Evidence on brain cancer and hematological malignancies after radiation exposure from pediatric CT scans

Prof. Dr. Michael Hauptmann
michael.hauptmann@mhb-fontane.de
Institute of Biostatistics and Registry Research

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Computed tomography: frequency & dose

In US per year
- 23m (1993), 70m (2007), 93m (2023)
- 3m (~3%) in children in 2023, including 1.6m head CTs

Smith-Bindman et al, JAMA Int Med 2025

Table 1. Typical Organ Radiation Doses from Various Radiologic Studies.

Study Type	Relevant Organ	Relevant Organ Dose* (mGy or mSv)
Dental radiography	Brain	0.005
Posterior–anterior chest radiography	Lung	0.01
Lateral chest radiography	Lung	0.15
Screening mammography	Breast	3
Adult abdominal CT	Stomach	10
Barium enema	Colon	15
Neonatal abdominal CT	Stomach	20
Pediatric head CT	Brain	46
Pediatric head CT	Bone marrow	12
Pediatric abdomen/pelvis CT	Bone marrow	8

~100,000 pediatric CTs 2015-2020 from UCSF Int'l CT Dose Registry

Chu et al, Rad Res 2025

Large studies with dosimetry

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nature medicine

Article

https://doi.org/10.1038/s41591-023-02620-0

Risk of hematological malignancies from CT radiation exposure in children, adolescents and young adults

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Magda Bosch de Basea Gomez[1,2,3], Isabelle T
Richard Harbron[1,2,3,5], Michael Hauptmann

EPI-CT study

Brain cancer after radiation exposure from CT examinations of children and young adults: results from the EPI-CT cohort study

Michael Hauptmann, Graham Byrnes, Elisabeth Cardis, Marie-Odile Bernier, Maria Blettner, Jérémie Dabin, Hilde Engels, Tore S Istad, Christoffer Johansen, Magnus Kaijser, Kristina Kjaerheim, Neige Journy, Johanna M Meulepas, Monika Moissonnier, Cecile Ronckers, Isabelle Thierry-Chef, Lucian Le Cornet, Andreas Jahnen, Roman Pokora, Magda Bosch de Basea, Jordi Figuerola, Carlo Maccia, Arvid Nordenskjold, Richard W Harbron, Choonsik Lee, Steven L Simon, Amy Berrington de Gonzalez, Joachim Schüz, Ausrele Kesminiene

Summary

Background The European EPI-CT study aims to quantify cancer risks from CT examinations of children and young

Lancet Oncol 2023; 24: 45–53

Neuro-Oncology

25(7), 1368–1376, 2023 | https://doi.org/10.1093/neuonc/noad012 | Advance Access date 25 April 2023

Computed tomography scan radiation and brain cancer incidence

Australian Study

Nicolas R. Smoll, Zoe Brady, Katrina J. Scurrah, Choonsik Lee, Amy Berrington de González, and John D. Mathews

PLOS ONE

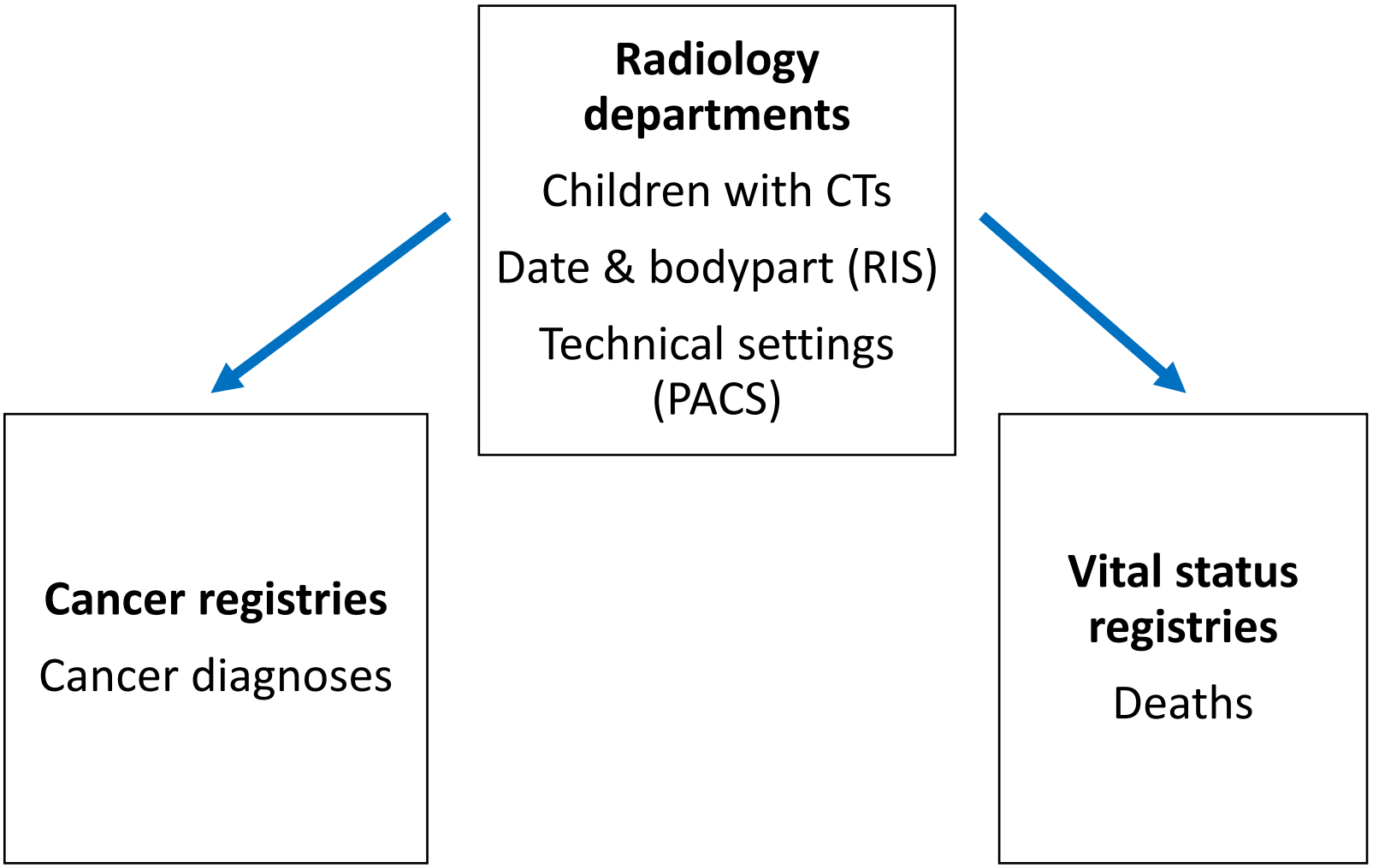
RESEARCH ARTICLE

Medical imaging utilization and associated radiation exposure in children with down syndrome

Emily C. Marlow[1], Jonathan M. Ducore[2], Marilyn L. Kwan[3], Erin J. A. Bowles[4], Robert T. Greenlee[5], Jason D. Pole[6,7,8], Alanna K. Rahm[9], Natasha K. Stout[10,11], Sheila Weinmann[12,13], Rebecca Smith-Bindman[14,15,16], Diana L. Miglioretti[4,17]*

Eagerly awaited: RIC study, Kaiser Permanente California & Ontaria Health Insurance

EPI-CT is a registry-based cohort study



EPI-CT Consortium

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Country	Hospitals	Patients	Period
UK	91	322,125	1985-2013
Netherlands	42	148,135	1979-2015
Sweden	29	121,805	1977-2013
France	24	119,399	2000-2011
Norway	27	77,252	1980-2021
Spain	36	84,592	1991-2013
Germany	20	47,096	1983-2010
Denmark	6	17,696	1999-2014
Belgium	2	10,074	2000-2015
Total	278	948,174	1977-2015

Mean follow-up ~8 years

Bernier et al, Int J Epidemiol 2018

European Commission

Organ dose estimation with NCICT

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NCICT beta version 2.0

File Batch Help

Patient parameters

Age: 5-year

Gender: Male / Female

Height: 111

Weight: 19

Scanner parameters

Manufacturer: Phillips

Model: Aura

Head filter / Body filter

nCTDIw (mGy/100mAs): 24.6

Pitch: 1

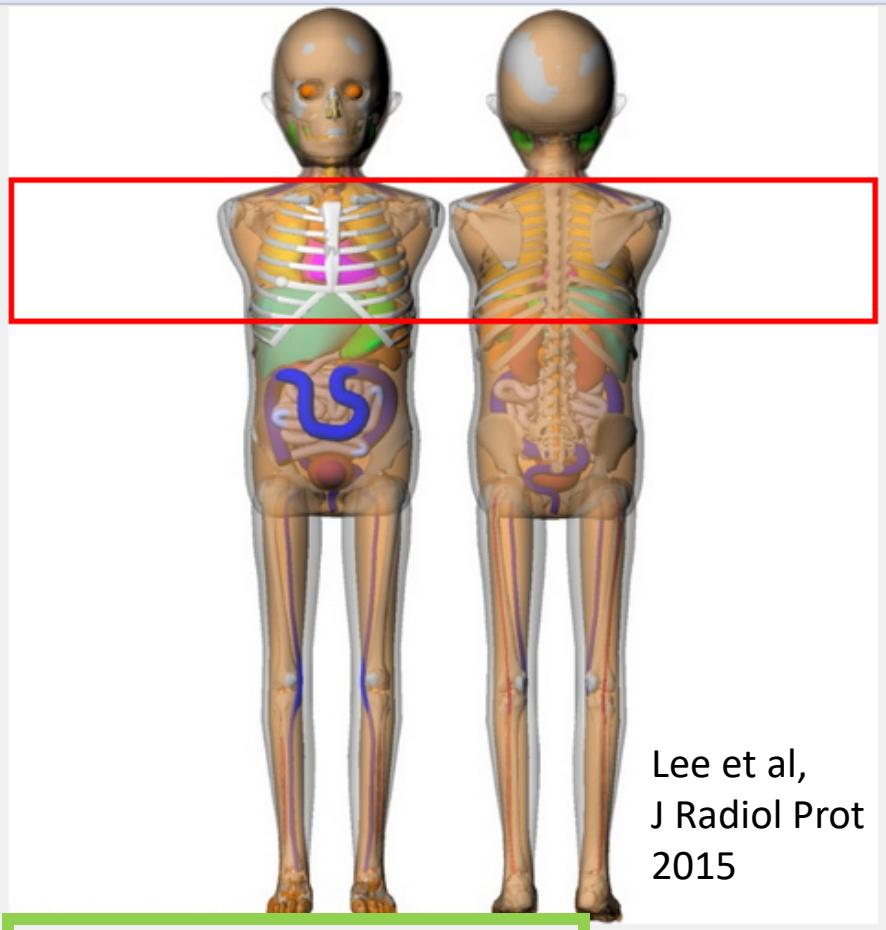
Tube potential (kVp): 120

Current x Time (mAs): 100

CTDIvol (mGy): 24,6

SSDE (mGy):

DLP (mGycm): 408



Lee et al,
J Radiol Prot
2015

General protocol: Chest

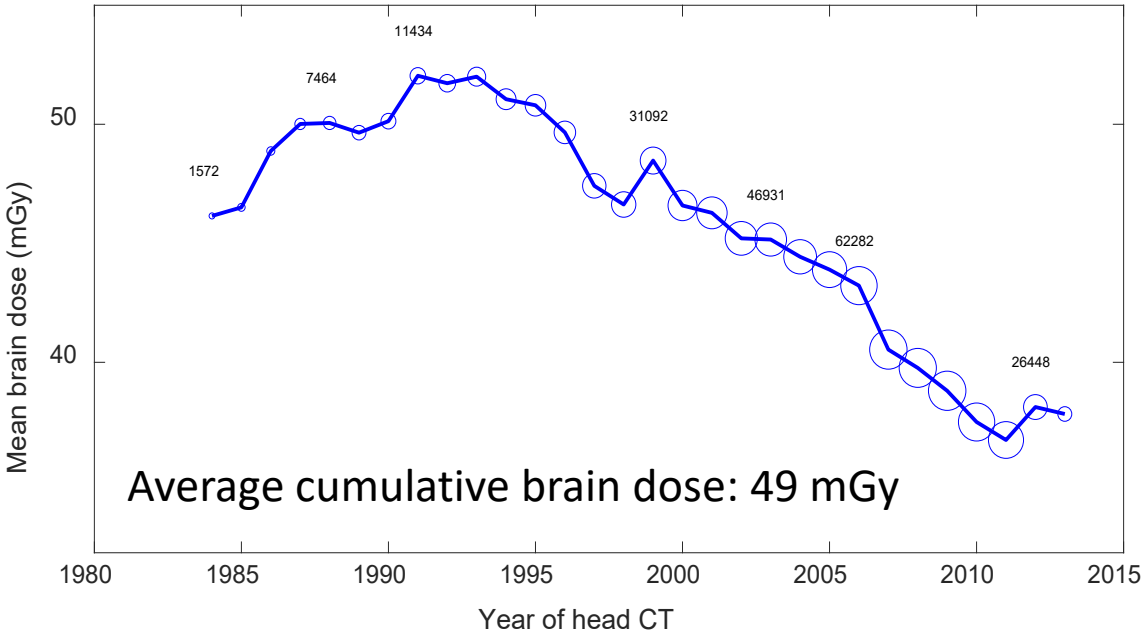
Scan Start (cm): 22

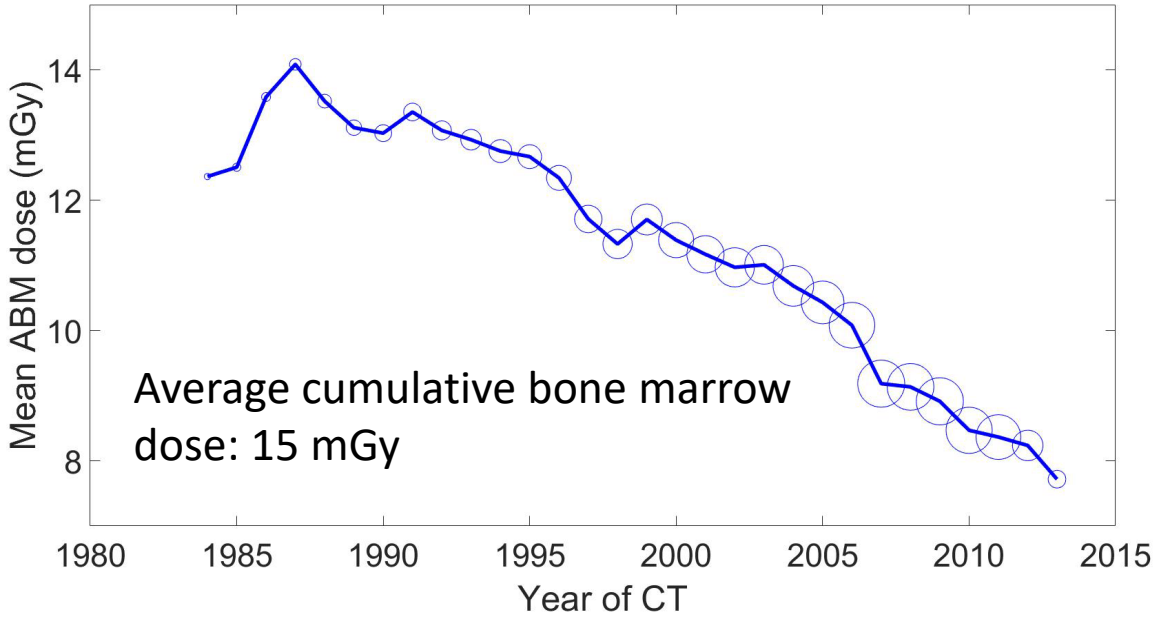
Scan End (cm): 38

Bar Graph

Copy organ list to Clipboard

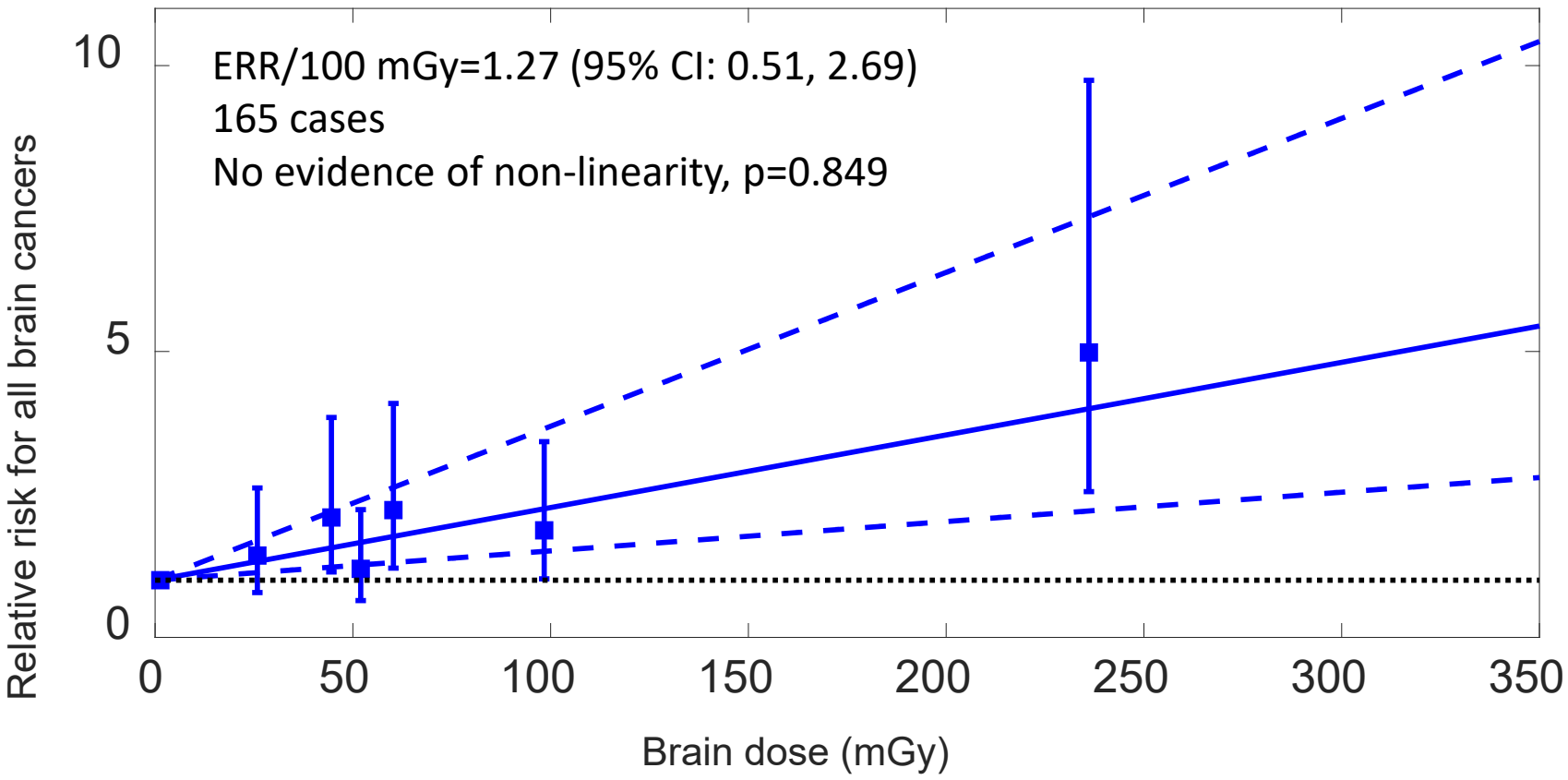
	Dose (mGy)
Brain	0,511
Pituitary gland	0,348
Lens	0,288
Eye balls	0,323
Salivary glands	2,17
Oral cavity	1,51
Spinal cord	11,094
Thyroid	23,785
Esophagus	18,036
Trachea	21,75
Thymus	23,021
Lungs	22,485
Breast	18,943
Heart wall	23,169
Stomach wall	9,507
Liver	12,057
Gall bladder	3,322
Adrenals	11,183
Spleen	11,671
Pancreas	2,859
Kidney	3,314
Small intestine	0,728
Colon	0,738
Rectosigmoid	0,206
Urinary bladder	0,134
Prostate	0
Uterus	0,176
Testes	0
Ovaries	0,219
Skin	4,379
Muscle	5,087
Active marrow	4,729
Shallow marrow	7,469
ED60	8,598
ED103	9,829





Mean dose to the brain and the bone marrow per (head) CT by year

Brain cancer dose-response



Poisson regression stratified for sex/birth cohort/country, 5-year lag, 5-year exclusion

Hauptmann et al, Lancet Oncol 2022

Relative risks by bone marrow dose

Dose categories (mGy)	Hematological malignancies					
	All		Lymphoid		Myeloid	
	#	RR	#	RR	#	RR
[0,5)	125	1.00	91	1.00	34	1.00
[5,10)	171	1.10 (0.87, 1.39)	120	1.07 (0.81, 1.42)	47	1.08 (0.69, 1.71)
[10,15)	157	1.53 (1.20, 1.97)	123	1.65 (1.24, 2.20)	32	1.16 (0.70, 1.92)
[15,25)	165	1.40 (1.09, 1.80)	121	1.41 (1.05, 1.90)	42	1.31 (0.80, 2.15)
[25,50)	114	1.87 (1.42, 2.45)	81	1.81 (1.32, 2.49)	32	1.96 (1.17, 3.29)
[50+]	58	2.66 (1.92, 3.70)	42	2.64 (1.80, 3.89)	16	2.75 (1.47, 5.14)
P for trend		*0.022*		*0.025*		*0.02*
ERR/100 mGy (95% CI)		1.96 (1.10, 3.12)		2.01 (1.02, 3.42)		2.02 (0.47, 4.77)

Poisson regression stratified for sex/birth cohort/country, 2-year lag, 2-year exclusion, no evidence of non-linearity

Bosch de Basea, Nat Med 2023

Interpretation of results

- Brain cancer results supported by Australian study
- Somewhat higher risks than a-bomb survivors (LSS*)

	LSS	EPI-CT
Brain	0.61 (0.01, 6.39)	1.27 (0.51, 2.69)
Leukemia excl. CLL	0.77 (0.31, 1.2)	1.66 (0.43, 3.74)
NHL	0.88 (0.36, 3.6)	2.51 (1.14, 4.73)

- Strength: exposure events electronically recorded
- Major weakness: lack of data on indication
  → risk of indication bias & reverse causation
  - Slow growing tumors
  - Cancer susceptibility syndromes (CSS)
- Indirect evidence: indication bias & reverse causation unlikely to explain results

*Age at exposure<20 (35 NHL) yrs, follow-up<20 yrs after exposure

Clinical implications

- Per 10,000 children with 1 head CT (20 mGy), about 1 radiation-induced brain cancer expected in following decade
- Per 10,000 children with 1 CT (8 mGy), 1-2 radiation-induced hematological malignancies expected in following decade
- 3.3 million pediatric CTs per year in the US in 2023, including 1.6 million head CTs

Projected number of cancers caused

- US, 2023: 61,510,000 patients had 93,000,000 CT examinations (based on IMV Medical Information Division CT Market Outlook Report)

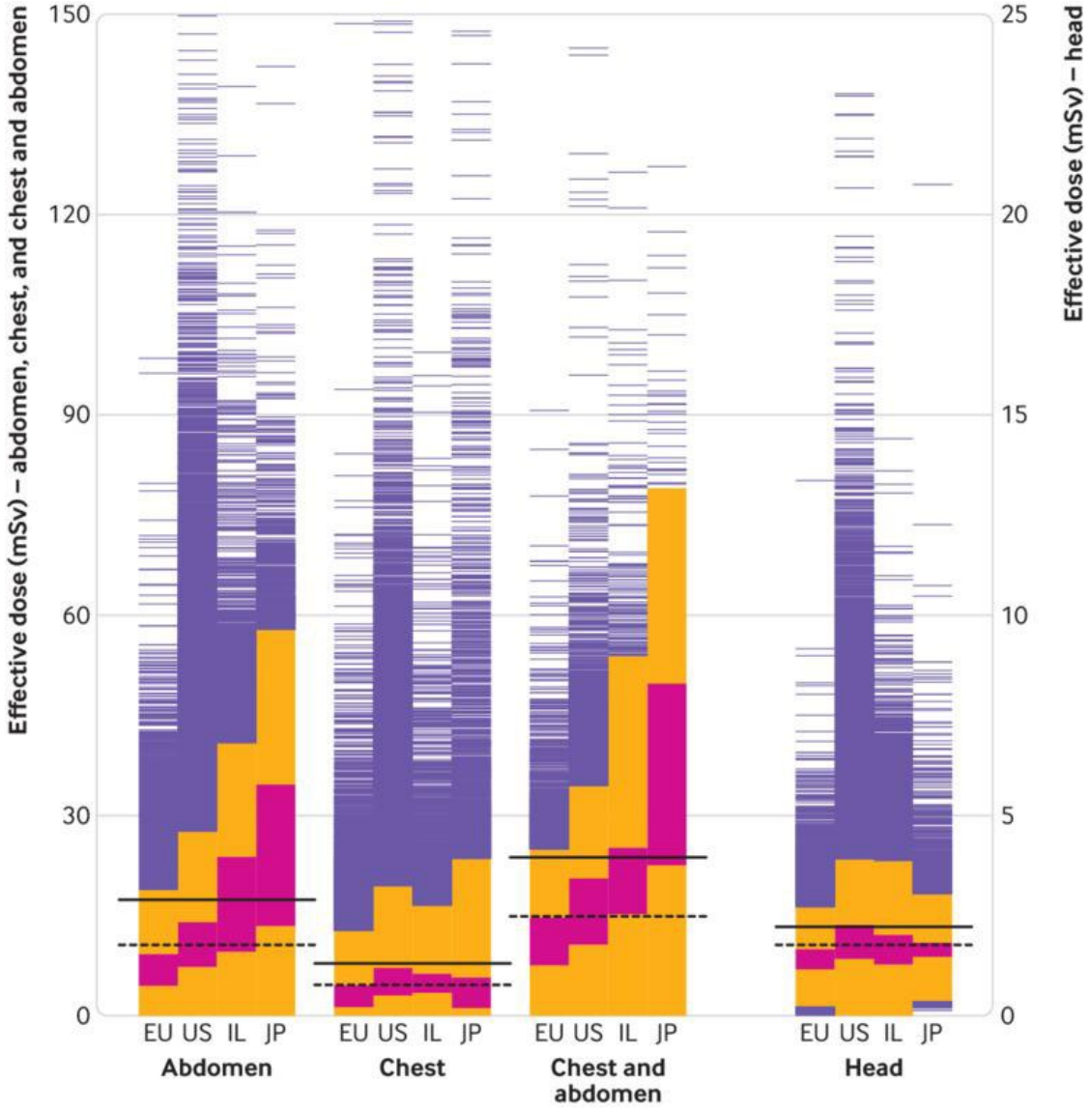
JAMA Internal Medicine | Original Investigation

Projected Lifetime Cancer Risks From Current Computed Tomography Imaging

Rebecca Smith-Bindman, MD; Philip W. Chu, MS; Hana Azman Firdaus, MPH; Carly Stewart, MHA; Matthew Malekhedayat, BS; Susan Alber, PhD; Wesley E. Bolch, PhD; Malini Mahendra, MD; Amy Berrington de González, DPhil; Diana L. Miglioretti, PhD

- Age & sex distribution from 120,000 CTs (0.1%) in the ACR National Radiology Data Registry 2016-2020: 2,570,000 (4.2%) children
- 103,000 radiation-induced cancers projected to result from 2023 CTs, including 9700 in children (leukemia 550, brain 440)
- CT-associated cancer may account for 5% of new cancer diagnoses annually
- Projections largely based on BEIR VII model (LSS data) from 2005

Dose reduction & CT reduction?



International dose variation 2015-2017

- 2 million adult CTs
- 151 institutions
- 7 countries
- 4-17-fold range

More (randomized) studies on effectiveness of CT and improved patient outcomes?

Smith-Bindman et al, BMJ 2019

Conclusions

- Strong dose-response for brain cancer and hematologic malignancies after pediatric CT
- Significant ERR down to <50 mGy, no threshold
- Confounding by indication unlikely (external evidence)
- Substantial number of brain cancers and hematological malignancies due CT-related radiation
- No empirical evidence yet for adult CT exposures or for other cancer sites, other diseases (cognition?)
- Longer follow-up needed to evaluate latency patters but unlikely due to UK privacy regulations

image gently®

The Alliance for Radiation Safety in Pediatric Imaging

Upcoming: Risk of Pediatric and Adolescent Cancer Associated with Medical Imaging (RIC) Study

- North America (Kaiser Permanente) and Ontario
- Children exposed to diagnostic medical radiation in utero & during childhood

	RIC		EPI-CT	Australia
	Fetal-exposure cohort	Childhood-exposure cohort		
Children	3,474,000	3,724,632	1,170,186	611,544
Cancers	6,606	6,358		
Leukemias	2394	2,372		
Avg f-up (yr)	10.8	9.7	9.3	13.5
Exposed to CT	17,370	219,753	1,170,186 344 leukemia	611,544 246 leukemia

Kwan et al, Cancer Causes Control 2022