Patient-Specific Metrics for Scan Parameter Adaption in CT-Based Lung Cancer Screening

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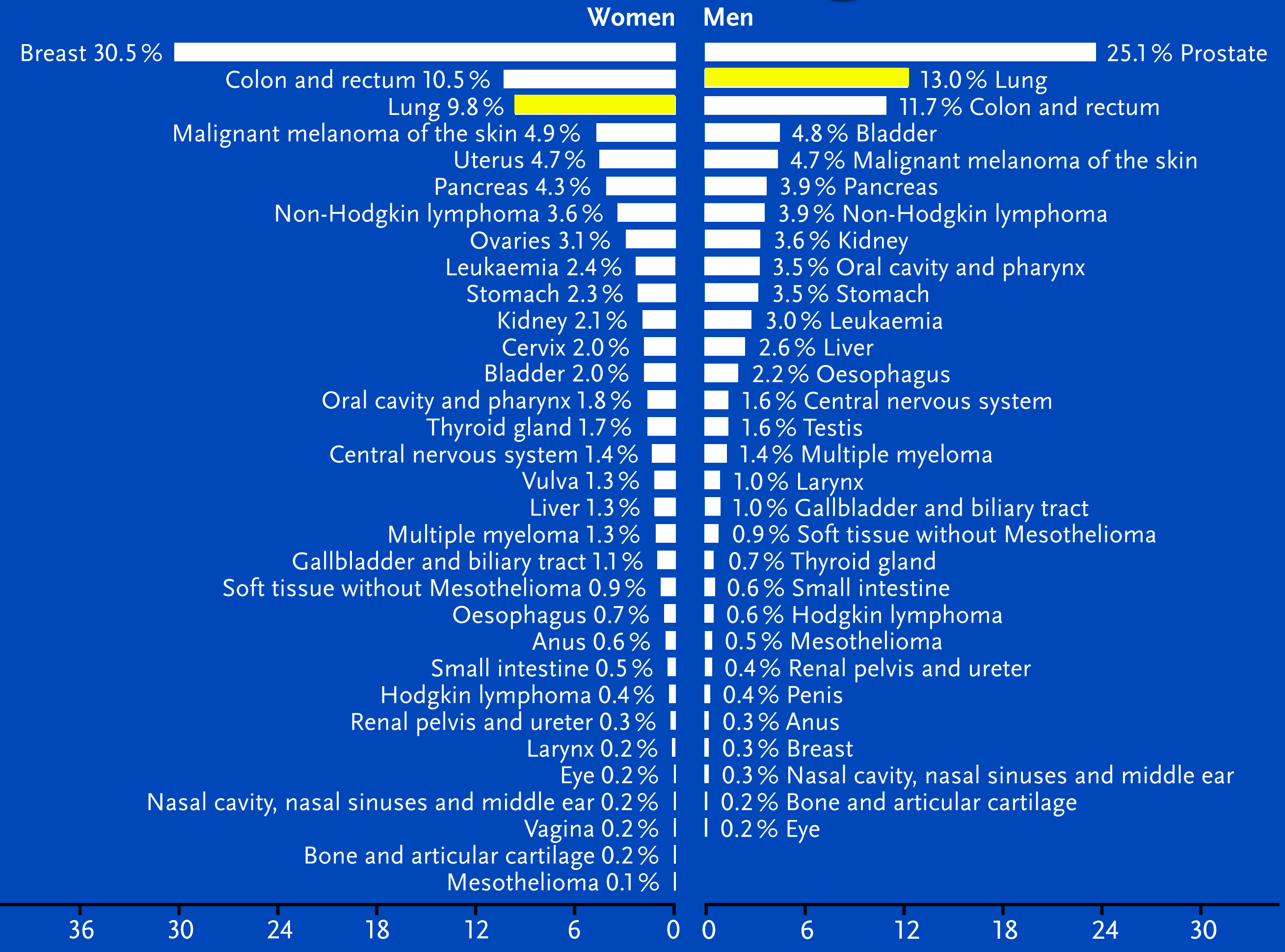
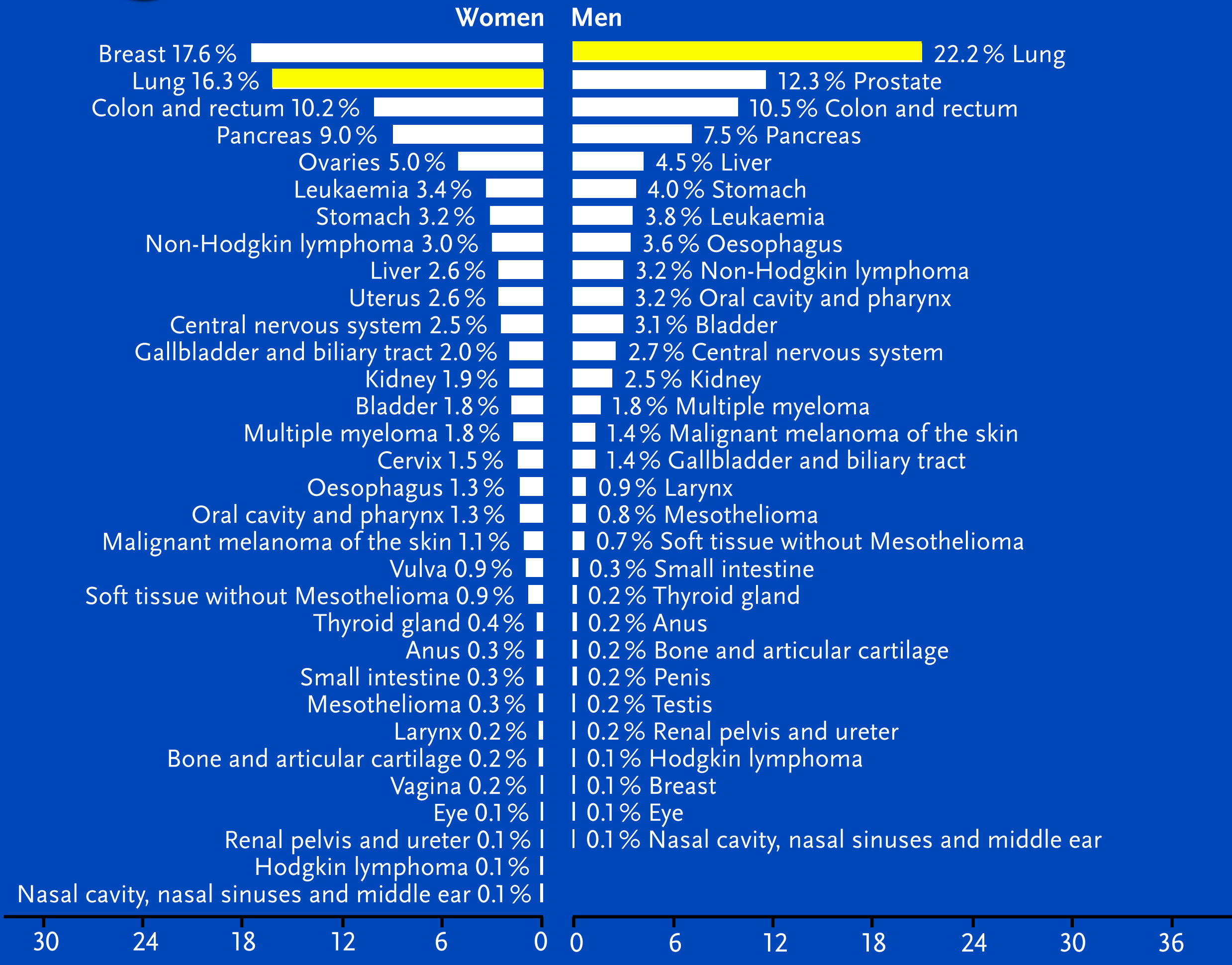
DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Lung Cancer – Significance





Most frequent tumour sites as percent of all incident cancer cases in Germany 2020. Adapted from.

Most frequent tumour sites when cancer was cause of death in Germany 2020. Adapted from.

Zentrum für Krebsregisterdaten, “Cancer in Germany 2019/2020”, Cancer in Germany, page 14-21. (2020)

Low Dose CT Screening – Trial Results

Benefits:

- **Early detection leads to more effective treatment**
- **Reduction in lung cancer mortality**
- **15% relative reduction in lung cancer mortality compared to chest X-ray**

Risks:

- **Cumulative exposure**
- **False positives**
- **Overdiagnosis**
- **Risk-Benefit: The benefits for high-risk populations outweigh the risks**

RCT	*N*	Comparison	$CTDI_{max}$
NLST USA	53,454	LDCT vs. chest X-ray	≈ 4 mGy*
NELSON Netherlands and Belgium	15,822	LDCT vs. no screening	0.8, 1.6, 3.2 mGy
DLCST Denmark	4,104	LDCT vs. no screening	?
LUSI Germany	4,052	LDCT vs. no screening	?
MILD Italy	4,099	Annual vs. biennial LDCT	?

***Larke, F.J. et al. "Estimated radiation dose associated with low-dose chest CT of average-size participants in the National Lung Screening Trial". AJR (2011).**

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Technical Demands by the BfS

Parameter	Requirement	Comment
Dose conversion	k = 0.019 mSv/mGy/cm	$D_{eff} = k \cdot \text{DLP}$
Topogram CTDI	≤ 20% of screening CTDI	Use additional prefilter
Scan length	Adapt to lung	Not longer than lung
Scan time	≤ 15 s	Breath hold required
Spiral pitch value	According to vendor	Moderate to high
Rotation time	≤ 1 s	
Screening CTDI dose cap	≤ 1.3 mGy	For BMI = 26 kg/m^2
Additional prefilter	Yes	At least for BMI ≤ 40 kg/m^2
TCM, auto kV-selection	Yes	TCM in α and z
Dynamic collimation	Yes, if at least 64 detector rows	To avoid overbeaming
Reconstruction	Iterative or deep learning	
Spatial resolution	Between 0.8 and 1.0 mm	For low contrasts (150 HU)
Slice thickness	≤ 0.7 mm	
Voxel size (isotropic)	≤ 70% of spatial resolution	
Image noise	Low enough to be diagnostic	
Exposure parameters and dose levels are to be adapted to patient size!		

Bundesamt für Strahlenschutz. “Lungekrebsfrüherkennung mittes Niedrigdosis Computertomographie”. Bundesanzeiger (2021).

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BMI – A Representative Patient Size Metric for Phantom Assessments?

1.3 mGy CTDI$_{vol}$ dose cap for a reference patient with a BMI of 26 kg/m^2.

QRM thorax phantom

$$\text{BMI} = \frac{\text{Mass}}{\text{Height}^2} = \frac{2.7\ \text{kg}}{(0.1\ \text{m})^2} = 270\frac{\text{kg}}{\text{m}^2}$$

Aim

To use our semiantropomorphic thorax phantom for QA, the phantom must be connected with patient size properties (the BfS' 26 kg/m^2).

We do this by:

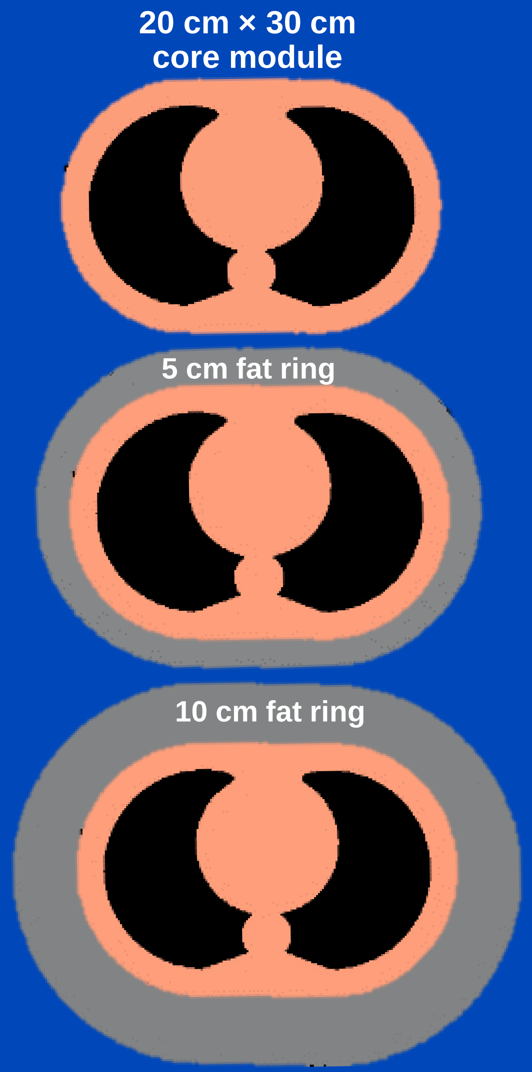
1. Determining the equivalent BMI of a thorax phantom such that the phantom with equivalent BMI of that of a patient yield similar image quality.
2. Evaluating how the recommended $CTDI_{vol}$ dose cap should be adapted for patients with varying BMIs in lung cancer scans.
3. Identifying a metric for varying patient and phantom sizes that can be used to estimate the necessary $CTDI_{vol}$ to achieve a desired image quality.

Patient and Phantom
Acquisition and Reconstruction Parameters

Dataset	Patients	Phantoms
Number of scans	100	9
Voltage	100 or 120 kV	120 kV
Pitch	0.6 or 1.2	1.2
Collimation	64 · 0.6 mm	
CT-Model	Somatom Definition Flash	
$CTDI_{vol}$	0.5 mGy – 14 mGy	1.0 mGy, 1.3 mGy, 1.6 mGy
Reconstruction type	FBP/ Safire 3	FBP/ Safire 3
Voxel size	0.3 mm	
Viewing thickness	3.0 mm	
Kernel	Bl57	

Acquisition: Voltage, Pitch, Collimation, CT-Model, $CTDI_{vol}$

Reconstruction: Reconstruction type, Voxel size, Viewing thickness, Kernel



Manual Dose Adaption

- For FBP, noise is influenced by patient size and tube output.

‘size’

Dose necessary for $\sigma = \sigma_{\mathrm{ref}}$

$$\sigma^2 \propto \frac{e^{\mu \cdot D}}{\mathrm{CTDI_{vol}}} \longrightarrow \mathrm{CTDI}^{\mathrm{rel}}_{\mathrm{vol}} \propto e^{\mu \cdot D} \qquad \mathrm{CTDI}^{\mathrm{rel}}_{\mathrm{vol}} \equiv \frac{\mathrm{CTDI_{vol}}}{\mathrm{mGy}} \cdot \frac{\sigma^2}{\sigma^2_{\mathrm{ref}}}$$

’tube output’

- The necessary dose output $\mathrm{CTDI}^{\mathrm{rel}}_{\mathrm{vol}}$ to achieve image quality σ_{ref} is then:

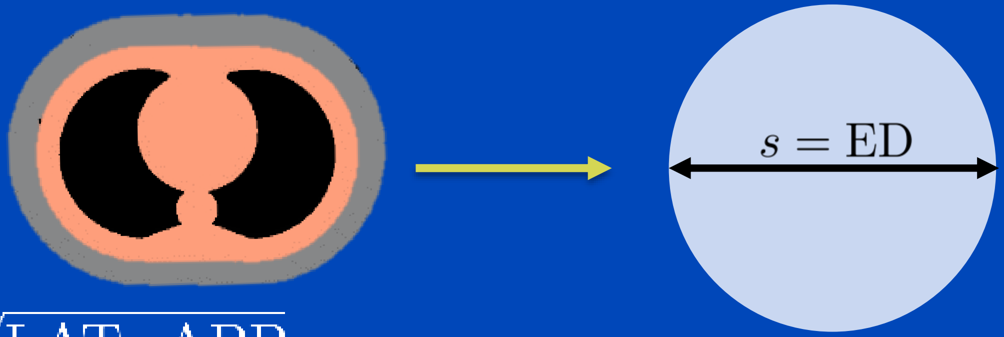
$$\log \mathrm{CTDI}^{\mathrm{rel}}_{\mathrm{vol}} \propto s$$

length in units cm

attenuation

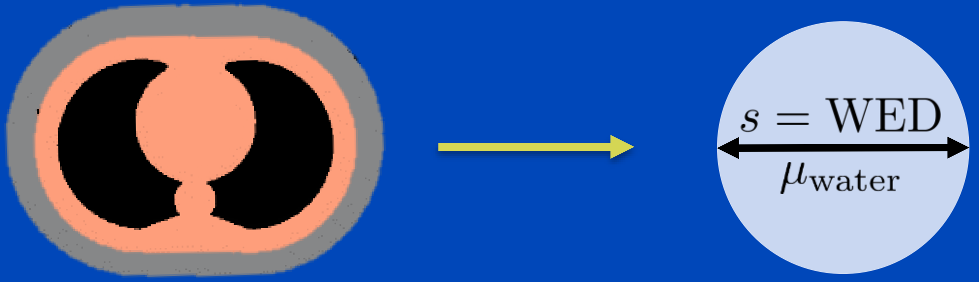
Example Surrogate for Size s

- **Effective diameter (ED):**
  Diameter of a circle with equivalent area



$$\mathrm{ED} = \sqrt{\mathrm{LAT} \cdot \mathrm{APP}}$$

- **Water-equivalent diameter (WED):**
  Diameter of a circle with $\mu(x, y) = \mu_{water}$ of equivalent mean attenuation

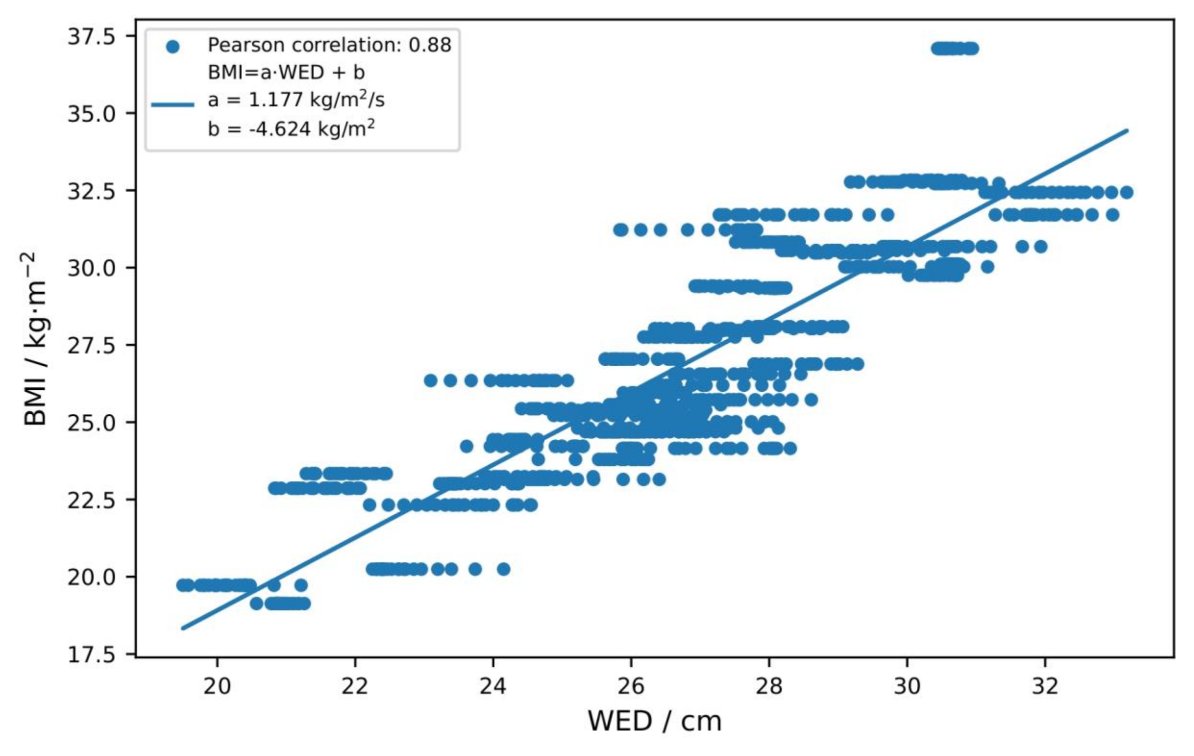


LAT = lateral diameter
AP = anterior-posterior diameter

$$\mathrm{WED} = 2 \cdot \sqrt{\left(\frac{1}{1000\ \mathrm{HU}} \frac{\sum_{\mathrm{ROI}} \mathrm{CT}(x,y)}{N_{\mathrm{ROI}}} + 1\right) \cdot \frac{A_{\mathrm{ROI}}}{\pi}}$$

Boone et al. “Size-Specific Dose Estimates (SSDE) in pediatric and adult body CT examinations”. AAPM (2011).
McCoullough et al. “Use of Water Equivalent Diameter for Calculating Patient Size and Size–Dependent Dose Estimates (SSDE) in CT”. AAPM (2014).

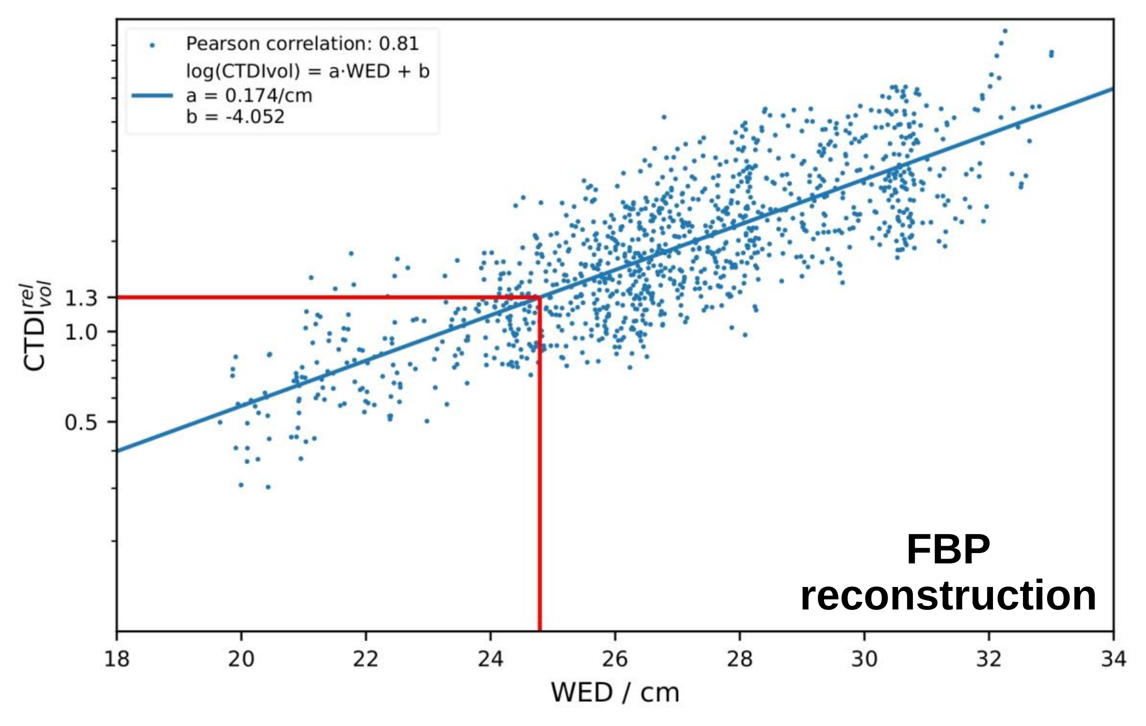
Calibration Curve: BMI as a Function of WED

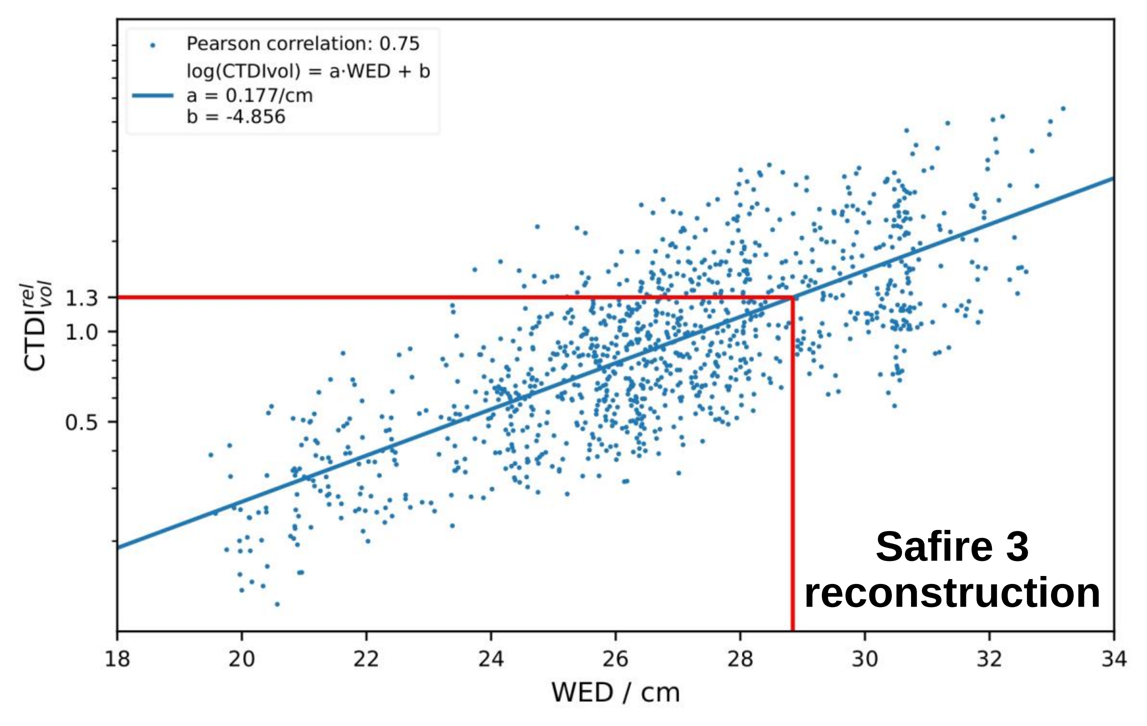


Phantom size	**WED**	**BMI** (from linear fit)
Small	20.6 cm	19.6 kg/m^2
Medium	26.7 cm	26.8 kg/m^2
Large	32.4 cm	33.5 kg/m^2

Calibration curve between the WED and the BMI based on 100 patients.

CTDI as a Function of WED to Achieve a Given Image Noise (here: 70 HU)





Phantom size	WED	Equivalent BMI	CTDI for FBP	CTDI for Safire 3
Small	20.6 cm	19.6 kg/m^2	0.63 mGy	0.30 mGy
Medium	26.7 cm	26.8 kg/m^2	1.81 mGy	0.88 mGy
Large	32.4 cm	33.5 kg/m^2	4.88 mGy	2.41 mGy

Correlation between the WED and the required CTDI$_{vol}$ (log-scale) to achieve 70 HU image noise in lung scans.

Conclusions and Outlook

- Size in CT-based lung scans and needs to be properly accounted for.
- Assuming the attenuation based WED the dose to achieve a 70 HU image noise can be estimated by

If reconstructed using FBP

$$\mathrm{CTDI}_{\mathrm{vol}}^{\mathrm{rel}} = \exp\left(\frac{0.174}{\mathrm{cm}} \cdot \mathrm{WED} - 4.052\right)$$

If reconstructed using Safire 3

$$\mathrm{CTDI}_{\mathrm{vol}}^{\mathrm{rel}} = \exp\left(\frac{0.177}{\mathrm{cm}} \cdot \mathrm{WED} - 4.856\right)$$

- For phantom assessments, the equivalent ‘BMI’ can be estimated by comparison of WED with BMI.

$$\mathrm{BMI} = \frac{1.177\ \mathrm{kg}}{\mathrm{m}^2\ \mathrm{s}}\ \mathrm{WED} - 4.624\frac{\mathrm{kg}}{\mathrm{m}^2}$$

Thank You!

- This presentation will soon be available at www.dkfz.de/ct.
- Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (marc.kachelriess@dkfz.de).
- Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.