

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

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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
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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	$k = 0.019 \text{ mSv/mGy/cm}$	$D_{\text{eff}} = k \cdot \text{DLP}$
Topogram CTDI	$\leq 20\%$ of screening CTDI	Use additional prefilter
Scan length	Adapt to lung	Not longer than lung
Scan time	$\leq 15 \text{ s}$	Breath hold required
Spiral pitch value	According to vendor	Moderate to high
Rotation time	$\leq 1 \text{ s}$	
Screening CTDI	$\leq 1.3 \text{ mGy}$	For BMI = 26 kg/m ²
Additional prefilter ¹	Yes	At least for BMI $\leq 40 \text{ kg/m}^2$
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	$\leq 0.7 \text{ mm}$	
Voxel size (isotropic)	$\leq 70\%$ of spatial resolution	
Image noise	Low enough to be diagnostic	

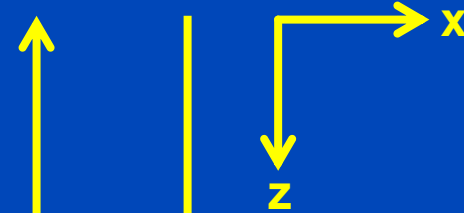
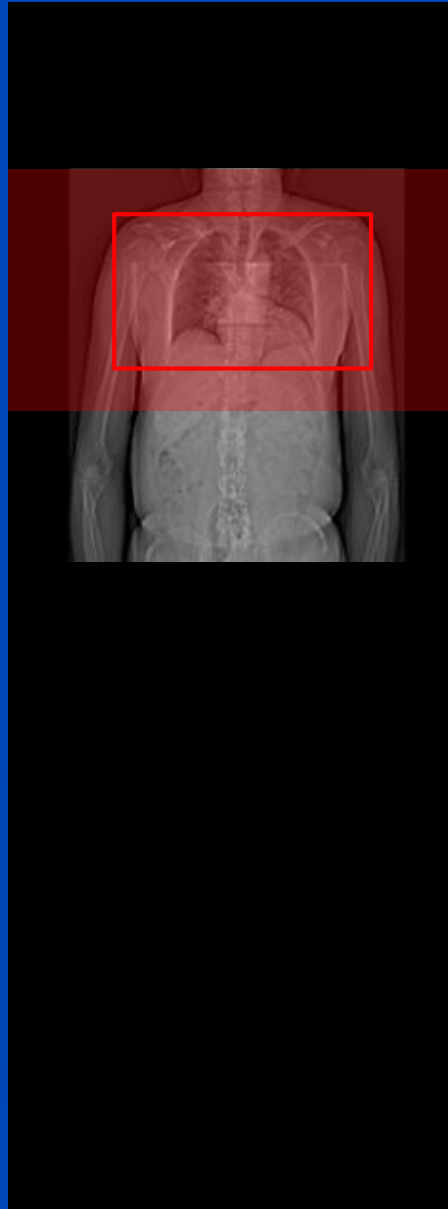
Exposure parameters and dose levels are to be adapted to patient size!

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

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.



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:

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

caudo-cranial cranio-caudal

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

mSv ↔ CTDI_{vol}

- **DLP = CTDI_{vol} × ScanLength**
- **$D_{\text{eff}} = \text{DLP} \times k$ mit $k = 0.019 \text{ mSv/mGy/cm}$**
- **The typical scan length for lung scans is around 25 cm.**
- **Then, CTDI = 1 mGy yields**
 $D_{\text{eff}} = 1 \text{ mGy} \cdot 25 \text{ cm} \cdot 0.019 \text{ mSv/mGy/cm} = 0.48 \text{ mSv}$
- **Rough rule of thumb for lung scans:**

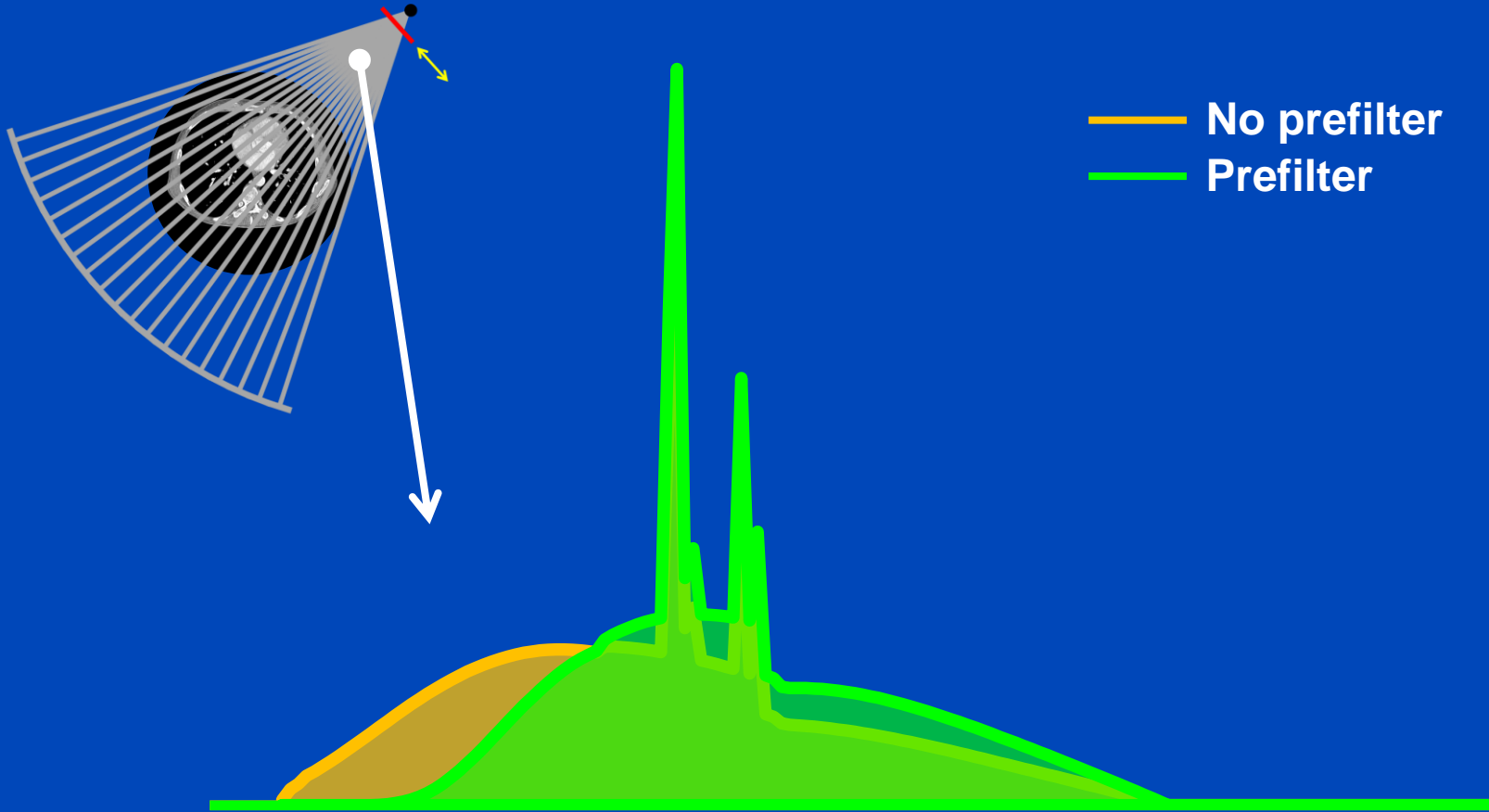
$$\text{CTDI}_{\text{vol}} \approx 2 D_{\text{eff}} \text{ mGy/mSv}$$

i.e.

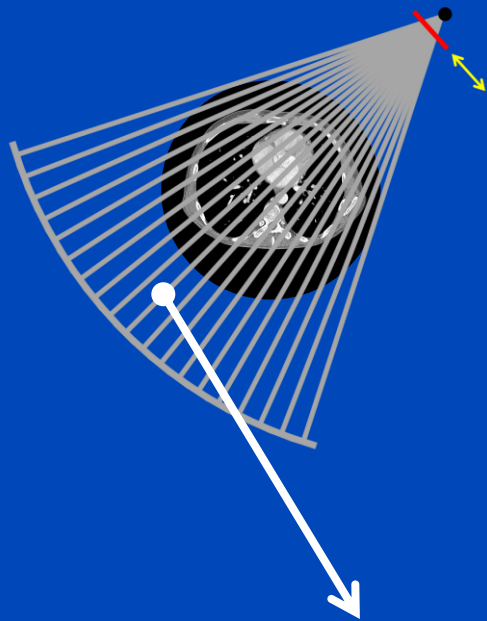
$$2 \text{ mGy} \approx 1 \text{ mSv}$$

for lung only scans.

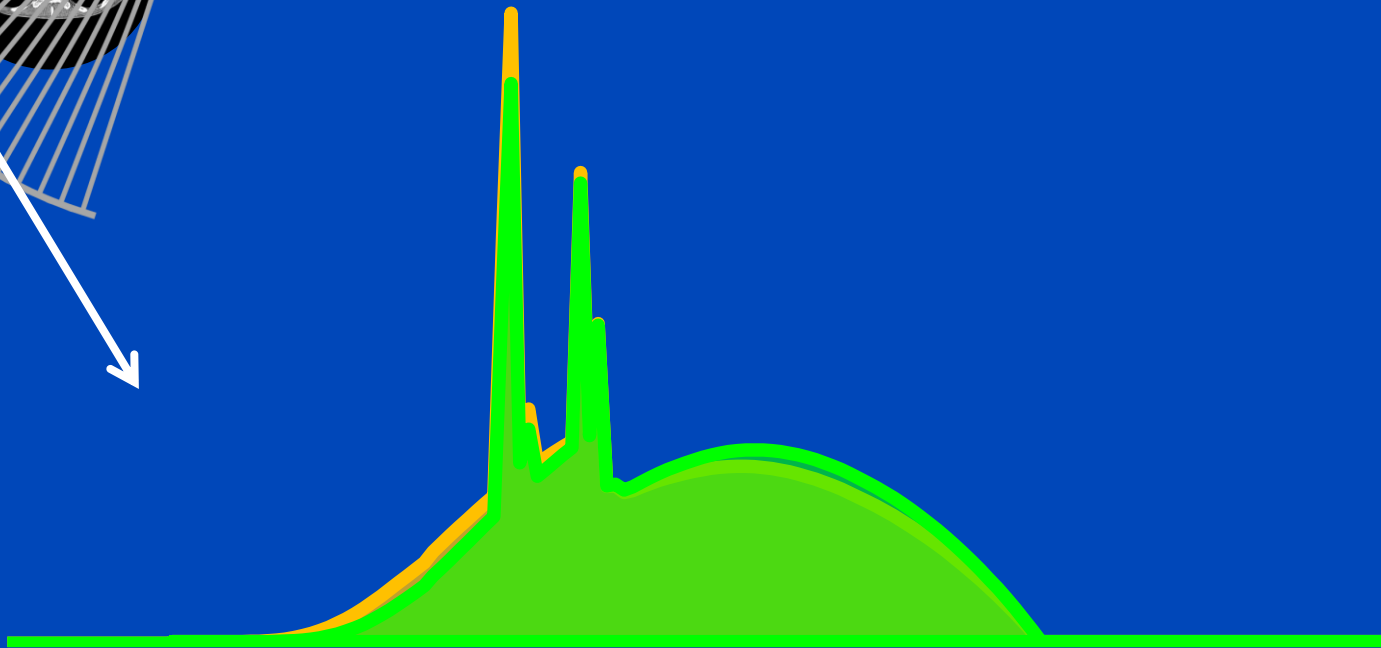
120 kV + 0 mm water with and without prefilter



120 kV + 320 mm water with and without prefilter






— No prefilter
— Prefilter



Study	Topic	Dose Reduction	Assessment	Reconstruction
Dewes et al., 2016	abdomen, urinary stones	22%	subjective	Iterative
Leyendecker et al., 2019	abdomen	81%	subjective, objective	Iterative
Gordic et al., 2014	chest, pulmonary nodules, phantom	95%	subjective	Iterative
Martini et al., 2016	chest, pulmonary nodules	97%	subjective	Iterative
Weis et al., 2017	chest, pediatric	77%	subjective, objective	iterative
Hasegawa et al., 2022	chest, detectability index, phantom	22% - 25%	objective	FBP
Apfaltrer et al., 2018	coronary artery calcium scoring	73%	subjective	FBP
Schabel et al., 2018	thoracic aorta calcification	92%	subjective	iterative
Wuest et al., 2016	paranasal sinus	73%	subjective, different scanners	FBP with different kernels
Rajendran et al., 2020	PC CT, sinus, temporal bone	67% (sinus) 85% (temporal bone)	objective, compares EI and PC detectors	FBP
Jeon et al., 2019	DECT, grout diagnosis	65%	subjective, different scanners	iterative
Agostini et al., 2021	chest, DECT, COVID-19	89%	subjective, different pitch	iterative
Saltybaeva et al., 2019	topogram	80%	effect on TCM	-

- **Abdominal CT**
 - Leyendecker, Pierre, et al. "Prospective evaluation of ultra-low-dose contrast-enhanced 100-kV abdominal computed tomography with tin filter: effect on radiation dose reduction and image quality with a third-generation dual-source CT system." *European radiology* 29.4 (2019): 2107-2116.
 - Dewes, Patricia, et al. "Low-dose abdominal computed tomography for detection of urinary stone disease– Impact of additional spectral shaping of the X-ray beam on image quality and dose parameters." *European journal of radiology* 85.6 (2016): 1058-1062.
- **Coronary artery calcium scoring**
 - Apfaltrer, Georg, et al. "High-pitch low-voltage CT coronary artery calcium scoring with tin filtration: accuracy and radiation dose reduction." *European radiology* 28.7 (2018): 3097-3104.
 - Schabel, Christoph, et al. "Tin-filtered low-dose chest CT to quantify macroscopic calcification burden of the thoracic aorta." *European radiology* 28 (2018): 1818-1825.
- **Chest CT**
 - Weis, Meike, et al. "Radiation dose comparison between 70 kVp and 100 kVp with spectral beam shaping for non-contrast-enhanced pediatric chest computed tomography: a prospective randomized controlled study." *Investigative radiology* 52.3 (2017): 155-162.
 - Martini, Katharina, et al. "Evaluation of pulmonary nodules and infection on chest CT with radiation dose equivalent to chest radiography: Prospective intra-individual comparison study to standard dose CT." *European journal of radiology* 85.2 (2016): 360-365.
 - Gordic, Sonja, et al. "Ultralow-dose chest computed tomography for pulmonary nodule detection: first performance evaluation of single energy scanning with spectral shaping." *Investigative radiology* 49.7 (2014): 465-473.
 - Hasegawa, Akira, et al. "A tin filter's dose reduction effect revisited: Using the detectability index in low-dose computed tomography for the chest." *Physica Medica* 99 (2022): 61-67.
- **Sinus CT**
 - Wuest, Wolfgang, et al. "Low-dose CT of the paranasal sinuses: minimizing X-ray exposure with spectral shaping." *European radiology* 26.11 (2016): 4155-4161.
 - Rajendran, Kishore, et al. "Dose reduction for sinus and temporal bone imaging using photon-counting detector CT with an additional tin filter." *Investigative radiology* 55.2 (2020): 91-100.
- **Gout diagnosis**
 - Jeon, Ji Young, et al. "The effect of tube voltage combination on image artefact and radiation dose in dual-source dual-energy CT: comparison between conventional 80/140 kV and 80/150 kV plus tin filter for gout protocol." *European radiology* 29.3 (2019): 1248-1257.
- **COVID-19**
 - Agostini, Andrea, et al. "Third-generation iterative reconstruction on a dual-source, high-pitch, low-dose chest CT protocol with tin filter for spectral shaping at 100 kV: a study on a small series of COVID-19 patients." *Radiol med* 126 (2021), 388–398.
- **Topogram**
 - Saltybaeva, Natalia, Andreas Krauss, and Hatem Alkadhi. "Radiation dose reduction from computed tomography localizer radiographs using a tin spectral shaping filter." *Medical physics* 46.2 (2019): 544-549.

Dose Reduction by Patient-Specific Tin or Copper Prefilters¹ (1000 mAs Limit)

	Child (15 cm x 10 cm) 	Adult (30 cm x 20 cm) 	Obese (50 cm x 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% <small>0.5 mGy CTDI</small>	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
- Philips: none
- Siemens: 0.4 mm, 0.6 mm, and 0.7 mm (in different systems)

¹Steidel, 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.

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

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 assuming 50% participation¹ yields an expected screening population of 1.3 million persons. This are about 650,000 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)

¹Value taken from German mammography screening program.



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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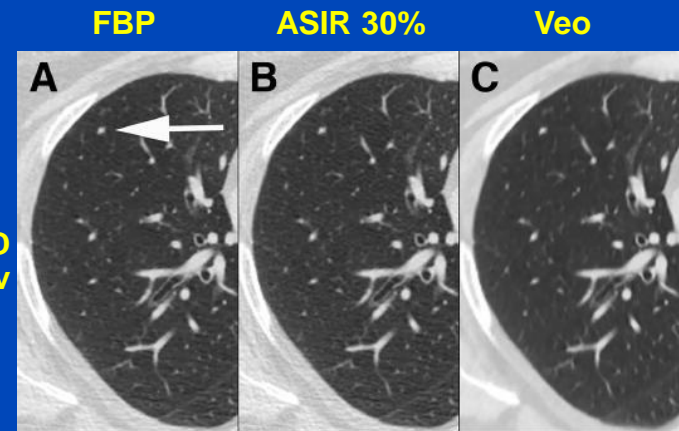
^b Department of Diagnostic Radiology, Li Ka Shing Faculty of Medicine, University of Hong Kong, Hong Kong

^c Department of Radiology, Derriford Hospital, Derriford Road, Plymouth, PL6 8DH, United Kingdom

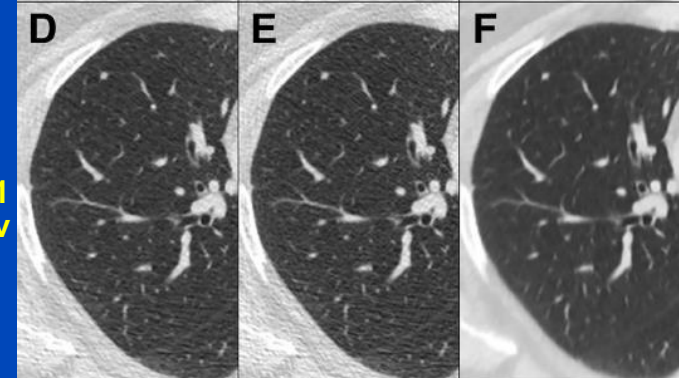
^d University of Exeter Medical School, Exeter, United Kingdom



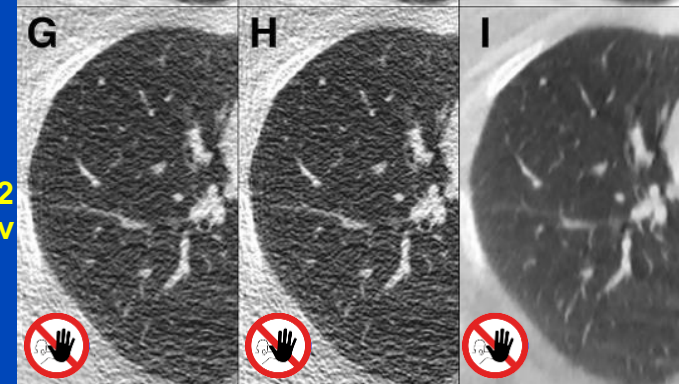
STD
3.3 mSv



RD1
0.96 mSv



RD2
0.14 mSv



BMI = 33 kg/m²

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.



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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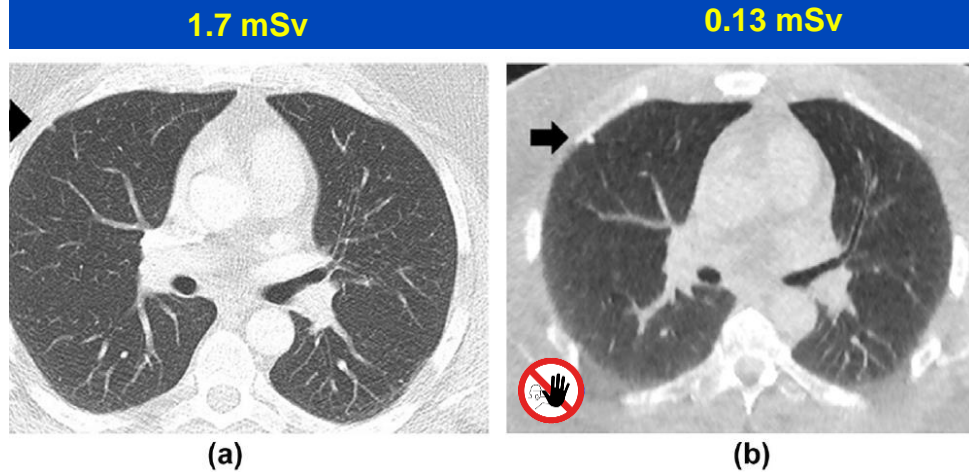


Figure 1 Nodules were clearly seen on both LD- (a) and ULD-CT (b) images.

- 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 ≥ 4 mm 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.

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

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	LDCT	ULDCT
CTDI _{vol} (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

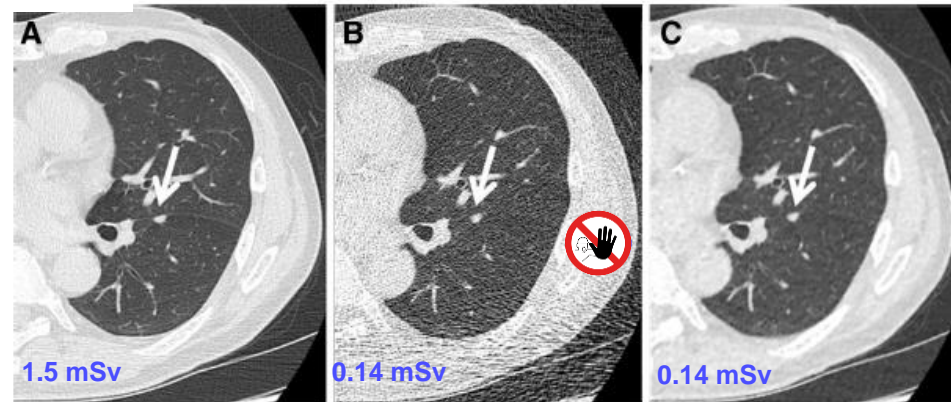


Fig. 5 63-year-old man with a 7-mm solid nodule in the right upper lobe detected by lung cancer screening. **a** Low-dose CT (LDCT) image reconstructed with filtered back projection (FBP). The *arrow* points to the nodule. **b** Ultra-low-dose CT (ULDCT) image reconstructed with FBP. While identification 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

- 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)



Performance of ultralow-dose CT with iterative reconstruction in lung cancer screening: limiting radiation exposure to the equivalent of conventional chest X-ray imaging

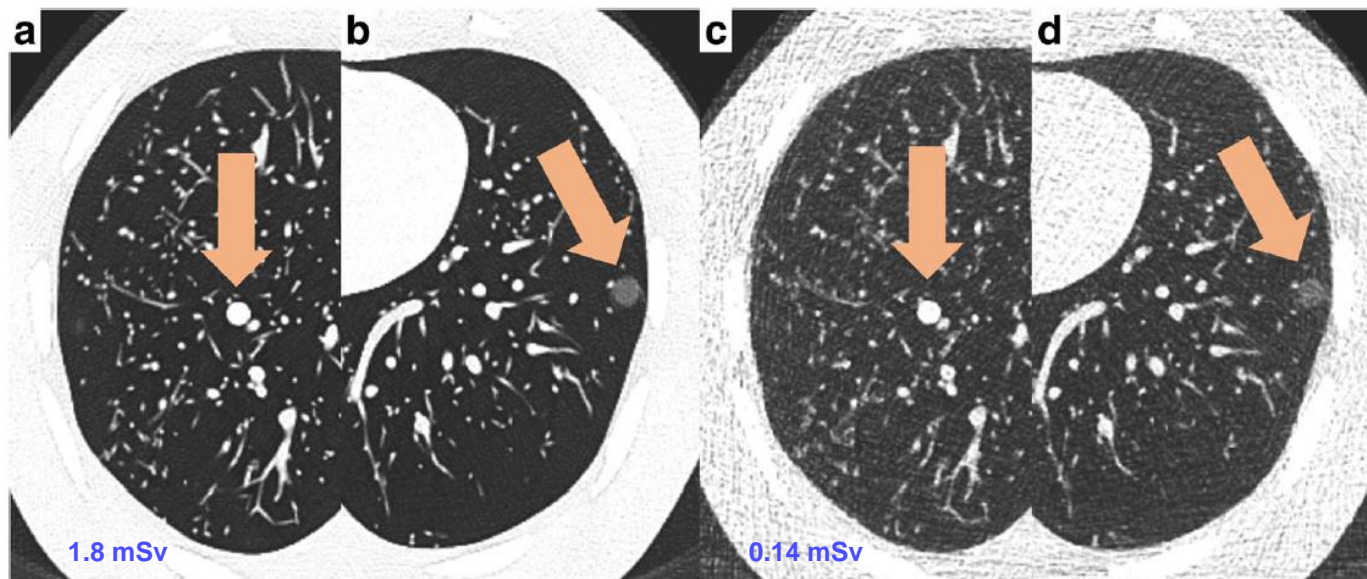
Huber Adrian^{1,2} · Landau Julia¹ · Ebner Lukas^{1,3} · Büttikofer Yanik¹ · Leidolt Lars¹ · Brela Barbara¹ · May Michelle¹ · Heverhagen Johannes¹ · Christe Andreas¹

Chest phantom only!
Somatom Flash with Stellar detector + IRIS
1 mm slice thickness and 1 mm increment
Kernels: I30 for standard dose, I70 for ULD, I50 for CAD

Table 1 Acquisition protocol and reconstruction settings for the standard and the ultralow-dose acquisitions

	Standard acquisitions	Ultralow-dose acquisitions
Dose	CTDIvol 3.15 mGy/DLP 126 mGy*cm (40 cm scan-length)	CTDIvol 0.22 mGy/DLP: 9 mGy*cm (40-cm scan length)
Tube voltage	100 kVp	80 kVp
Tube current-time product	100 reference mAs	6 mAs
Primary collimation	0.6 mm	
Cantry rotation time	0.28 s	
Pitch	2.2	
Standard readout reconstructions	Axial stacks with a slice thickness of 1 mm and an increment of 1 mm in a lung parenchyma window (level: -600; window width: 1,200) with an I70 convolution kernel for the standard acquisitions and an I130 convolution kernel for the ultralow-dose acquisitions	
Readout with MIP reconstructions	MIP axial stacks with a slice thickness of 8 mm and an increment of 2 mm in a lung parenchyma window (level: -600; window width: 1,200) with an I70 convolution kernel for the standard acquisitions and an I130 convolution kernel for the ultralow-dose acquisitions	
Readout with the CAD software	Axial stacks with a slice thickness of 1 mm and an increment of 1 mm in a lung parenchyma window (level: -600; window width: 1,200) with an I150 convolution kernel	

Fig. 1 Image comparison (1-mm axial stack): the standard acquisitions (tube voltage: 100 kVp, tube current: 100 mAs, effective dose: 1.81 mSv) with a solid (a) and a ground-glass nodule (b) compared to the ultralow-dose acquisitions (tube voltage: 80 kVp, tube current-time product: 6 mAs, effective dose: 0.135 mSv) of the same solid (c) and ground-glass (d) nodule

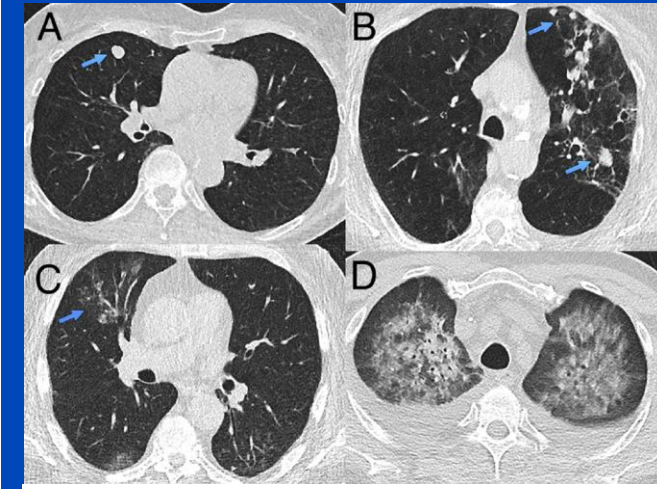




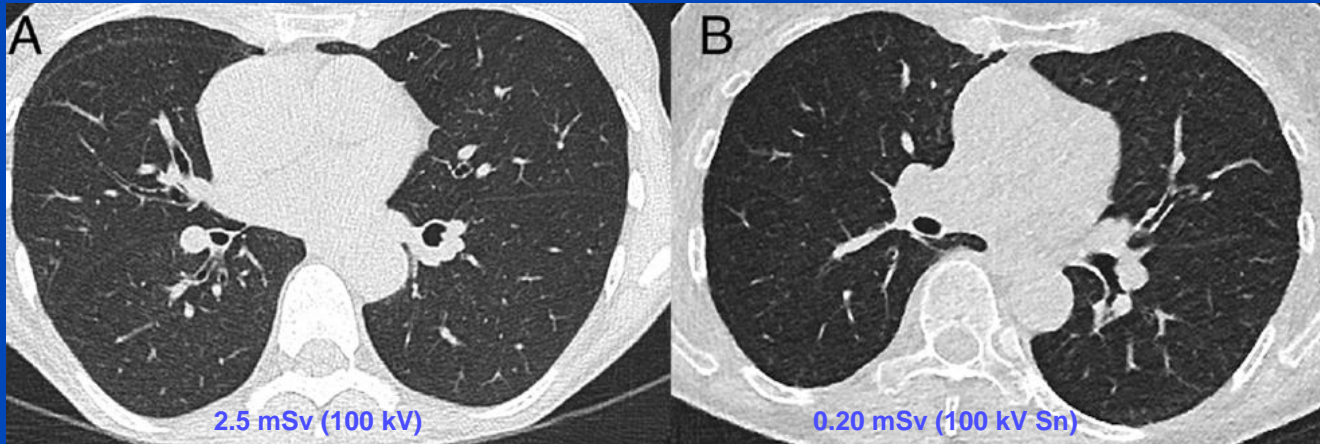
Unenhanced third-generation dual-source chest CT using a tin filter for spectral shaping at 100 kVp

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100kVp 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: BI57; 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



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.

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???

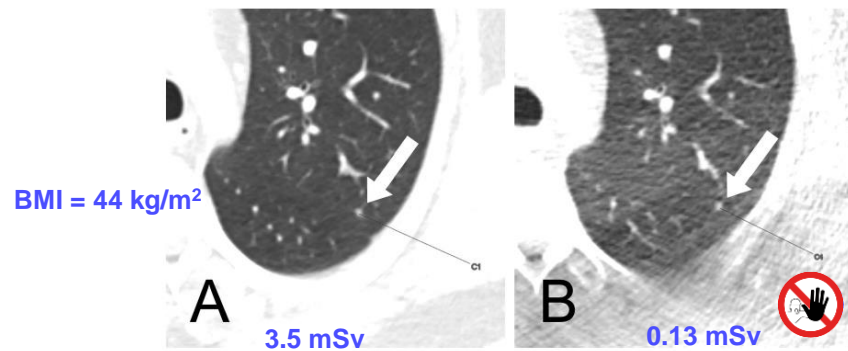


Fig. 4. Representative transverse CT sections of the lung in a 33-year-old man with a body mass index of 43.6 kg/m^2 scanned with standard dose (A) (effective dose 3.54 mSv) and ultralow dose (B) (effective dose 0.13 mSv) reconstructed with soft kernel. A 4 mm solid pulmonary nodule in the left upper lobe was marked by computer-aided detection (CAD) software in both protocols (i.e. true positive finding).

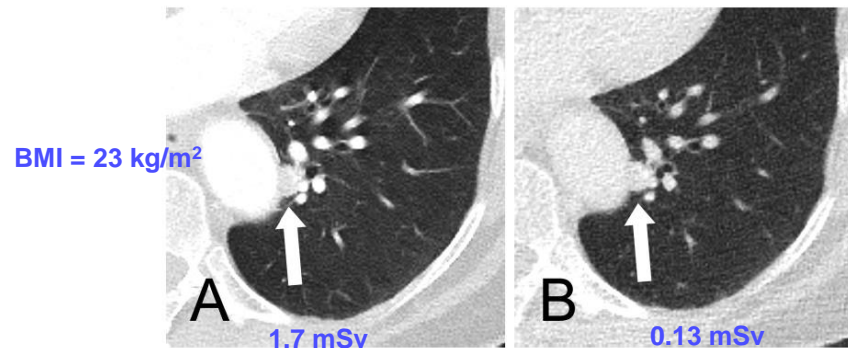


Fig. 5. Representative transverse CT sections of the lung in a 73-year-old woman with a body mass index of 23.0 kg/m^2 scanned with standard dose (A) (effective dose 1.68 mSv) and ultralow dose (B) (effective dose 0.13 mSv). A 11 mm solid pulmonary nodule (arrow) in the left lower lobe adjacent to pulmonary 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.

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 $400 \times 400 \text{ mm}^2$ 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.



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

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Hatem Alkadhi⁶ · Sebastian Leschka^{2,6} · Simon Wildermuth²

Eur Radiol (2017) 27:3290–3299

3297

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

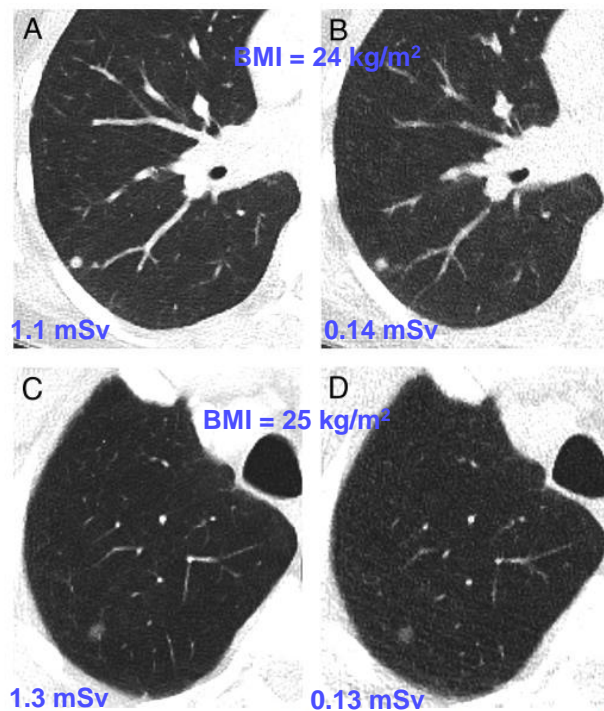


Fig. 5 Representative transverse CT sections of the lung in a 33-year-old woman with a body mass index of 23.6 kg/m² scanned with standard dose (A) at 110 kVp and 38 mAs (effective dose, 1.1 mSv; size-specific dose estimate, 3.09 mGy) and ultralow dose (B) at 100 kVp and 70 mAs (effective dose, 0.14 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)

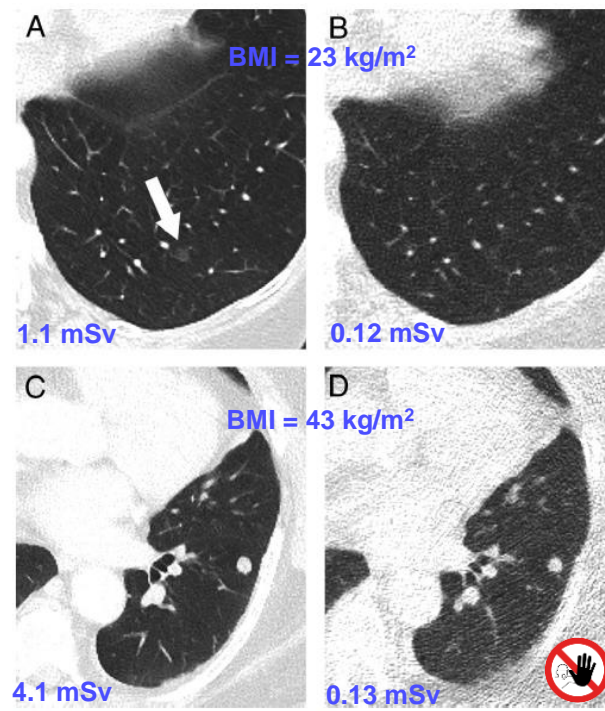


Fig. 6 Representative transverse CT sections of the lung in a 75-year-old woman with a body mass index of 24.4 kg/m² scanned with standard dose (A) at 100 kVp and 54 mAs (effective dose, 1.09 mSv; size-specific dose estimate, 3.13 mGy) and ultralow dose (B) at 100 kVp and 70 mAs (effective dose, 0.12 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. Preferably, 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)

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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!

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