CT Requirements for Lung Cancer Screening (LCS)

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DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Why Bother about Dose?

- Screening population is mainly healthy – most participants do not have lung cancer.
- Lung cancer grows quickly. Screening needs to be repeated, e.g. annually.
- Participants thus undergo 20 to 30 screening CT scans in their life.
- Cumulative dose is relevant. Dose of a single screening scan must be very low.

Facts about annual effective dose

- D_{eff} due to natural radiation
  - 2.1 mSv in Germany
  - 3.2 mSv in Europe
  - 3.1 mSv in the US
- Occupational D_{eff} limit
  - 20 mSv in Europe
  - 50 mSv in the US

Germany, as an Example

Bundesanzeiger

Herausgegeben vom
Bundesministerium der Justiz
und für Verbraucherschutz

www.bundesanzeiger.de

Bekanntmachung

Veröffentlicht am Montag, 6. Dezember 2021
BAnz AT 06.12.2021 B4
Seite 1 von 142

BfS = Federal Office for Radiation Protection (Germany)

Bundesamt
für Strahlenschutz

Bericht

Lungenkrebsfrüherkennung mittels Niedrigdosis-Computertomographie

**Wissenschaftliche Bewertung
des Bundesamtes für Strahlenschutz
gemäß § 84 Absatz 3 Strahlenschutzgesetz**

Other countries likely have somewhat different regulations/recommendations.

BfS Group of External Experts

Prof. Dr. Gerald Antoch	Universitätsklinikum Düsseldorf
Prof. Dr. Peter Bartenstein	Klinikum der Universität München
Prof. Dr. Stefan Delorme	Deutsches Krebsforschungszentrum
Prof. Dr. Joachim Ficker	Klinikum Nürnberg
Prof. Dr. Rudolf Kaaks	Deutsches Krebsforschungszentrum
Prof. Dr. Marc Kachelrieß	Deutsches Krebsforschungszentrum
Prof. Dr. Hans-Ulrich Kauczor	Universitätsklinikum Heidelberg
Dr. Belinda Martschinke	Verband der privaten Krankenversicherung e.V.
Prof. Dr. Michael Pfeifer	Klinik Donaustauf
Prof. Dr. Mathias Prokop	Radboud University Nijmegen
PD Dr. Niels Reinmuth	Asklepios Fachkliniken München-Gauting
Prof. Dr. Stefan Sauerland	Institut für Qualität und Wirtschaftlichkeit im Gesundheitswesen
Prof. Dr. Erich Stoelben	Kliniken der Stadt Köln gGmbH
	Der Gemeinsame Bundesausschuss war durch eine Vertreterin der Geschäftsstelle bei den Sitzungen der Sachverständigengruppe vertreten.

Epidemiology – Nuclear Medicine – Physics – Pneumology – Radiology + Health Insurance

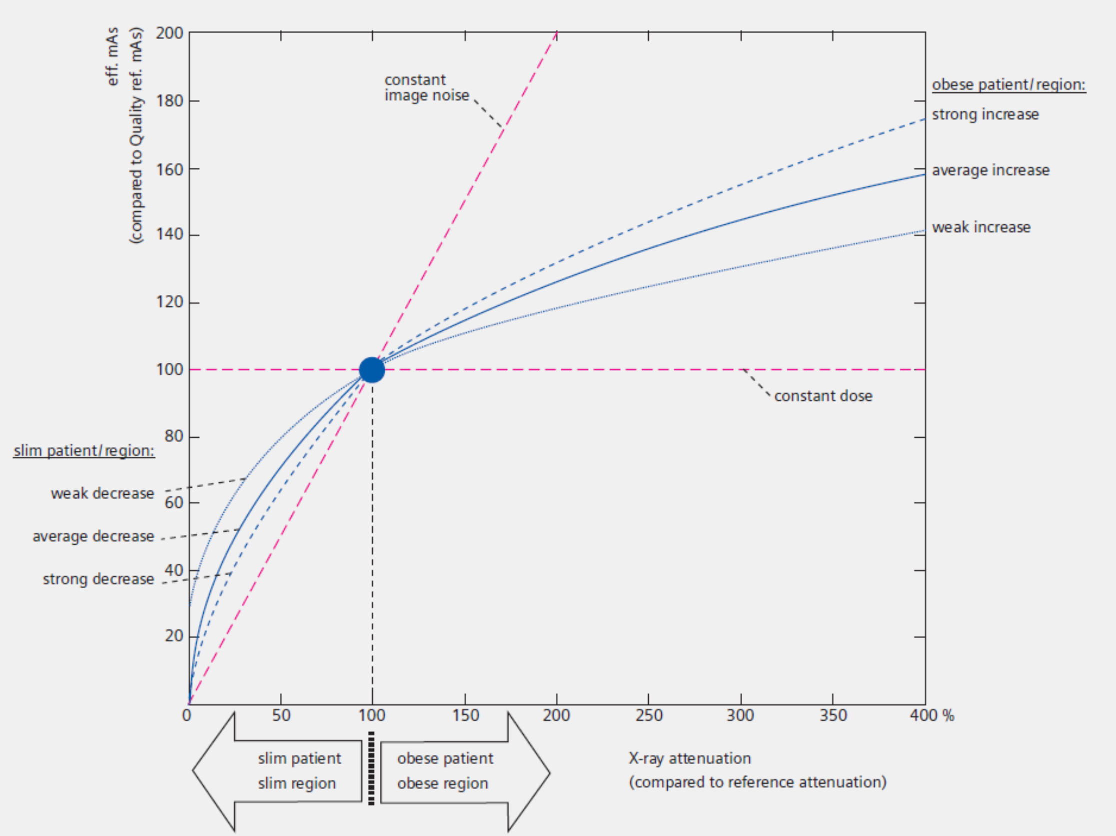
Technical Demands According to BfS

Parameter	Requirement	Comment
Dose conversion	k = 0.019 mSv/mGy/cm	$D_{eff} = k \cdot \mathrm{DLP}$
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	≤ 1.3 mGy	For BMI = 26 kg/m^2
Additional prefilter[1]	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 (50 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 be adapted to patient size!

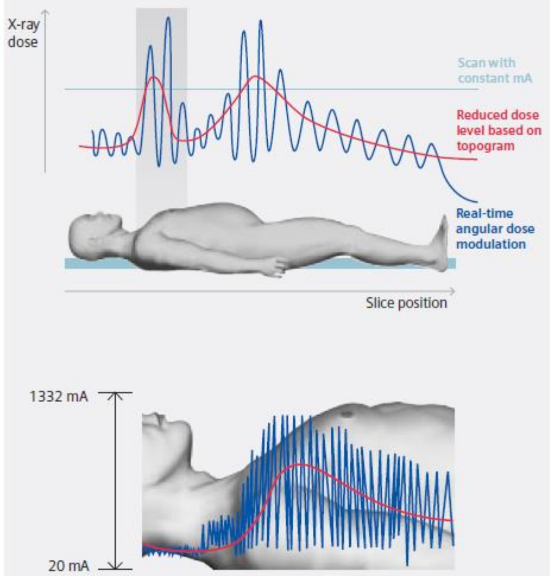
[1]Prefilter that can be adjusted to patient size, e.g. removable for large patients.

Effect of Modulation Strengths on Radiation Dose for Slim and Obese Patients



[1] *The sophisticated algorithm provides desired image quality for all patients, slim to obese. Individual preferences on tube current increase and decrease can be realized by choosing strong, moderate or weak.*

CT-Scan With CARE Dose4D

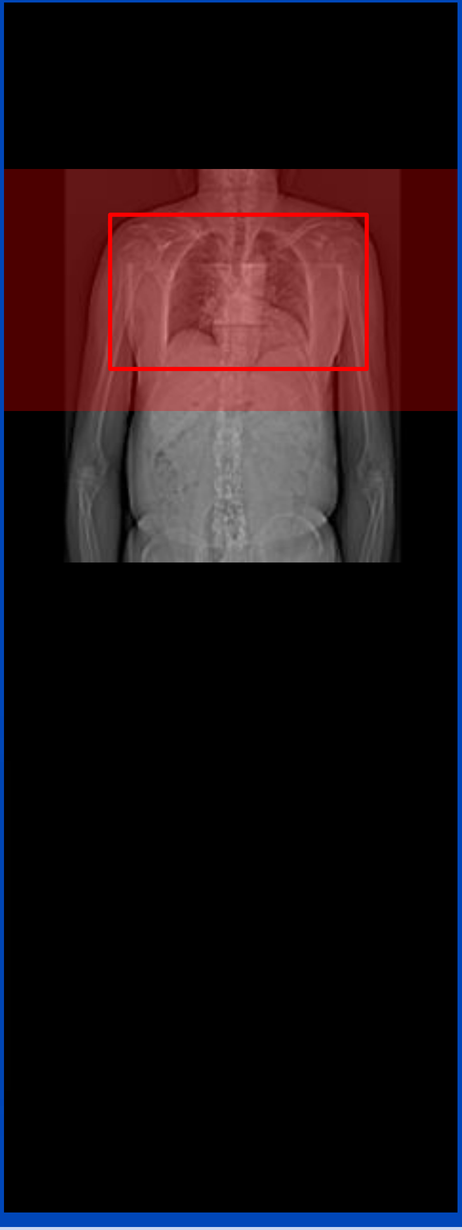


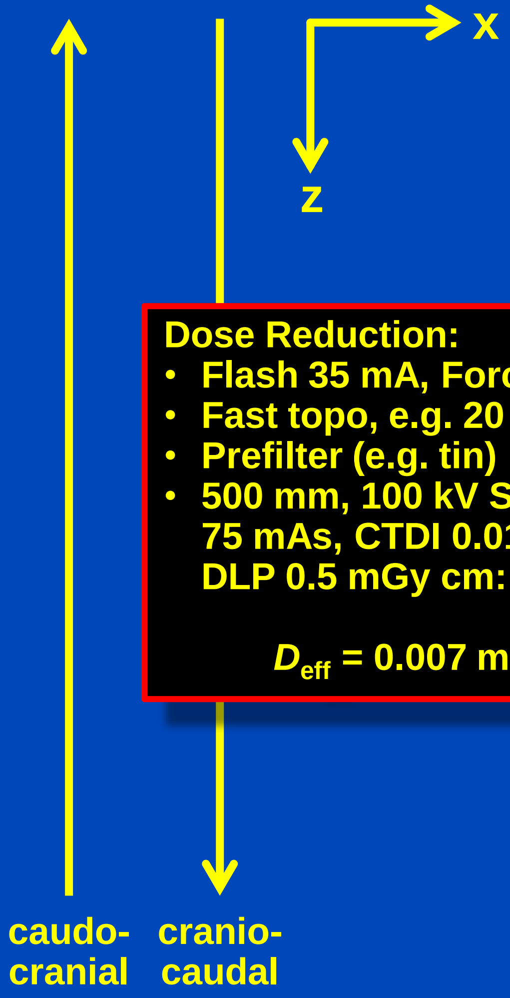
[3] *Instead of just taking into account the patient's external dimensions and apparent size, CARE Dose4D analyzes the cross-secional anatomy in real-time and adjust the emitted X-ray dose accordingly – providing excellent image quality with minimized exposure.*

Topogram (a.p. view)

Dose consideration:
- 10 cm/s table speed and 6×0.6 mm collimation imply 36 ms exposure per z-position.
- At 120 kV and 6×0.6 mm the Flash 32 cm CTDI is 11 mGy/100 mAs.
- With 35 mA tube current and 36 ms exposure we obtain 1.3 mAs and 0.14 mGy CTDI.
- Assume a scan length of 50 cm to get DLP = 7 mGy cm.
- With k = 0.014 mSv/mGy/cm (chest) we obtain an effective dose of 0.1 mSv.

Protocol type	Head	Adult body	Child body
Shaped filter	Standard	Standard	Narrow
Phantom size	Ø 16 cm	Ø 32 cm	Ø 32 cm
	$CTDI_{vol}$ µGy/mA	$CTDI_{vol}$ µGy/mA	$CTDI_{vol}$ µGy/mA
70 kV	1.7	0.7	0.6
80 kV	2.6	1.2	0.9
100 kV	5.2	2.4	2.0
120 kV	8.3	4.0	3.3
140 kV	11.9	5.8	5.1





Dose Reduction:
- Flash 35 mA, Force 20 mA
- Fast topo, e.g. 20 cm/s
- Prefilter (e.g. tin)
- 500 mm, 100 kV Sn, 75 mAs, CTDI 0.01 mGy, DLP 0.5 mGy cm:

$$D_{\text{eff}} = 0.007 \text{ mSv}$$

mSv $\leftrightarrow$ CTDI$_{vol}$

- **DLP = CTDI$_{vol}$ × ScanLength**
- **D_{eff} = DLP × k mit k = 0.019 mSv/mGy/cm**
- **The typical scan length for lung scans is around 25 cm.**
- **Then, CTDI = 1 mGy yields**
  D_{eff} = 1 mGy · 25 cm · 0.019 mSv/mGy/cm = 0.48 mSv

- **Rough rule of thumb for lung scans:**

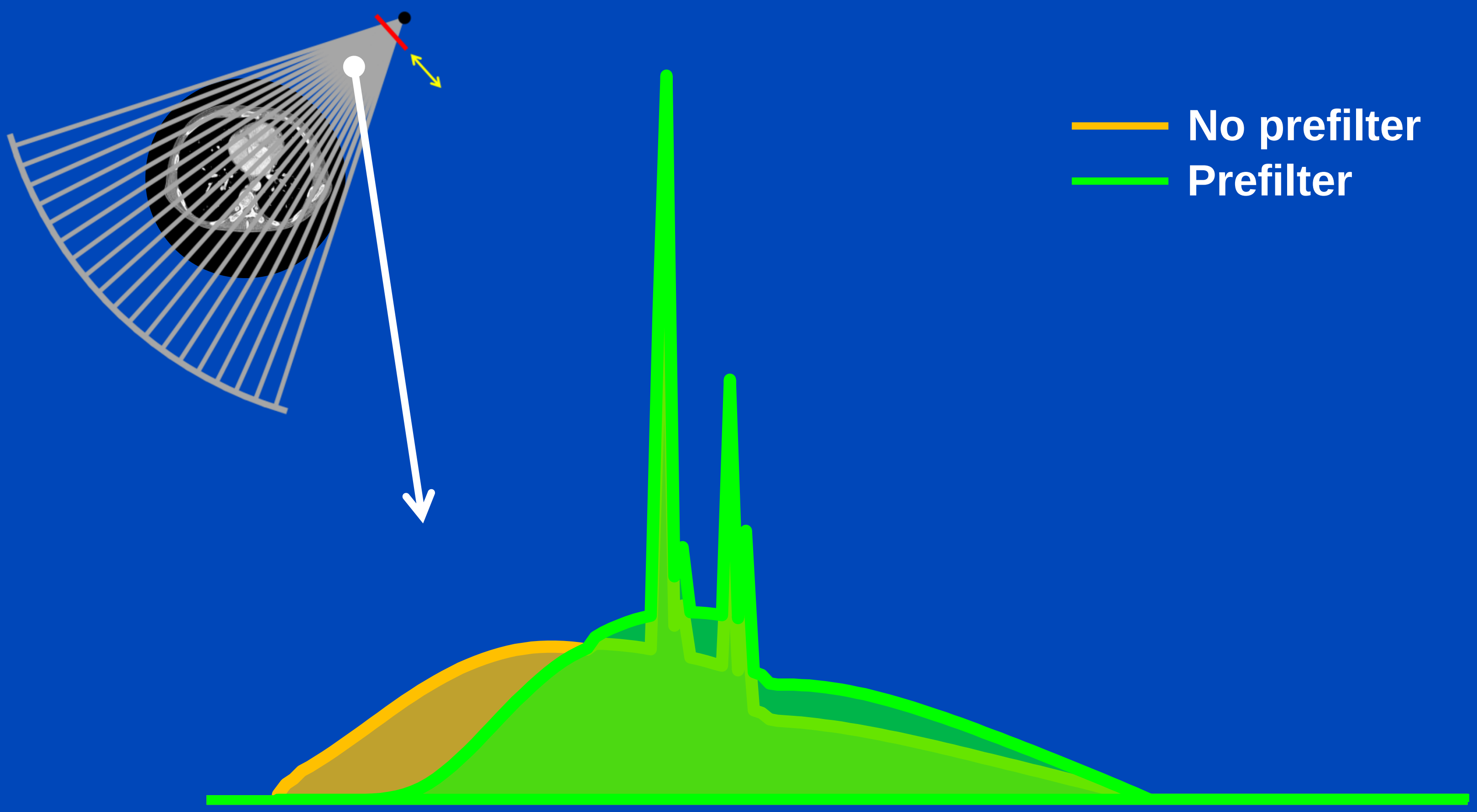
  CTDI$_{vol}$ ≈ 2 D_{eff} mGy/mSv

  i.e.

  2 mGy ≈ 1 mSv

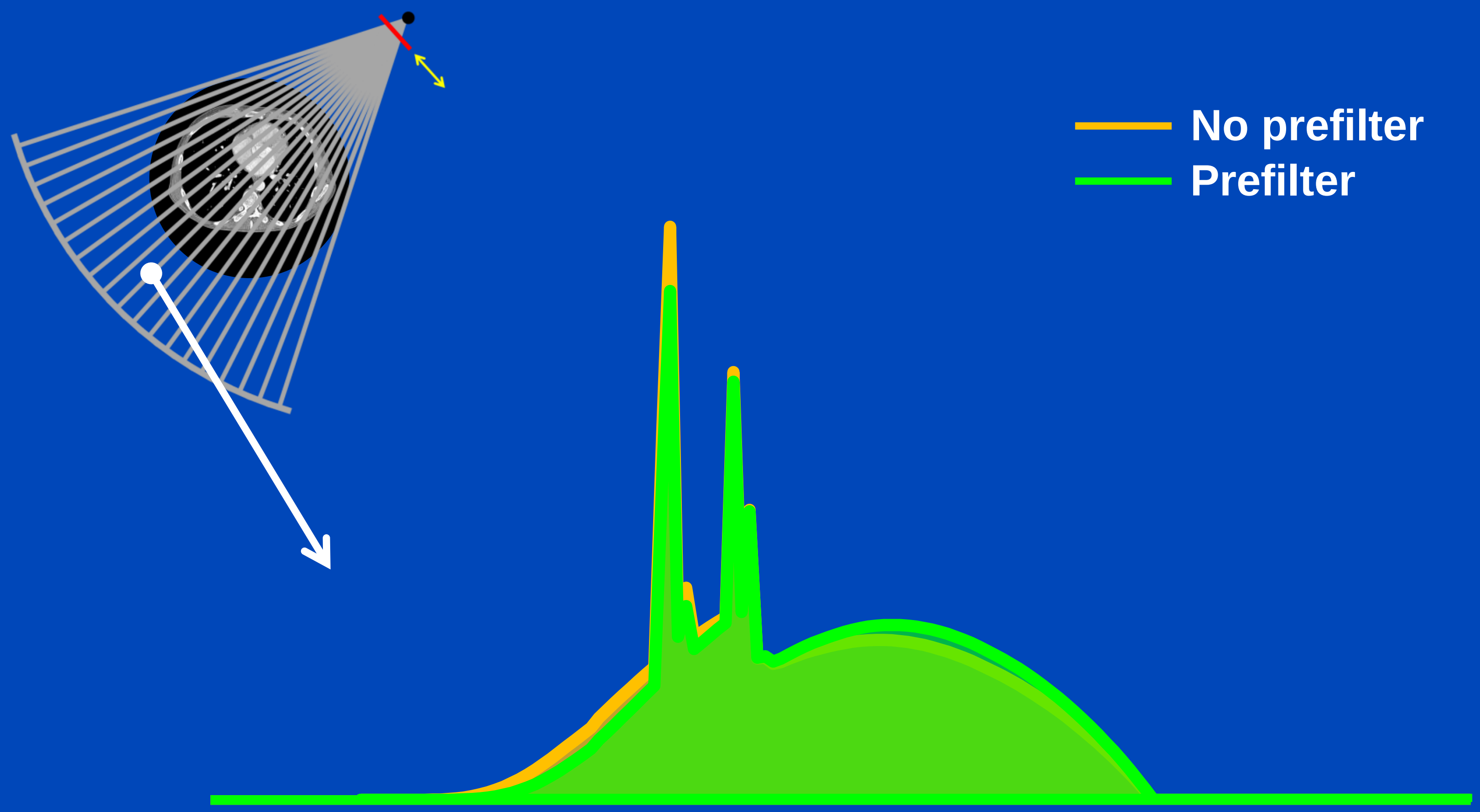
  for lung only scans.

120 kV + 0 mm water with and without prefilter



dkfz.

120 kV + 320 mm water with and without prefilter



Reference	Topic	Dose Reduction	Assessment	Recon
Agostini et al., 2021	chest, DECT, COVID-19	89%	subjective, different pitch values	iterative
Apfaltrer et al., 2018	coronary artery calcium scoring	73%	subjective	FBP
Axer et al., 2022	urolithiasis	20%	subjetive	iterative
Dewes et al., 2016	abdomen, urinary stones	22%	subjective	iterative
Gordic et al., 2014	chest, pulmonary nodules, phantom	95%	subjective	iterative
Grunz et al., 2022	urinary stone	18% - 38%	subjective, objective	iterative
Hasegawa et al., 2022	chest, detectability index, phantom	22% - 25%	objective	FBP
Jeon et al., 2019	DECT, gout diagnosis	65%	subjective, different scanners	iterative
Kimura et al., 2022	colorectal cancer	89%	subjective	iterative, FBP
Kunz et al., 2022	urinary tract	62%	frequency of calculi detection	iterative
Leyendecker et al., 2019	abdomen	81%	subjective, objective	iterative
Martini et al., 2016	chest, pulmonary nodules	97%	subjective	iterative
Rajendran et al., 2020	sinus, temporal bone	67% - 85%	objective, EICT and PCCT	FBP
Saltybaeva et al., 2019	topogram	80%	effect on TCM	-
Schabel et al., 2018	thoracic aorta calcification	92%	subjective	iterative
Schüle et al., 2022	pelvis	90%	subjective, objective	iterative, FBP
Takemitsu et al., 2022	topogram	80%	effect on TCM	-
Weis et al., 2017	chest, pediatric	77%	subjective, objective	iterative
Wuest et al., 2016	paranasal sinus	73%	subjective, different scanners	FBP
Zhang et al., 2022	guided lung biopsy	73%	subjective	iterative

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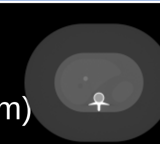
- Schüle, Simone, et al. "Low-dose CT imaging of the pelvis in follow-up examinations-significant dose reduction and impact of tin filtration: Evaluation by phantom studies and first systematic retrospective patient analyses." *Investigative Radiology* 57(12):789-801, 2022.

Dose Reduction by Patient-Specific Tin or Copper Prefilters[1] (1000 mAs Limit)

	Child (15 cm × 10 cm) 	**Adult** (30 cm × 20 cm) 	**Obese** (50 cm × 40 cm) 
Soft tissue (basis)	3 mAs, 90 kV	10 mAs, 130 kV	60 mAs, 150 kV
Sn, 0.4 mm	0.4 mm, 34 mAs, 75 kV **11%**	0.4 mm, 74 mAs, 100 kV **25%**	0.4 mm, 140 mAs, 150 kV **35%**
Sn, 0.6 mm	0.6 mm, 100 mAs, 75 kV **15%**	0.6 mm, 100 mAs, 105 kV **29%** 0.5 mGy CTDI	0.6 mm, 160 mAs, 150 kV **40%**
Sn, optimal thickness	0.9 mm, 1000 mAs, 70 kV **17%**	2.0 mm, 1000 mAs, 105 kV **35%**	2.2 mm, 1000 mAs, 150 kV **50%**
Cu, optimal thickness	3.0 mm, 1000 mAs, 70 kV **17%**	6.7 mm, 1000 mAs, 105 kV **31%**	6.9 mm, 1000 mAs, 150 kV **50%**

Literature reports 20% to 80% to be clinically achievable with Sn.

Patient-specific, i.e. removable, prefilters provided by vendors:
- **Canon: Ag**, maybe 0.5 mm
- **GE: none**, but 1 mm Cu is said to be used for topograms
- **Philips: none**
- **Siemens: 0.4 mm, 0.6 mm, and 0.7 mm (in different systems)**

[1]Steidel, Maier, Sawall, Kachelrieß. Dose reduction potential in diagnostic single energy CT through patient-specific prefilters and a wider range of tube voltages. Med. Phys. 49(1):93-106, 2022.

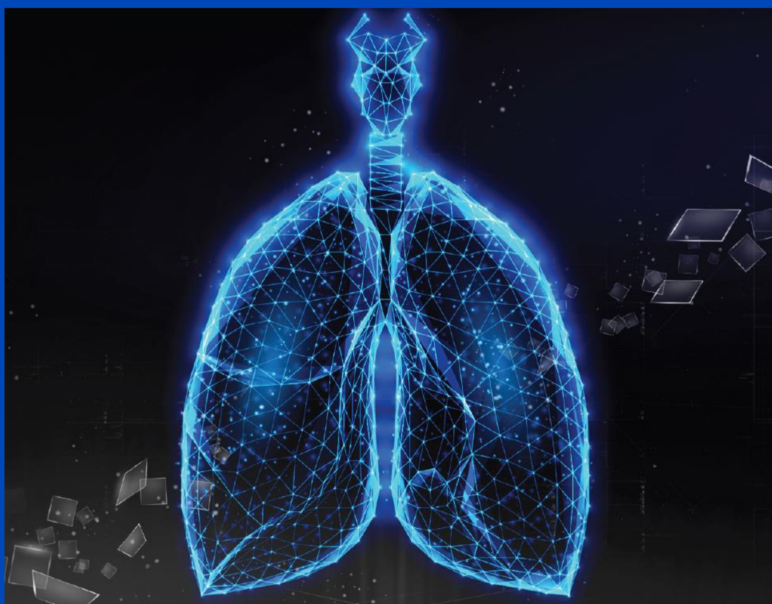
Removable Prefilters in Use Today

- 0.4 mm Sn for Siemens‘ Somatom Flash, Drive, go.Now, go.Up and go.all
- 0.6 mm Sn for Siemens‘ Somatom Force, Edge Plus, go.Top and Definition Edge
- 0.4 mm and 0.7 mm Sn for Siemens‘ Somatom X.cite
- ≈ 0.5 mm Au for Canon‘s Aquilion ONE Prism Edition
- ≈ 1 mm Cu for topograms only (!) in GE‘s Revolution Apex systems

High-End and Mid-Range CT, 2023

CT-System	Rotation, Cone, Coll.	Max. Power, Anode Angle, Name, Max. mA @ low kV	Patient-specific prefilters	Detector Configuration, Type, Name	FOM, Reconstruction Matrix	Special Reconstruction Algorithms	Spectral	
Canon Aquilion ONE Prism Edition	0.275 s, 15°, 160 mm	100 kW, 10°, MegaCool Vi, 600 mA @ 80 kV	**Ag, {0, *x*} mm**	320 × 0.5 mm, EI, PUREViSION	50 cm, 512	iterative (AIDR 3D), deep (AiCE, PIQE)	fast TVS with DL	H
Canon Aquilion Precision Edition	0.35 s, 3.8°, 40 mm	72 kW, 7°, MegaCool, 600 mA @ 80 kV	none	160 × 0.25 mm, EI, PUREViSION	50 cm, 512, 1024, 2048	iterative (AIDR 3D), deep (AiCE)	2 scans	H
GE Revolution Apex Elite	0.23 s, 15°, 160 mm	108 kW, 10°, Quantix 160, 1300 mA @ 70+80 kV	none	256 × 0.625 mm, EI, GemStone Clarity	50 cm, 512		fast TVS or 2 scans	H
GE Revolution Apex Plus	0.28 s, 7.6°, 80 mm	108 kW, 10°, Quantix 160, 1300 mA @ 70 kV	none	128 × 0.625 mm, EI, GemStone Clarity	50 cm, 512	deep (TrueFidelity), SnapshotFreeze	fast TVS or 2 scans	M
Philips Spectral CT 7500	0.27 s, 7.7°, 80 mm	120 kW, 8°, iMRC, 925 mA @ 80 kV	none	2 · 128 × 0.625 mm, EI, NanoPanel Prism	50 cm, 512, 768, 1024	iterative (iDose)	sandwich	H
Philips Incisive CT	0.35 s, 3.9°, 40 mm	80 kW, vMRC	none	2 · 64 × 0.625 mm, EI	50 cm, 512, 768, 1024	iterative (iDose), deep (Precise Image&Cardiac)		M
Siemens Somatom X.ceed	0.25 s, 3.7°, 38.4 mm	120 kW, 8°, Vectron, 1300 mA @ 70+80+90 kV	**Sn, {0, 0.4, 0.7} mm**	2 · 64 × 0.6 mm, EI, Stellar	50 cm, 512, 768, 1024	iterative (ADMIRE)	split filter (Twin Beam) or 2 scans (Twin Spiral)	M
Siemens Somatom Force	0.25 s, 5.5°, 57.6 mm	2 · 120 kW, 8°, Vectron, 2 · 1300 mA @ 70+80+90 kV	**Sn, {0, 0.6} mm**	2 · 2 · 96 × 0.6 mm, EI, Stellar	50 cm/35 cm, 512, 768, 1024	iterative (ADMIRE)	DSCT	H
Siemens Naeotom Alpha	0.25 s, 5.5°, 57.6 mm	2 · 120 kW, 8°, Vectron, 2 · 1300 mA @ 70+90 kV	**Sn, {0, 0.4, 0.7} mm**	2 · 144×0.4 or 2 · 120×0.2 mm, PC	50 cm/36 cm, 512, 768, 1024	iterative (QIR)	DSCT and PCCT	H

Canon now also likes Patient-Specific Prefilters: SilverBeam



"Now, we are able to offer ultra-low dose chest for lung cancer screening. That's a game-changer!"

Dr. Marcus Chen, Director of Cardiothoracic Imaging at the National Institutes for Health (NIH), Maryland, US.

… and they use this technique to replace the topogram by an ultra low dose spiral scan.

What about GE?

- GE does not yet admit that they like the filters.
- They propose to use Cu for topograms (scout is now smart scout) to preheat the tube.

Radiation Protection Dosimetry (2022), Vol. 198, No. 6, pp. 334–338
Advance Access publication 22 April 2022
https://doi.org/10.1093/rpd/ncac057

PHANTOM STUDY OF THE ENTRANCE SURFACE DOSE OF A NEW CT SCOUT ACQUISITION THAT ALSO SERVES AS A TUBE WARM-UP

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Received 9 August 2021; revised 1 March 2022; editorial decision 28 March 2022; accepted 28 March 2022

How did we arrive at these demands?

- Literature review showed good and bad examples (next slides).
  - Diagnostic image quality must be guaranteed!
  - Thus dose limit must not be too restrictive.
- Projecting the NLST trial to Germany and assuming 50% participation[1] yields about 1,300,000 additional CT scans per year.
  - Availability of sufficiently many CT systems must be guaranteed!
  - Thus technical demands must not be too restrictive.

Comments:

- Considering only high end CT systems, the demands could be much stricter (e.g. 0.2 mGy for the reference patient).
- Demands will be continuously adapted, e.g.
  - Lower dose values (significantly less than 1.3 mGy)
  - Patient-specific prefilters required (and not only recommended)
  - More patient-specific prefilters (e.g. more than one thickness selectable)
  - Breast-specific TCM required (and not only recommended)

[1]Value taken from German mammography screening program.

dkfz.

European Journal of Radiology 91 (2017) 130–141

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Prospective intra-individual comparison of standard dose versus reduced-dose thoracic CT using hybrid and pure iterative reconstruction in a follow-up cohort of pulmonary nodules—Effect of detectability of pulmonary nodules with lowering dose based on nodule size, type and body mass index

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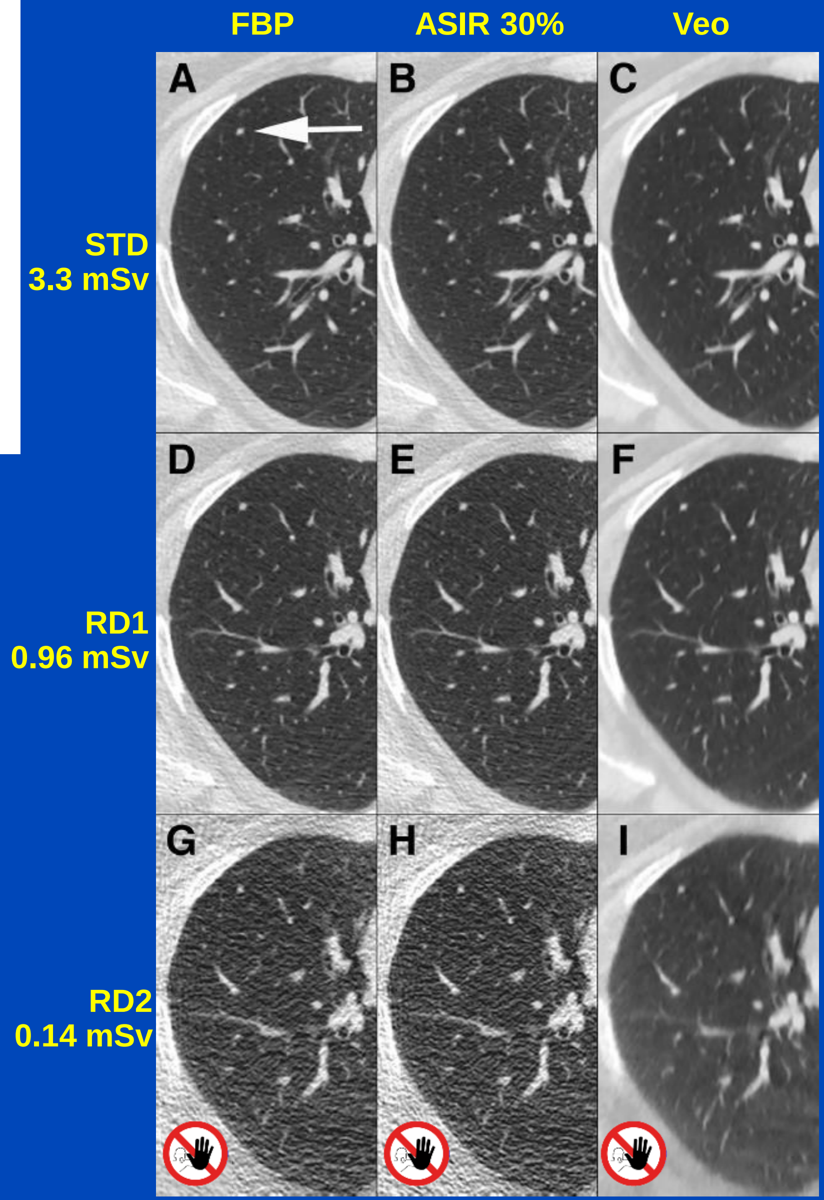
Radiation doses as per protocol.

	CTDI Vol (mGy)	DLP (mGy-cm)	SSDE (mGy)	Effective Dose (mSv)
STD	6.6 ± 2.6	235.4 ± 90.1	7.4 ± 2.5	3.30 ± 1.26
RD1	2.0 ± 1.5	68.7 ± 51.4	2.1 ± 1.5	0.96 ± 0.72
RD2	0.3 ± 0.01	9.9 ± 0.9	0.3 ± 0.1	0.14 ± 0.01

CTDIvol-CT Dose Index Volume; DLP-Dose Length Product; SSDE-Size-specific dose estimates; mGy-milliGray; mSv-milliSievert. STD-Standard dose; RD1-Reduced dose 1; RD2-Reduced dose 2.

Patients scanned 3 times.

All examinations were performed with a 64-row detector CT scanner (Discovery 750 HD; GE Healthcare, Wisconsin, USA). No intravenous contrast was given. Standard dose scan parameters were as follows: tube voltage 120, rotation time 0.5 s, pitch 1.375:1, noise index 39.6, tube current range 10–750 mA. Reduced-dose 1 (RD1) scan parameters were as follows: tube voltage 100, rotation time 0.5 s, pitch 1.375:1, noise index 85, tube current range 10–750 mA. Reduced-dose 2 (RD2) scan parameters were as follows: tube voltage 100, rotation time 0.5 s, pitch 0.984:1, fixed tube current 10 mA.



BMI = 33 kg/m²

Clinical Radiology 74 (2019) 409.e17–409.e22

Contents lists available at ScienceDirect

Clinical Radiology

journal homepage: www.clinicalradiologyonline.net

Lung nodules are reliably detectable on ultra-low-dose CT utilising model-based iterative reconstruction with radiation equivalent to plain radiography

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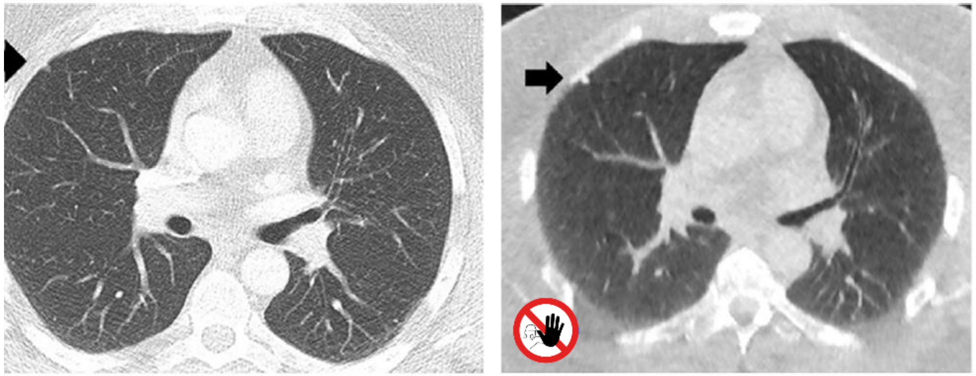

Figure 1 Nodules were clearly seen on both LD- (a) and ULD-CT (b) images.

- **GE, 100 kV < 80 kg, 120 kV > 80 kg**
- **ASIR for low dose, Veo for ultra low dose recons**
- **0.13 mSv ultra low dose CT**
- **Nodules 4 mm or larger**
- **Ultra low dose images are very blurry.**

Both the standard LD-CT and ULD-CT were performed at the same sitting. Each scan was performed with a single breath-hold on the CT750 HD scanner (GE Healthcare, Milwaukee, WI, USA). The following parameters were used for both the LD-CT and ULD-CT: 100 kVp (<80 kg) and 120 kVp (>80 kg), 40 mm collimation, 1.375 pitch, 0.4 second rotation speed. For the LD-CT, tube current was modulated to achieve target dose–length product (DLP) of 70 mGy.cm (<80 kg) or 105 mGy.cm (>80 kg), whereas 10 mA was used for ULD-CT.

AIM: To determine if ultra-low-dose (ULD) computed tomography (CT) utilising model-based iterative reconstruction (MBIR) with radiation equivalent to plain radiography allows the detection of lung nodules.

MATERIALS AND METHODS: Ninety-nine individuals undergoing surveillance of solid pulmonary nodules undertook a low-dose (LD) and ULD CT during the same sitting. Image pairs were read blinded, in random order, and independently by two experienced thoracic radiologists. With LD-CT as the reference standard, the number, size, and location of nodules was compared, and inter-rater agreement was established.

RESULTS: There was very good inter-rater agreement with regards nodules ≥4mm for both the LD- (k=0.931) and ULD-CT (k=0.869). One hundred and ninety-nine nodules were reported on the LD-CT by both radiologists and 196 reported on the ULD-CT, with no nodules reported only on the ULD-CT. This gives a sensitivity of 98.5% and specificity of 100% for ULD-CT with MBIR. The effective dose of radiation was significantly different between the two scans ($p<0.0001$), 1.67 mSv for the LD-CT and 0.13 mSv for the ULD-CT.

CONCLUSION: ULD-CT utilising MBIR and delivering radiation equivalent to plain radiography, allows detection of lung nodules with high sensitivity. The attendant 10-fold reduction in radiation may allow for dramatic reductions in cumulative radiation exposure.

Jpn J Radiol (2017) 35:179–189
DOI 10.1007/s11604-017-0618-y

ORIGINAL ARTICLE

Lung cancer screening with ultra-low dose CT using full iterative reconstruction

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	LDCT	ULDCT
CTDIvol (mGy)	3.01 (0.09)	0.30 (0.00)
DLP (mGy cm)	105.32 (8.51)	10.50 (0.78)
ED (mSv)	1.48 (0.12)	0.14 (0.01)
SSDE (mGy)	4.01 (0.28)	0.40 (0.03)

Data are the mean [standard deviation (SD)]

LDCT low-dose CT, *ULDCT* ultra-low-dose CT, $CTDI_{vol}$ volume CT dose index, *DLP* dose-length product, *ED* effective dose, *SSDE* size-specific dose estimate

- **Acquilion One (320 slice) 120 kV**
- **2 mm slice thickness and 2 mm increment**
- **FBP and FIRST (Forward projected model-based Iterative Reconstruction SoluTion)**
- **Patients scanned twice (Std+ULD)**

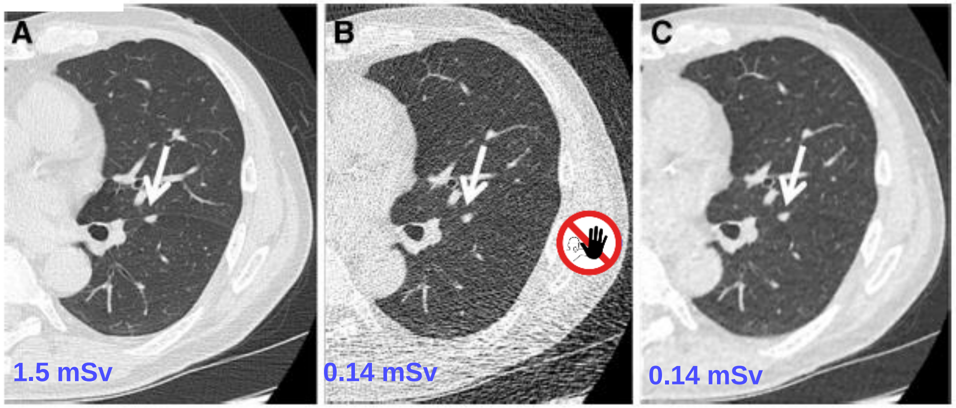

Fig. 5 63-year-old man with a 7-mm solid nodule in the right upper lobe detected by lung cancer screening. **a** Low-dose CT (LDCT) image reconstructed with filtered back projection (FBP). The *arrow* points to the nodule. **b** Ultra-low-dose CT (ULDCT) image reconstructed with FBP. While identification of the pulmonary nodule is easy, characterization of its nodule density and margin is difficult. **c** Ultra-low-dose CT (ULDCT) image reconstructed with full iterative reconstruction (IR). Although the spatial resolution is inferior to the LDCT image, identification and characterization of the nodule is easy

European Journal of Radiology 84 (2015) 1608–1613

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Unenhanced third-generation dual-source chest CT using a tin filter for spectral shaping at 100 kVp

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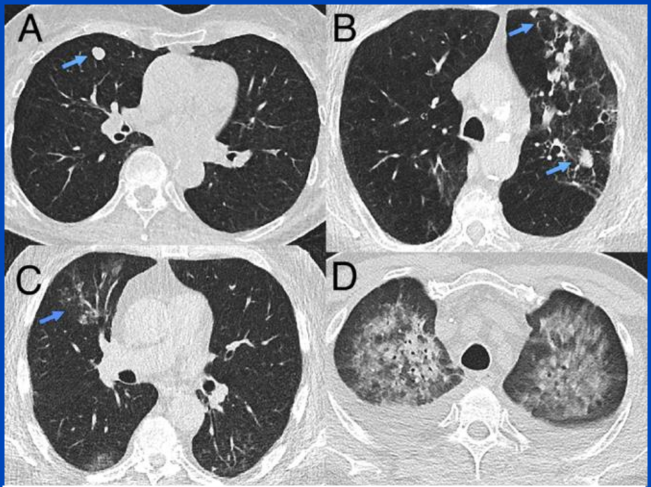
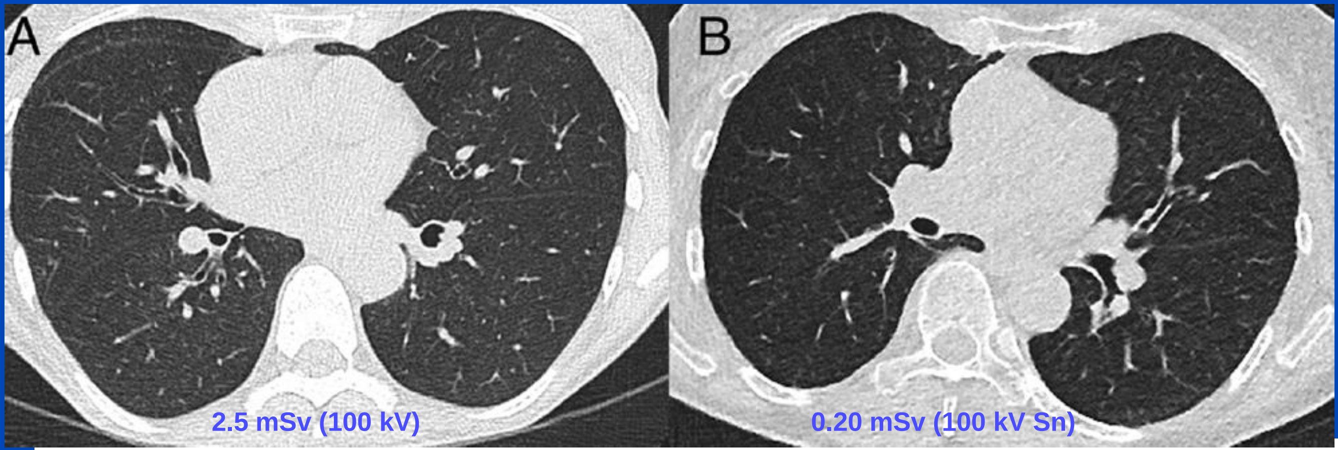


100 kVp with spectral shaping. (A and B) Lung nodules, (C) atypical pneumonia, (D) pneumocystis pneumonia.



(A) 100 kVp without spectral shaping ($CTDI_{vol}$ 3.8 mGy; DLP 137 mGy cm). (B) 100 kVp with spectral shaping ($CTDI_{vol}$ 0.32 mGy; DLP 11 mGy cm).

All images were reconstructed with a slice thickness of 1.5 mm in the axial and coronal planes using a corresponding lung kernel (3rd generation DSCT: Bl57; 2nd generation DSCT: I70f), with the 3rd generation DSCT utilizing a novel iterative reconstruction technique (Adaptive Model-based Iterative Reconstruction (ADMIRE), Siemens Healthcare, Forchheim, Germany). This algorithm was described in detail in a recent study [9]. The 2nd generation DSCT utilized a previously described iterative reconstruction algorithm (Sinogram Affirmed Iterative Reconstruction (SAFIRE), Siemens Healthcare, Forchheim, Germany). The iterative reconstruction algorithm was set at a level of 3 for all reconstructions. The iteration level of 3 was chosen since the retrospective studies from the 2nd generation DSCT were all performed with a strength level of 3. That strength level resulted in the best image quality based on our experience and was clinically performed in all retrospectively included studies on the 2nd generation DSCT. Further, initial results in a phantom study showed that iterative levels of 3 and 5 yield diagnostically acceptable results [9]. The images were then exported to an offline workstation (Aycan Osirix Pro 2, Aycan, Würzburg, Germany) for all data analysis.

Dosimetric parameters for both protocols.

	Reference mAs	Effective mAs	CTDI (mGy)	DLP (mGy cm)	Equiv. dose (mSv)
Group 100 kV Sn	96	167.5 ± 108.0	0.49 ± 0.18	17.7 ± 6.8	0.32 ± 0.12
Group 100 kV	96	79 ± 7.0	4.9 ± 1.9	166.9 ± 66.1	3.0 ± 1.2

European Journal of Radiology 85 (2016) 2217–2224

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Computer-aided detection (CAD) of solid pulmonary nodules in chest x-ray equivalent ultralow dose chest CT - first in-vivo results at dose levels of 0.13 mSv

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Objectives: To determine the value of computer-aided detection (CAD) for solid pulmonary nodules in ultralow radiation dose single-energy computed tomography (CT) of the chest using third-generation dual-source CT at 100 kV and fixed tube current at 70 mAs with tin filtration.
Methods: 202 consecutive patients undergoing clinically indicated standard dose chest CT (1.8 ± 0.7 mSv) were prospectively included and scanned with an additional ultralow dose CT (0.13 ± 0.01 mSv) in the same session. Standard of reference (SOR) was established by consensus reading of standard dose CT by two radiologists. CAD was performed in standard dose and ultralow dose CT with two different reconstruction kernels. CAD detection rate of nodules was evaluated including subgroups of different nodule sizes (<5, 5–7, >7 mm). Sensitivity was further analysed in multivariable mixed effects logistic regression.
Results: The SOR included 279 solid nodules (mean diameter 4.3 ± 3.4 mm, range 1–24 mm). There was no significant difference in per–nodule sensitivity of CAD in standard dose with 70% compared to 68% in ultralow dose CT both overall and in different size subgroups (all $p > 0.05$). CAD led to a significant increase of sensitivity for both radiologists reading the ultralow dose CT scans (all $p < 0.001$). In multivariable analysis, the use of CAD ($p < 0.001$), and nodule size ($p < 0.0001$) were independent predictors for nodule detection, but not BMI ($p = 0.933$) and the use of contrast agents ($p = 0.176$).
Conclusions: Computer-aided detection of solid pulmonary nodules using ultralow dose CT with chest X-ray equivalent radiation dose has similar sensitivities to those from standard dose CT. Adding CAD in ultralow dose CT significantly improves the sensitivity of radiologists.

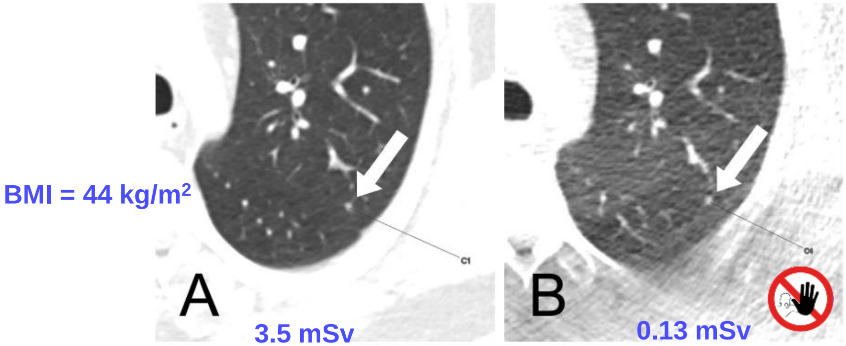

Fig. 4. Representative transverse CT sections of the lung in a 33-year-old man with a body mass index of 43.6 kg/m² scanned with standard dose (A) (effective dose 3.54 mSv) and ultralow dose (B) (effective dose 0.13 mSv) reconstructed with soft kernel. A 4 mm solid pulmonary nodule in the left upper lobe was marked by computer-aided detection (CAD) software in both protocols (i.e. true positive finding).

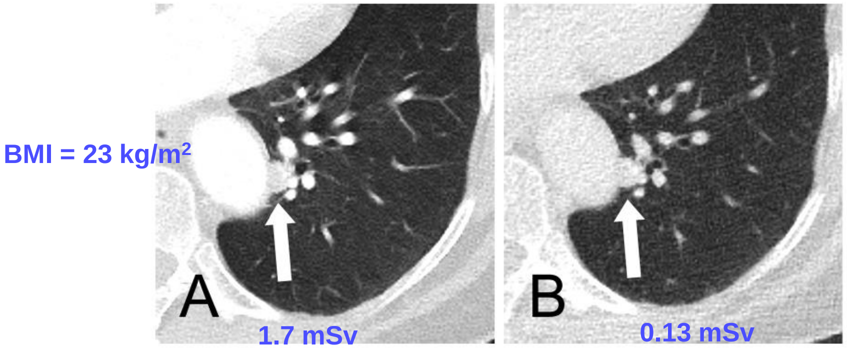

Fig. 5. Representative transverse CT sections of the lung in a 73-year-old woman with a body mass index of 23.0 kg/m² scanned with standard dose (A) (effective dose 1.68 mSv) and ultralow dose (B) (effective dose 0.13 mSv). A 11 mm solid pulmonary nodule (arrow) in the left lower lobe adjacent to pulmonary vessels and the descending aorta was not detected by computer-aided detection (CAD) software in both protocols (i.e. false negative finding). Note: The lesion was detected in ultralow dose CT by one of the two radiologists.

Somatom Force
ADMIRE 3
2 mm slice thickness
1.6 mm increment
Edge enhancing kernel (Br64)
Patients scanned twice (Std+ULD)
"ULD scans were performed at a fixed tube potential of 100 kV Sn with a fixed tube current time product of 70 mAs" Why fixed???

Standard dose and ultralow dose CT images were reconstructed with advanced modelled IR (ADMIRE) [15] at a strength level of 3 with a slice thickness of 2 mm, increment of 1.6 mm and using both an edge-enhancing convolution kernel (Br64: hereafter "lung kernel") and a smooth tissue convolution kernel (Br40: hereafter "soft kernel"). The reconstructed field-of-view (FoV) was 400 × 400 mm² and the image matrix was 512 × 512 pixels.

CT image analysis was performed on a high-definition liquid crystal display monitor (BARCO; Medical Imaging Systems, Kortrijk, Belgium) using the picture archiving and communication system (ImpaxEE, VersionR20XVSU2; Agfa Healthcare N.V., Mortsel, Belgium) of our department.

Eur Radiol (2017) 27:3290–3299
DOI 10.1007/s00330-017-4739-6

CHEST

Ultralow dose CT for pulmonary nodule detection with chest x-ray equivalent dose – a prospective intra-individual comparative study

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Lotus Desbiolles[2] • Fabian Rengier[4] • René Warschkow[5] • Ralf W. Bauer[2] •
Hatem Alkadhi[6] • Sebastian Leschka[2,6] • Simon Wildermuth[2]

Somatom Force
100 kV Sn
AEC/TCM off for low dose protocol
ADMIRE 3
2 mm slice thickness
1.6 mm increment
Edge enhancing kernel (Br64)
Patients scanned twice (Std+ULD)

Results 425 nodules (mean diameter 3.7 ± 2.9 mm) were found on SOR. Overall sensitivity for nodule detection by ultralow dose CT was 91%. In multivariate analysis, nodule type, size and patients BMI were independent predictors for sensitivity ($p < 0.001$).
Conclusions Ultralow dose chest CT at 100 kV with spectral shaping enables a high sensitivity for the detection of pulmonary nodules at exposure levels comparable to plain film chest X-ray.
Keypoints
- *91% of all lung nodules were detected with ultralow dose CT*
- *Sensitivity for subsolid nodule detection is lower in ultralow dose CT (77.5%)*
- *The mean effective radiation dose in 202 patients was 0.13 mSv*
- *Ultralow dose CT seems to be feasible for lung cancer screening*

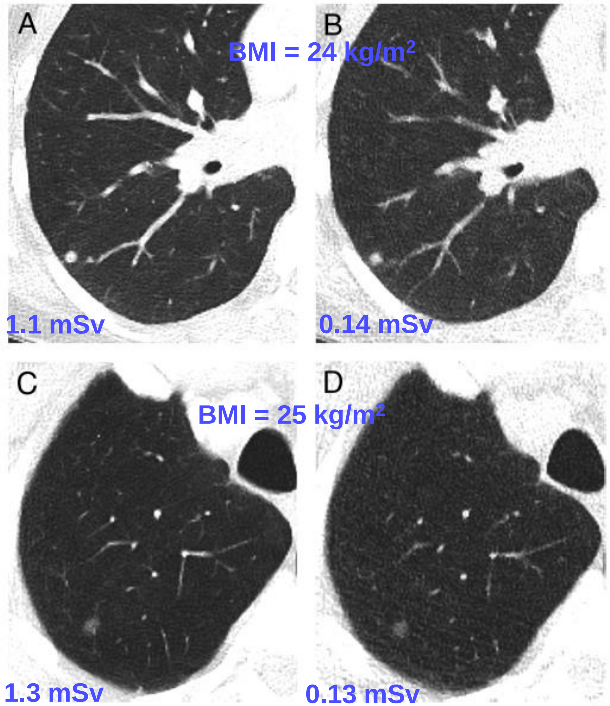

Fig. 5 Representative transverse CT sections of the lung in a 33-year-old woman with a body mass index of 23.6 kg/m2 scanned with standard dose (A) at 110 kVp and 38 mAs (effective dose, 1.1 mSv; size-specific dose estimate, 3.09 mGy) and ultralow dose (B) at 100 kVp and 70 mAs (effective dose, 0.14 mSv; size-specific dose estimate, 0.37 mGy). The solid pulmonary nodule in the right lower lobe was detected in ultralow dose CT by both readers (i.e., true positive finding). Representative transverse CT sections of the lung in a 79-year-old man with a body mass index of 24.9 kg/m2 scanned with standard dose (C) at 100 kVp and 62 mAs (effective dose, 1.33 mSv; size-specific dose estimate, 3.1 mGy) and ultralow dose (D) at 100 kVp and 70 mAs (effective dose, 0.13 mSv; size-specific dose estimate, 0.3 mGy). The subsolid pulmonary nodule in the right upper lobe was detected in ultralow dose CT by both readers (i.e. true positive finding)

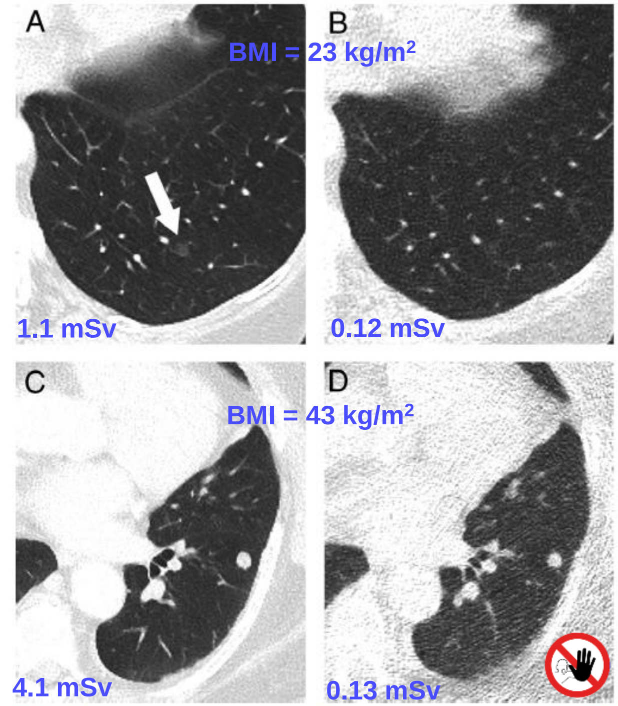

Fig. 6 Representative transverse CT sections of the lung in a 75-year-old woman with a body mass index of 24.4 kg/m2 scanned with standard dose (A) at 100 kVp and 54 mAs (effective dose, 1.09 mSv; size-specific dose estimate, 3.13 mGy) and ultralow dose (B) at 100 kVp and 70 mAs (effective dose, 0.12 mSv; size-specific dose estimate, 0.34 mGy). The subsolid pulmonary nodule in the left lower lobe (arrow) was not detected by either of the reader in ultralow dose CT (i.e., false negative finding). Representative transverse CT sections of the lung in a 75-year-old woman with a body mass index of 42.8 kg/m2 scanned with standard dose (C) at 110 kVp and 142 mAs (effective dose, 4.13 mSv; size-specific dose estimate, 6.86 mGy) and ultralow dose (D) at 100 kVp and 70 mAs (effective dose, 0.13 mSv; size-specific dose estimate, 0.22 mGy). Note the markedly increased image noise in the ultralow dose CT scan. In spite of the image noise the solid pulmonary nodule in the left lower lobe was detected in ultralow dose CT by both readers (i.e., true positive finding)

Main Points

- Adapt kV, mAs and dose to patient size. Thicker patients require higher kV, mAs and thus more dose.
- Use tube current modulation (TCM).
- Use patient-specific prefilters. Preferrably, several thicknesses of the filters should be provided.
- Reconstruct with moderate spatial resolution.
- Use iterative or deep learning reconstruction.

- **Do not exaggerate!**
- **Image quality must be maintained!**

Cooking Recipe (AAPM)

LUNG CANCER SCREENING CT (selected SIEMENS scanners, continued)

(Back to INDEX)

TOPOGRAM: PA; scan from top of shoulder through mid-liver.

SIEMENS	**Definition DS (Dual source 64-slice)**	**Somatom Drive (Dual source 128-slice)**	**Definition Flash (Dual source 128-slice)**	**Definition Force** (Dual source 192-slice)
Software version	VA44	VB10	VB10	VB10
Scan Mode	Spiral	Spiral	Spiral	Spiral
Rotation Time (s)	0.5	0.5	0.5	0.5
Detector Configuration	*64 × 0.6 mm (32 x 0.6 mm =19.2 mm)	*128 × 0.6 mm (64 x 0.6 mm = 38.4 mm)	*128 × 0.6 mm (64 x 0.6 mm = 38.4 mm)	*192 × 0.6 mm (96 x 0.6 mm = 57.6 mm)
Pitch	1.2	1.2	1.2	1.2
kV	120	100Sn **(0.4 mm)**	120	100Sn **(0.6 mm)**
Quality ref. mAs	20	81	20	101
CARE Dose4D	ON	ON	ON	ON
CARE kV	ON	ON	ON	ON
CTDIvol***	1.4 mGy	0.6mGy	1.3 mGy	0.4 mGy

RECON 1

Type	Axial	Axial	Axial	Axial
Kernel	B31f	Bf37, strength = 3**	Bf37, strength = 3**	Br40, strength = 3**
Slice (mm)	5.0	5.0	5.0	5.0
Increment (mm)	5.0	5.0	5.0	5.0

→ thicker prefilter means less dose

Conclusions

- Current recommendations specify ranges or limits for technical parameters.
- A continuous adaptation of the recommendations is necessary.
- To provide guidance to radiologists, the European professional societies should provide specific recommendations for the scan protocols.
  - EFOMP
  - ESR

Thank You!

The 8th International Conference on

Image Formation in X-Ray Computed Tomography

Conference Chair

Marc Kachelrieß, German Cancer Research Center (DKFZ), Heidelberg, Germany

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

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

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