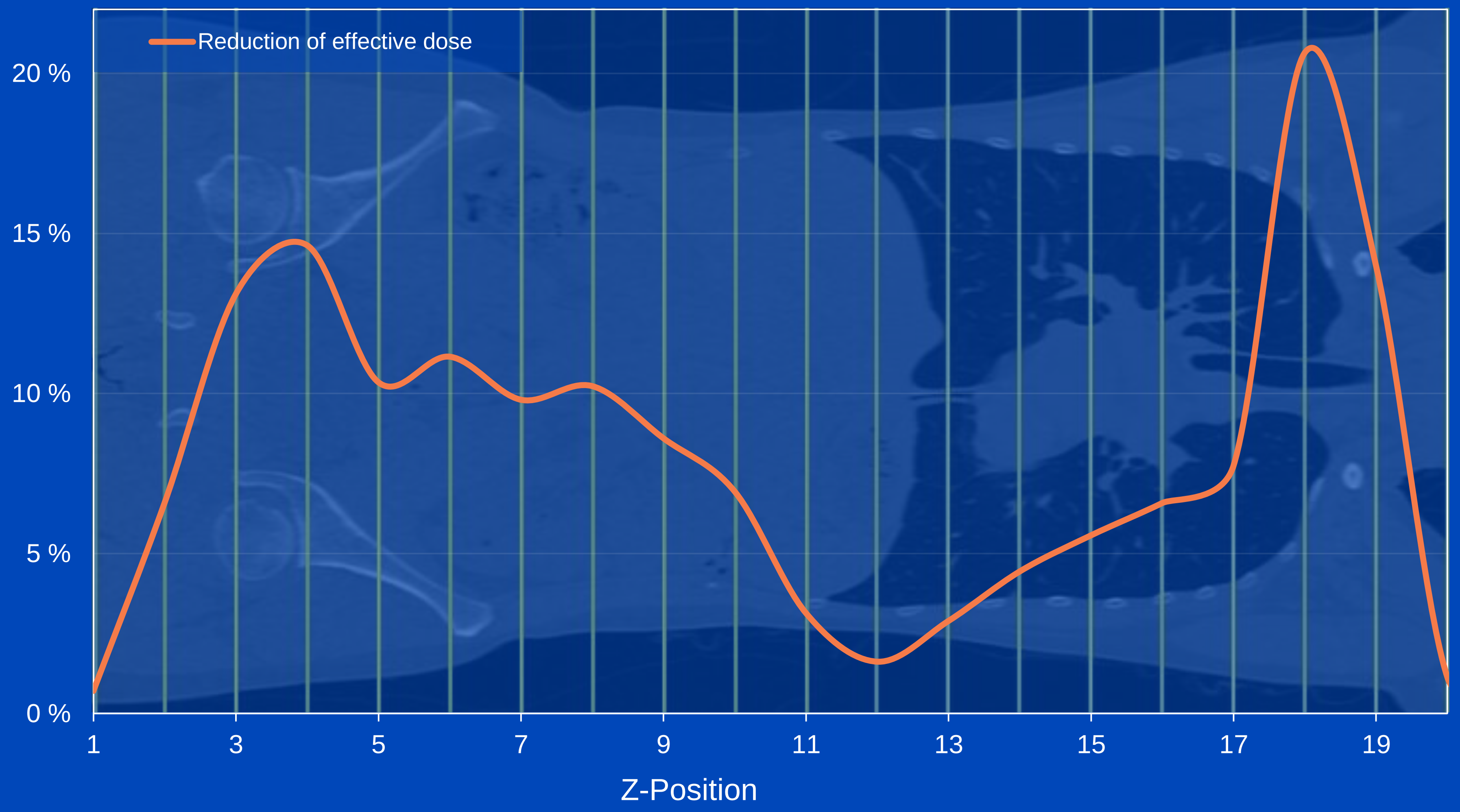
Results – Reduction of Effective Dose at 70 kV



→ **Reduction of the effective dose for the complete scan: 12 %**

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Conclusions

- Deep learning-based approaches may open new options for more sophisticated tube current modulation strategies.
- Here, the potential of a tube current modulation that minimizes the radiation risk instead of the mAs product was investigated.
- Compared to a conventional tube current modulation, the effective dose could be further reduced by about 12 %, 8 %, and 7 % for 70 kV, 120 kV and 150 kV, respectively.

Thank You!

This presentation is available at www.dkfz.de/ct

Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through Prof. Dr. Marc Kachelrieß (marc.kachelriess@dkfz.de).

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.