Doses from diagnosis, staging, response assessment and follow-up in patients submitted to radiotherapy

Marco Brambilla
Head of Medical Physics Department
University Hospital "Maggiore della Carità" Novara
marco.brambilla@maggioreosp.novara.it

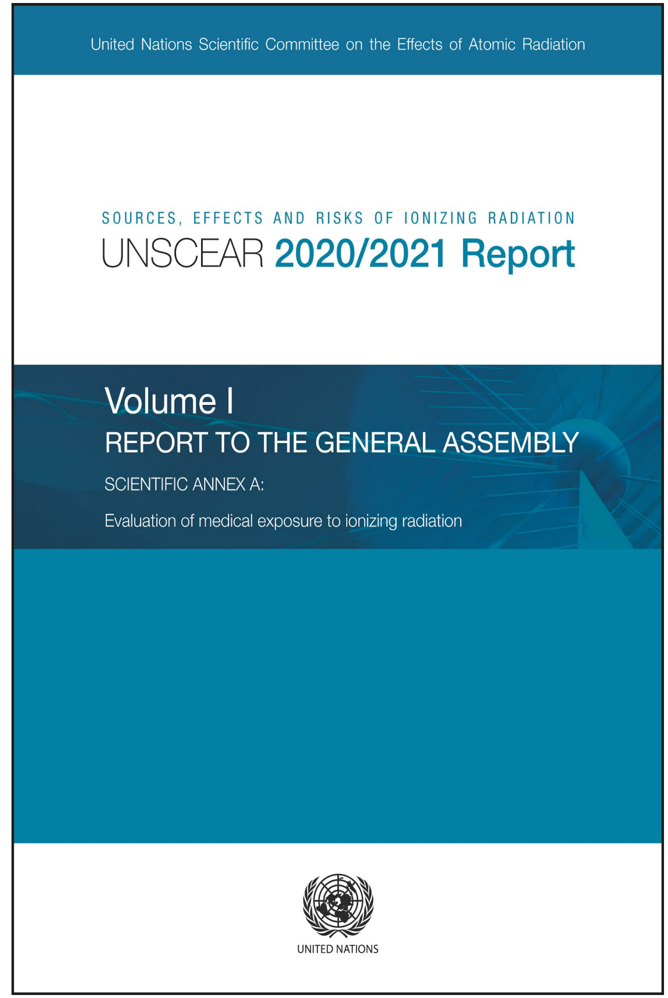
Joint ICTP-IAEA Workshop on Radiation Protection in Image-Guided Radiotherapy (IGRT)

Summary

- Overview of patient doses in medical imaging exposures
- Which patients undergo imaging with high cumulated radiation doses?

Data Collection

- Data collected between 2009-2018
- Frequencies and estimated effective doses of examinations/procedures
- Average Individual Effective Dose using tissue weighting factors as per ICRP 60

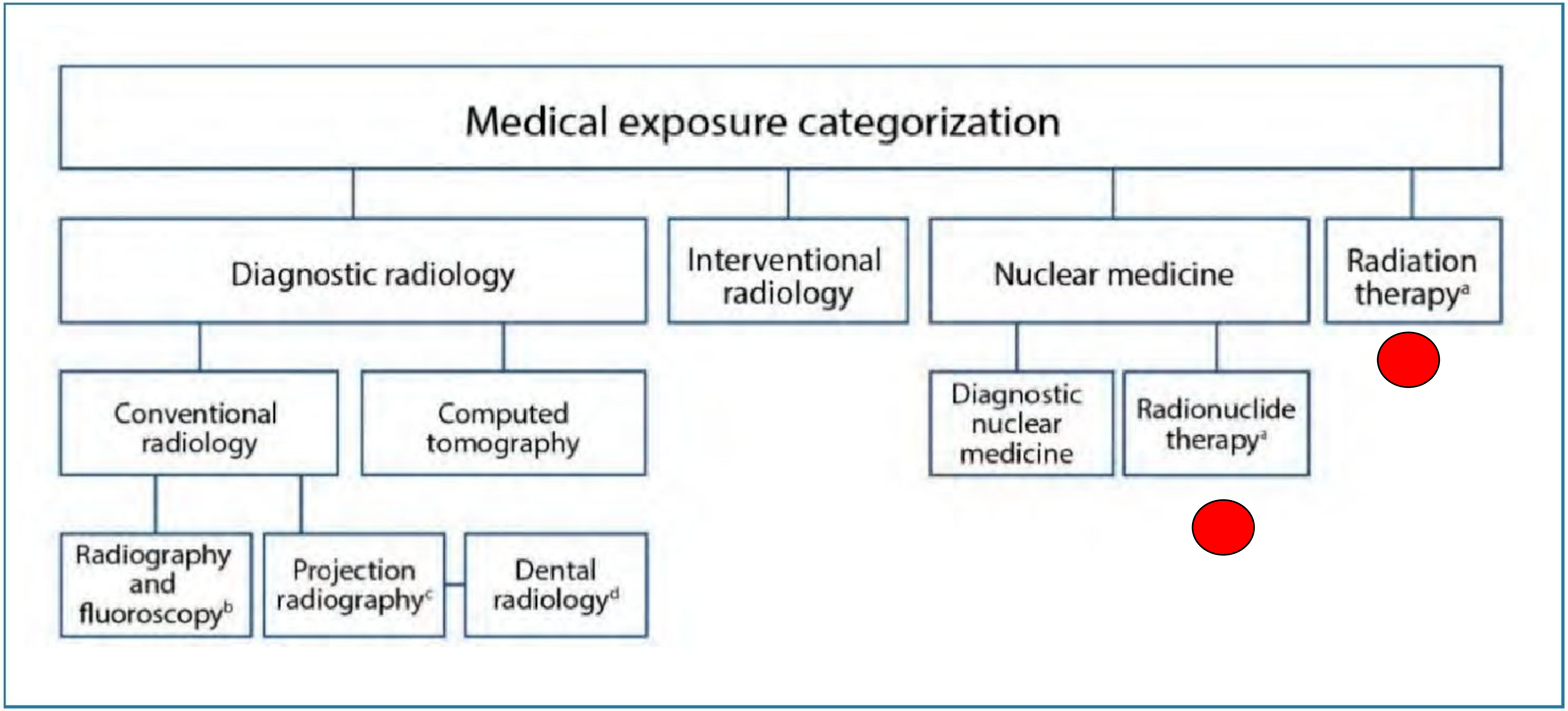


Main calculations

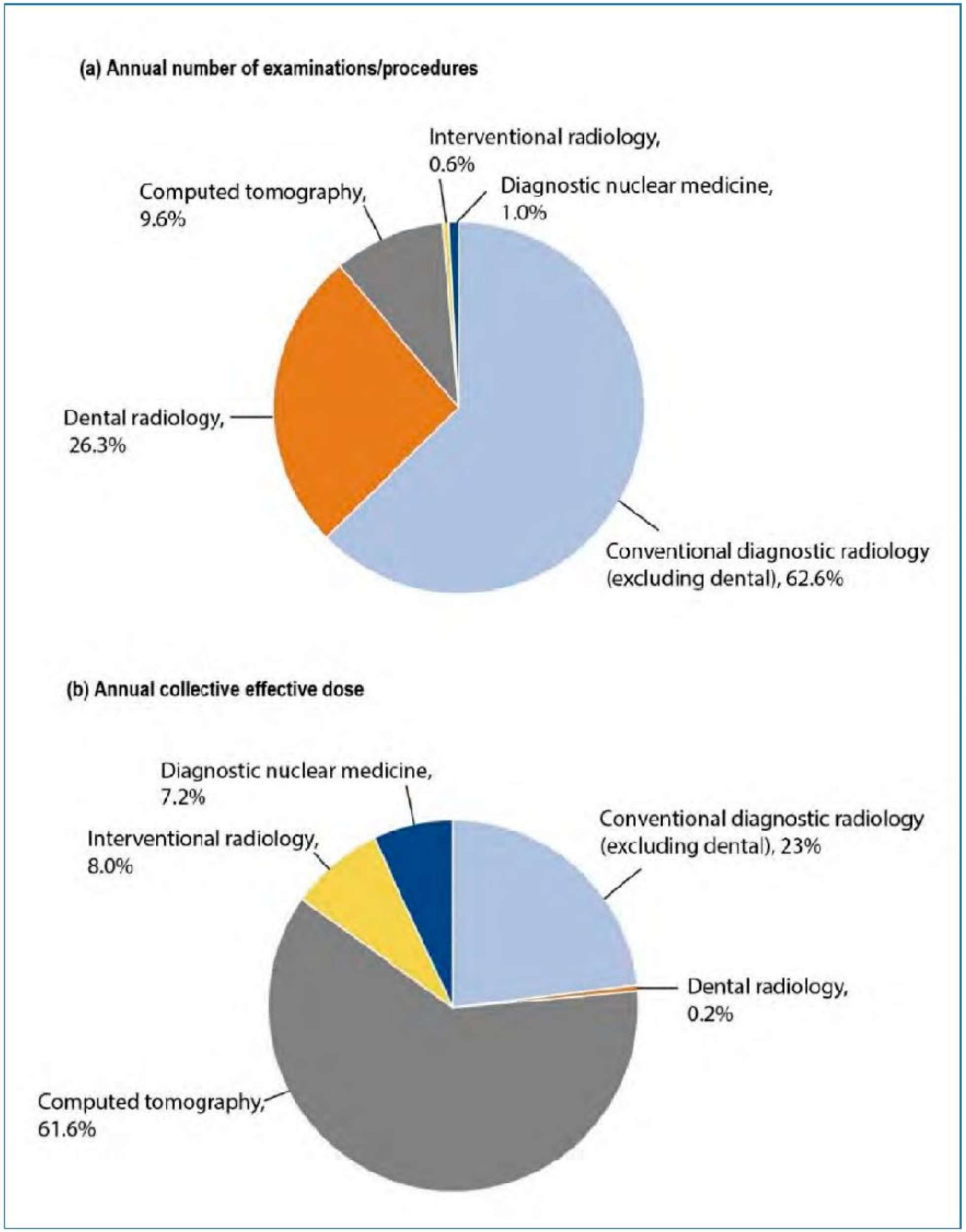
- N = number of imaging procedures **(N)**
- Effective Dose **(E)** per procedure (mSv)
- Collective Effective Dose **(S)** (person-Sievert) = **E*N**
- **Average Individual Effective Dose (E_W) (mSv)**
- **E_W = S/Population***

* World 7312 million population 2018

Modality categorization scheme used for UNSCEAR medical exposure global assessment



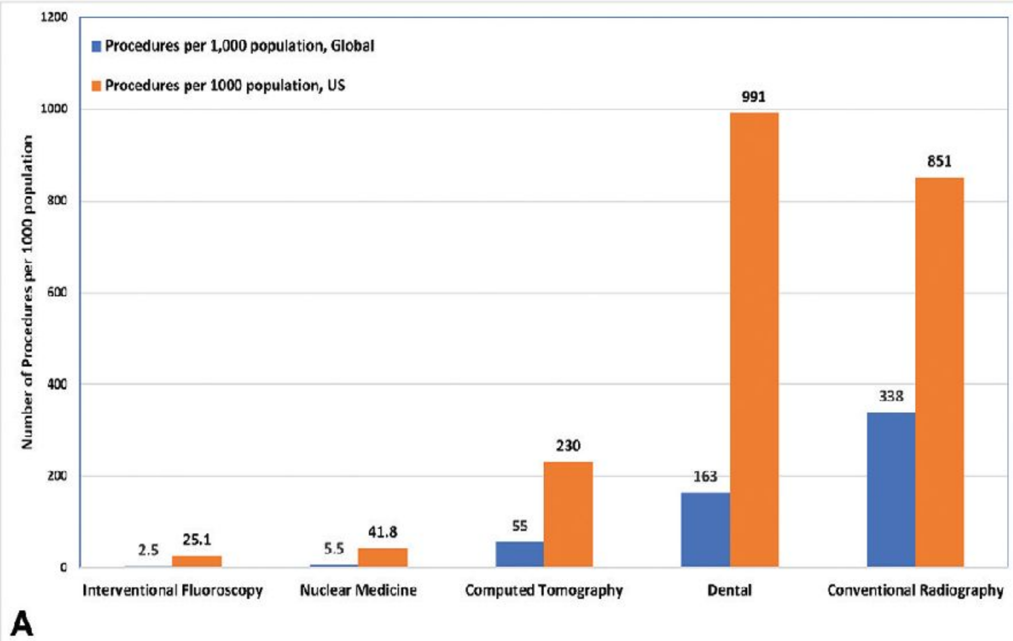
Relative contributions by modality category to (a) estimated annual number of examinations/procedures and (b) estimated annual collective effective dose (2009–2018)



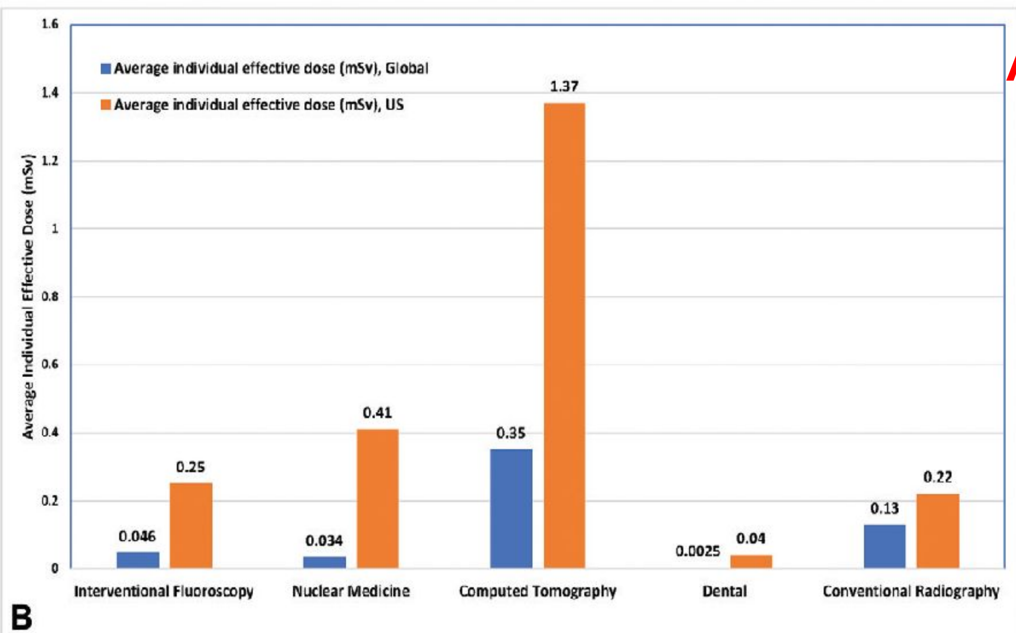
Modality category	*Examinations/ procedures (millions)* [a]	*Collective effective dose (1 000 man Sv)* [a,b]
Conventional radiology (excluding dental)	2 626	955
Dental radiology	1 101	10
Computed tomography	403	2 556
Interventional radiology	24	334
Diagnostic nuclear medicine	40	297
Radionuclide therapy [c]	1.4	Not included
Radiation therapy [c]	6.2	Not included
Total	**4 194**	**4 152**

UNSCEAR 2020-2021

Comparison of (A) procedures per 1000 people and (B) annual average individual effective dose for various categories between worldwide and United States.



PROCEDURES



Annual AVERAGE individual Effective Dose

GLOBAL

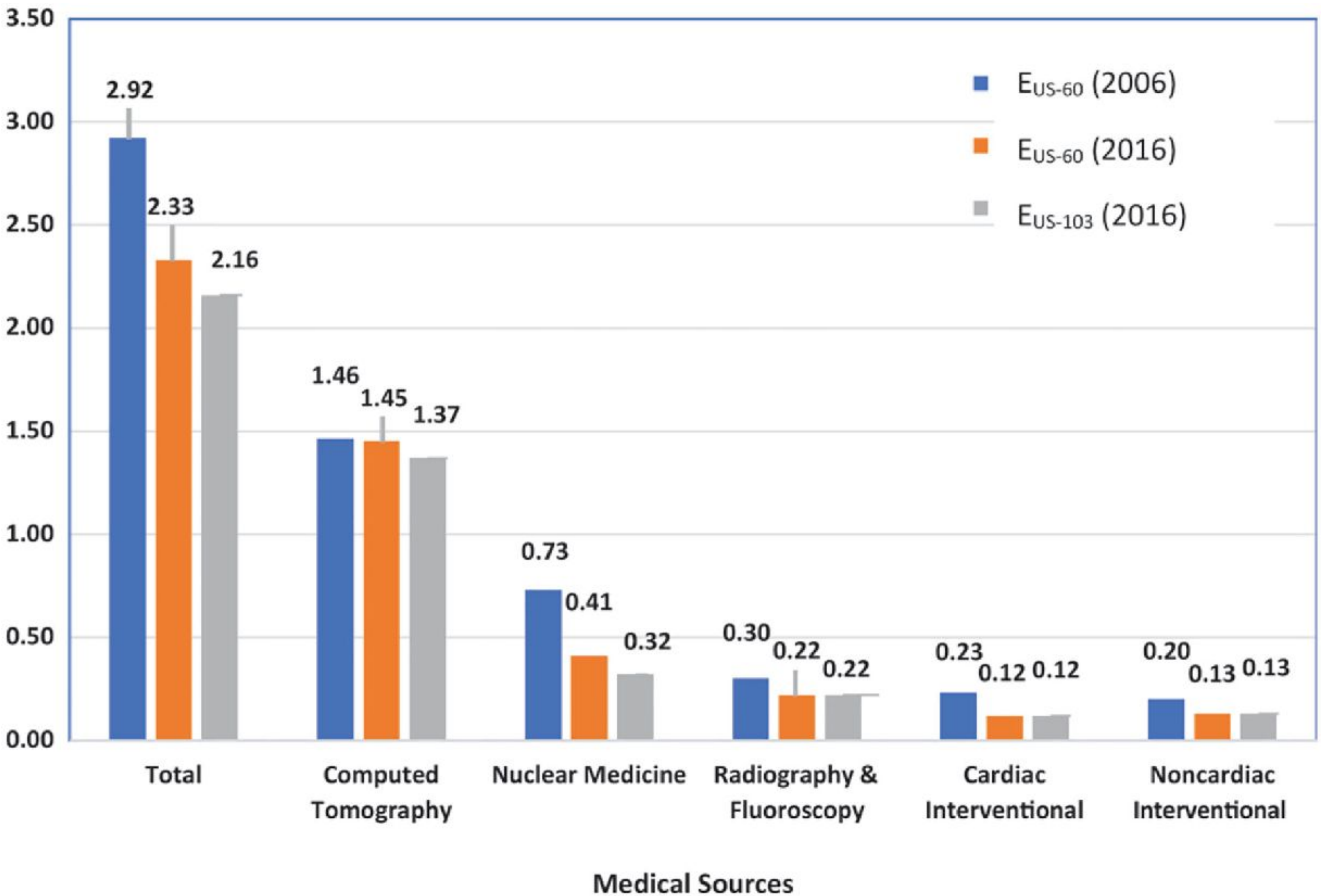
Annual per capita dose = 0.53 mSv

US

Annual per capita dose = 2.2 mSv

Mahesh M, 2023 Patient Exposure from Radiologic and Nuclear Medicine Procedures in the United States and Worldwide: 2009-2018. Radiology. 2023 Apr;307(1):e221263.

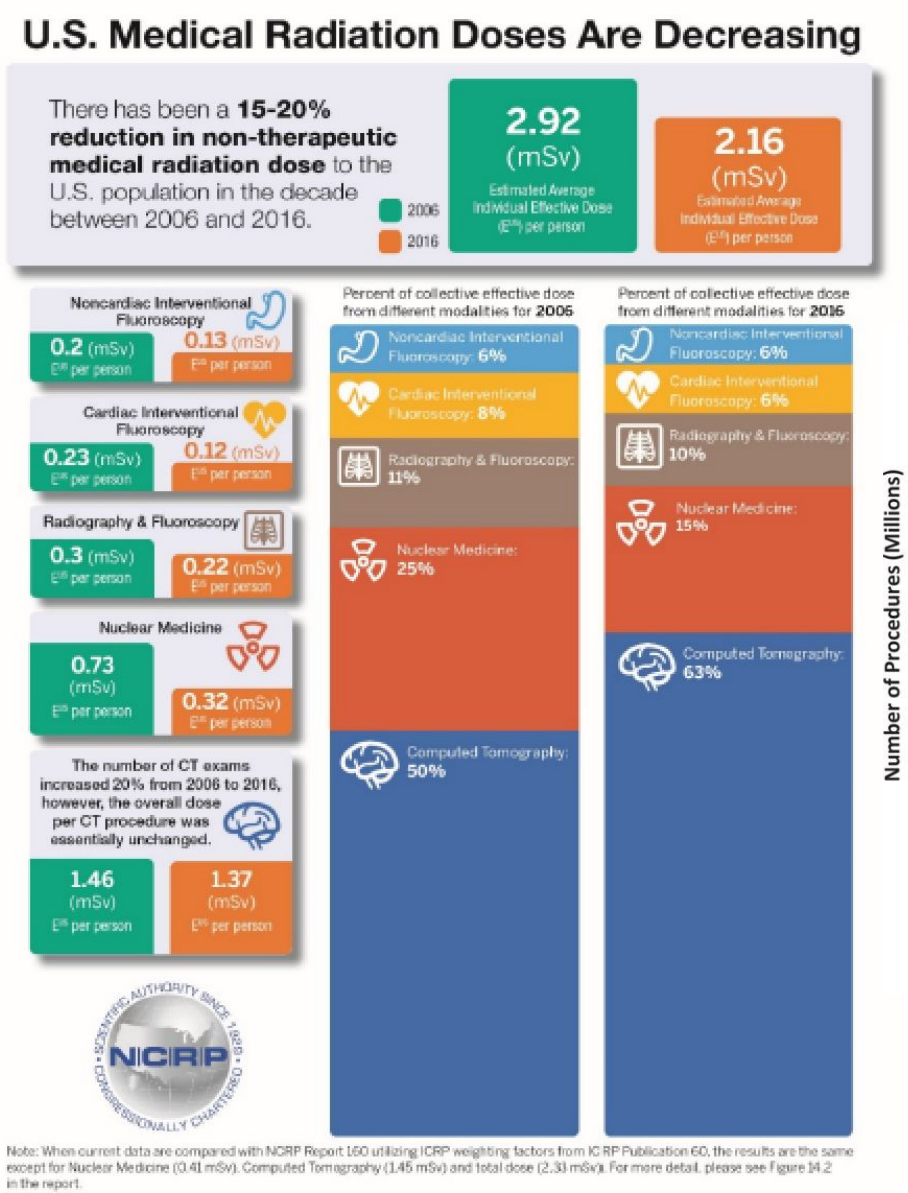
Average annual individual effective dose in the US from diagnostic patient radiation exposures (in mSv). Comparison between 2006 and 2016



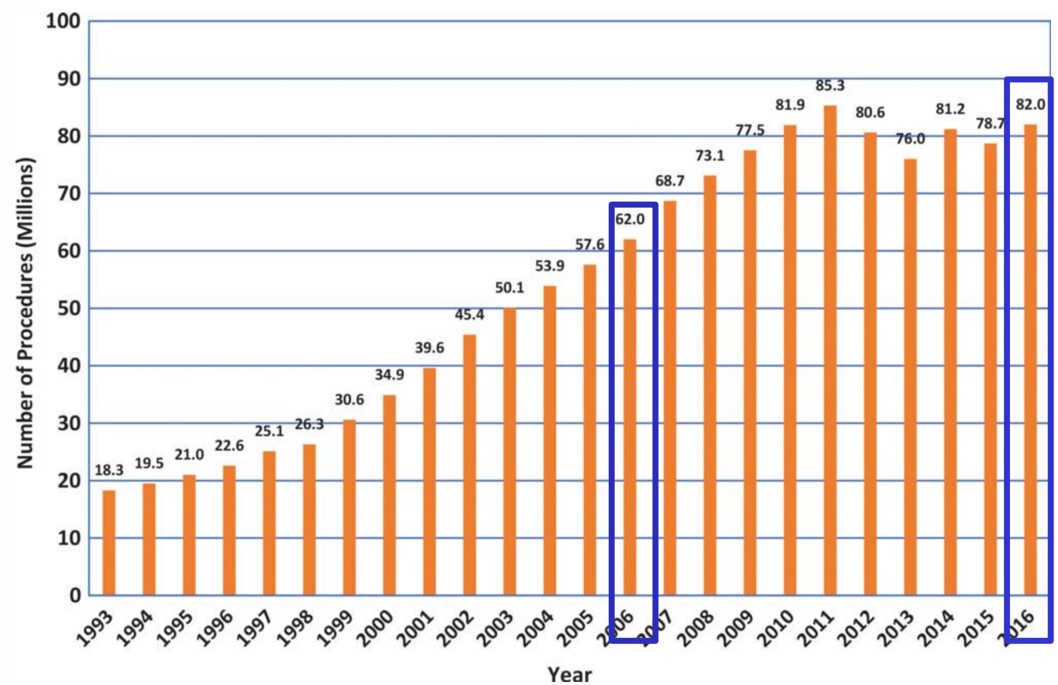
US individual effective dose from diagnostic and interventional medical procedures was estimated as 2,9 in 2006 and 2,2 in 2016, a decrease of approximately 20% in ten years

Mettler FA et al Patient Exposure from Radiologic and Nuclear Medicine Procedures in the United States: Procedure Volume and Effective Dose for the Period 2006-2016. Radiology. 2020 May;295(2):418-427.

NCRP Report n.184



There has been a substantial reduction in medical radiation doses to the U.S. population since NCRP Report No. 160 was published in 2009.



Number of CT procedures in the US Increased by 20% over 10 years! 2006 - 2016

UNSCEAR 2020-2021

Table 20. Comparison of UNSCEAR global medical exposure evaluations

Evaluation	*Annual number of examinations (millions)* [a]	*Annual frequency of examinations per 1 000 population* [a]	*Annual collective effective dose (1 000 man Sv)* [a,b]	*Annual effective dose per caput (mSv)* [a, b]
UNSCEAR 1988 Report [U4]	1 740	355	1 890	0.37
UNSCEAR 1993 Report [U5]	1 620	305	1 780	0.33
UNSCEAR 2000 Report [U6]	2 460	426	2 460	0.43
UNSCEAR 2008 Report [U9]	3 660	561	4 210	0.65
Current evaluation	4 190	574	4 150[b]	0.57

[a] Values are rounded.

[b] For the effective dose determination, ICRP 60 [I9] tissue weighting factors were applied.

Projection Radiology

Typical effective doses and average relative frequencies of procedures

Examination type	*Typical effective dose (mSv)*[a,b]	*Relative frequency (%)*[b]
CONVENTIONAL RADIOLOGY (EXCLUDING DENTAL)		
Projection radiography (excluding dental)		
Head (skull and facial bones)	0.08	2.3
Head (soft tissue)	0.15	0.06
Neck (cervical spine)	0.13	2.6
Neck (soft tissue)	0.51	0.05
Chest-thorax	0.08	32
Chest (thoracic spine)	0.45	1.9
Chest (shoulder girdle and ribs)	0.06	2.9
Mammography[c]	0.22	6.0
Mammography (screening)[c]	0.28	7.2
Lumbar spine	1.0	6.1
Lumbo-sacral joint only	0.33	0.37
Abdomen	0.61	2.9
Pelvis and hips (bone)	0.49	7.5
Pelvis (soft tissue)	1.5	0.35
Limbs and joints	0.02	21
Whole spine (trunk)	1.5	0.20
Skeletal (head and trunk)	0.5	0.29
Others[d]	0.22	2.9

Projection Radiology

Conversion factors used in effective doses calculation from DAP values for projection radiography examinations

Examination type	*Conversion factor (mSv/(Gy cm²))*
Head (skull and facial bones)	0.14
Head (soft tissue)	0.14
Neck (cervical spine)	0.28
Neck (soft tissue)	0.28
Chest-thorax	0.18
Chest (thoracic spine)	0.19
Chest (shoulder girdle and ribs)	0.19
Mammography	
Mammography (screening)	
Lumbar spine	0.21
Lumbo-sacral joint only	0.21
Abdomen	0.26
Pelvis and hips (bone)	0.29
Pelvis (soft tissue)	0.29
Limbs and joints	0.16

Radiography and Fluoroscopy

Typical effective doses and average relative frequencies of procedures

Examination type	Typical effective dose (mSv)[a,b]	Relative frequency (%)[b]
Radiography and fluoroscopy		
Gastrointestinal tract (barium studies)	3.4	0.59
Gastrointestinal tract (defecography)	8.8	0.04
Biliary tract (cholangiography)	8.5	0.02
Biliary tract (endoscopic retrograde cholangiopancreatography)	4.9	0.06
Biliary tract (cholecystography)	1.4	0.01
Urogenital tract (Intravenous urography)	2.4	0.23
Urogenital tract (kidney, bladder and urethra)	1.6	0.12
Myelography	5.5	0.01
Arthrography	2.1	0.09
Cerebral angiography	6.9	0.03
Cardiac angiography	7.0	0.78
Thoracic angiography	4.8	0.08
Examination type	Typical effective dose (mSv)[a,b]	Relative frequency (%)[b]
Abdominal angiography	8.0	0.03
Pelvic angiography	7.5	0.02
Peripheral angiography	3.2	0.09
Lymphangiography	1.0	0.0002
Others[d]	4.8	1.1

Radiography and Fluoroscopy

Conversion factors used for effective doses calculation from dose area product values for

radiography and fluoroscopy examinations

Examination type	*Conversion factor (mSv/(Gy cm²))*
Gastrointestinal tract (barium studies)	0.20
Gastrointestinal tract (defecography)	0.28
Biliary tract (cholangiography)	0.25
Biliary tract (ERCP)	0.26
Biliary tract (cholecystography)	
Urogenital tract (IVU)	0.18
Urogenital tract (kidney, bladder and urethra)	0.18
Myelography	
Arthrography	0.10
Cerebral angiography	0.087
Cardiac angiography	0.20
Peripheral angiography	0.10

Dental Radiology

Typical effective doses and average relative frequencies of procedures

Examination type	*Typical Effective dose (mSv)*	*Relative Frequency (%)*
Dental Intraoral	0.006	74
Dental Panoramic	0.024	26

Dental Radiology

Typical effective doses and average relative frequencies of procedures

Examination type	*Typical Effective dose (mSv)*	*Relative Frequency (%)*
Dental Intraoral	0.006	74
Dental Panoramic	0.024	26

Computed Tomography

Typical effective doses and average relative frequencies of procedures

Examination type	*Typical effective dose (mSv)*[a,b]	*Relative frequency (%)*[b]
CT-head (skull and facial bones)	1.5	13.6
CT-head (soft tissue and brain)	1.9	16.4
CT-neck (cervical spine)	3.1	2.9
CT-neck (soft tissue)	2.8	1.2
CT-chest (thoracic spine)	8.0	1.4
CT-chest (thorax)	6.4	15.7
CT-abdomen (lumbar spine)	9.4	4.2
CT-abdomen (abdomen)	11	15.4
CT-abdomen (liver, pancreas, kidneys)	10	3.2
CT-pelvis (pelvic bones)	8.8	2.4
CT-pelvis (pelvic soft tissue and vascular)	11	2.8
CT-pelvis (pelvimetry)	5.0	0.05
CT-full spine (neck, chest, abdomen)	14	1.4
CT-trunk (chest, abdomen, pelvis)	17	3.9
CT-limbs	2.1	2.4
CT-dental	0.7	0.3
Cone beam CT-dental	0.13	1.0
Cone beam CT-others	0.06	0.1
Others[d]	6.4	11.5

Computed Tomography

Conversion factors used for effective dose calculations from dose length product values

for computed tomography examinations

Examination type	*Conversion factor (mSv/(mGy cm))*
CT-head (skull and facial bones)	0.0021
CT-head (soft tissue and brain)	0.0021
CT-neck (cervical spine)	0.0059
CT-neck (soft tissue)	0.0059
CT-chest (thoracic spine)	0.014
CT-chest (thorax)	0.014
CT-abdomen (lumbar spine)	0.015
CT-abdomen (abdomen)	0.015
CT-abdomen (liver, pancreas, kidneys)	0.015
CT-pelvis (pelvic bones)	0.015
CT-pelvis (pelvic soft tissue and vascular)	0.015
CT-pelvis (pelvimetry)	0.015
CT-full spine (neck, chest and abdomen)	0.015
CT-trunk (chest, abdomen and pelvis)	0.015
CT-limbs	0.001
CT-dental	0.0021
CBCT-dental	0.002
CBCT-others	

Interventional Radiology

Typical effective doses and average relative frequencies of procedures

Examination type	*Typical effective dose (mSv)[a]*	*Relative frequency (%)*
Head (cerebral intervention)	12.6	1.0
PTCA	20.6	37.6
Chest (pacemaker)	1.4	4.8
Thoracic intervention (other)	2.8	8.1
Abdomen (biliary and urinary intervention)	7.2	3.3
Abdomen (TIPS)	27.8	0.1
Abdominal interventions (other)	32.0	1.8
Pelvic interventions	7.0	1.0
Limb interventions	13.6	3.8
Other interventional procedures	13.9	38.5

Nuclear Medicine Gamma camera and SPECT

Typical effective doses and average relative frequencies of procedures

Procedure	*Radiopharmaceutical component*[a]			*CT component*[a]	
	Isotope	*Typical effective dose (mSv)*	*Relative frequency (%)*	*Typical effective dose (mSv)*	*Fraction of CT (%)*
GAMMA CAMERA AND SPECT PROCEDURES					
Nervous system	^{99m}Tc	6.6	1.8	0.3	54
Nervous system	^{123}I	9.2	1.9		
Skeletal	^{99m}Tc	3.6	28.4	3.0	34
Cardiovascular	^{99m}Tc	6.8	23.7	1.0	55
Cardiovascular	^{201}Tl	14.4	3.4		
Pulmonary	^{99m}Tc	2.3	6.3	1.9	30
Endocrine	^{99m}Tc	3.0	12.8	1.4	24
Endocrine	^{123}I	24.5	1.6		
Gastrointestinal	^{99m}Tc	2.9	2.3	3.2	6
Genitourinary	^{99m}Tc	1.1	8.7		
Oncology	All	6.8	3.6	2.7	54
Infection, inflammation	^{99m}Tc	6.8	2.0	2.5	81
Lymphatics	^{99m}Tc	0.08	3.5		
Weighted dose per procedure (mSv)		4.9		0.6	
Fraction of SPECT systems with CT			32.2		
Weighted CT component				0.2	
Weighted dose per gamma camera and SPECT				**5.1**	

Nuclear Medicine PET

Typical effective doses and average relative frequencies of procedures

Procedure	*Radiopharmaceutical component*[a]			*CT component*[a]	
	Isotope	*Typical effective dose (mSv)*	*Relative frequency (%)*	*Typical effective dose (mSv)*	*Fraction of CT (%)*
Oncology	^{18}F	15.9	90.7	All procedures assumed to include CT Doses include CT component	
Oncology	^{68}Ga	12.4	1.3		
Cardiovascular	^{18}F	15.4	1.7		
Cardiovascular	^{15}O	1.6	0.3		
Skeletal	^{18}F	16.9	1.3		
Nervous system	^{18}F	5.4	2.6		
Infection, inflammation	^{18}F	16.8	0.5		
Weighted dose per PET procedure (mSv)		15.3			
Fraction of PET in all nuclear medicine procedures			17		
Combined weighted dose for nuclear medicine including PET				**6.8**	

Conclusions

- The current evaluation shows only a slight change from the UNSCEAR 2008 Report and a slight reduction in the effective dose per caput.
- This contrasts with the previous two UNSCEAR reports which showed notable increases, not only in the total number of examinations but also in the frequencies of examinations per 1,000 population and the annual effective dose per caput.
- This evaluation shows the influence of technological changes and changes in medical practice as previously more common procedures were supplanted by different techniques or phased out entirely.
- The use of computed tomography has continued to grow and the contribution from
- interventional radiology has increased rapidly. It appears likely that these two trends will continue and, thus, the effective dose per caput may be expected to rise again in the future as access to these techniques using ionizing radiation spreads to lower middle- and low-income countries.

Repeated radiation doses – the inconsistency

For radiation workers, we acknowledge and track cumulative radiation dose

Prior exposures matter

For imaging patients, we do not consistently acknowledge and track cumulative radiation dose

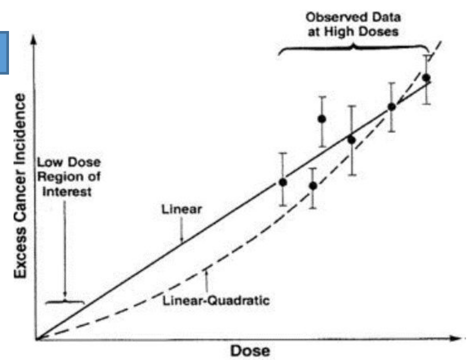
Prior exposures do NOT matter

Cumulative risk

Risk associated with a series of recurrent exposures to ionizing radiation is the summation of risk associated with every single low-dose exposure. Type 1 risk

Type 1 – risk that increase in effect with each added risk
Example 1 – smoking – smoking a cigarette will not cause lung cancer but if you continue to do it the risk of cancer increases.
Example 2 – Obesity – if you eat an hamburger this will not cause obesity but if you eat one hamburger per day your risk of becoming obese increases

Type 2 – risks that when done simultaneously cause greater danger than when done one at a time
Example 1 – driving, while smoking, while eating an hamburger, while texting
Example 2 (not assessed) – exposure to ionizing radiation, while receiving immunosuppressant therapy



The linear no-threshold (LNT) model of ionizing radiation–induced cancer assumes that every increment of radiation dose, no matter how small, constitutes an increased cancer risk for humans. Linear no-threshold is presently the most widely applied model for radiation risk assessment.

CED> 100 mSv per modality - CT

European Radiology (2020) 30:1828–1836
https://doi.org/10.1007/s00330-019-06523-y

COMPUTED TOMOGRAPHY

Patients undergoing recurrent CT scans: assessing the magnitude

Madan M. Rehani[1] · Kai Yang[1] · Emily R. Melick[1] · John Heil[2] · Dušan Šalát[3] · William F. Sensakovic[4,5] · Bob Liu[1]

Of the 2.5 million (2,504,585) patients who underwent 4.8 million (4,819,661) CT exams during the period of between 1 and 5 years, a total of 33,407 **(1.33%)** patients received a CED of ≥ 100 mSv.

The percentages in the 3 institutions ranged from 1.4% to 3.4%

European Radiology
https://doi.org/10.1007/s00330-019-06528-7

COMPUTED TOMOGRAPHY

Multinational data on cumulative radiation exposure of patients from recurrent radiological procedures: call for action

Marco Brambilla[1] · Jenia Vassileva[2] · Agnieszka Kuchcinska[3] · Madan M. Rehani[4]

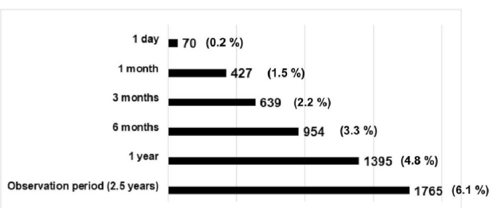
The data in this study from 20 countries covering 0.7 million patients during the period of between 0.4 and 6.1 years indicated that **0.65%** patients received CED ≥ 100 mSv.

These values ranged from 0 to **5.0%**

Patients undergoing multiphase CT scans and receiving a cumulative effective dose of ≥ 100 mSv in a single episode of care

Marco Brambilla[1] · Barbara Cannillo[1] · Andrea D'Alessio[1] · Roberta Matheoud[1] · Maria F. Agliata[2] · Alessandro Carriero[2]

Received: 18 November 2020 / Accepted: 22 December 2020



Among 28870 patients who underwent 49834 CT in 2.5 years:

70 received > 100 mSv in one day (0.24%)

427 received > 100 mSv within a month (1.5%)

1395 received > 100 mSv within a year **(4.8%)**

1765 received > 100 mSv in 2.5 years (6.1%)

COMPUTED TOMOGRAPHY

Cumulative radiation exposure from multimodality recurrent imaging of CT, fluoroscopically guided intervention, and nuclear medicine

Xinhua Li[1*], Madan M. Rehani[1], Theodore A. Marschall[1], Kai Yang[1] and Bob Liu[1]

Of the 189.030 patients who underwent 575,326 CT exams during the period of 4 years, a total of **5.3%** of patients received a CED of ≥ 100 mSv.

Occurrence – Prevalence - Incidence

Most of the studies assessing patients with CED ≥ 100 mSv reported an "occurrence" by extending their period of observation to a variable number of years in which the doses were cumulated while some studies collected the data only through surveys with the well-known problems of low return rate, potential bias and inaccuracy of data, making difficult the quantitative assessment of the phenomenon as well as the comparison between hospital regarding the management of patients with recurrent exposures.

PREVALENCE is a measure of the number (or the proportion) of
1. existing cases of
2. patients who accrued a CED≥ 100 mSv in the
3. population of patients who undergo a CT examination within a
3. Specific time period (regardless of when they first developed the characteristic)

INCIDENCE is a measure of the number (or the proportion) of
1. new cases of
2. patients accruing a CED≥ 100 mSv that develop in the
3. population of patients who undergo a CT examination in
3. one year/ three years

We should avoid speaking generically about occurrence!!!
Prevalence cannot be used to estimate risk of NEW cases!!!

Recurrent patients with high CED due to repeated CT scans

COMPUTED TOMOGRAPHY

Optimisation of protection in the medical exposure of recurrent adult patients due to computed tomography procedures: development of recurrent exposures reference levels

Marco Bramilla[1*], Luca Berton[2], Rosario F. Balzano[3], Barbara Cannillo[1], Alessandro Carriero[4], Stephane Chauvie[5], Teresa Gallo[6], Samantha Cornacchia[7], Claudia Cutaia[8], Andrea D'Alessio[1], Roberto Emanuele[5], Paolo Fonio[9], Roberta Matheoud[1], Michele Stasi[8], Alberto Talenti[10] and Osvaldo Rampado[2]

Table 3 Three-year cumulative incidence of patients with CED ≥ 100 mSv ($I_{100;3}$ (%)). Descriptive statistics of number and % of recurrent patients, number of examinations, number of patients with CED ≥ 100 mSv, CED values in different hospitals, reported for the year 2021

Hospital	*N.* of patients in 2021	Recurrent pts		*N.* of pts with CED ≥ 100 mSv	$I_{100;3}$	CED (mSv)				*N* of exams/pts	
		N	%		%	Median	Max	First quartile	Third quartile	Mean	Max
H1	29,812	10,454	35.0	2057	6.7	13.1	544	4.5	36.3	2.4	28
H2	13,165	3457	26.2	148	1.1	9.4	244	3.6	25.0	2.4	24
H3	17,697	6734	38.0	2023	11.4	20.7	700	6.4	53.5	2.5	32
H4	14,025	3158	23.0	961	7.0	12.5	937	6.3	35.4	1.9	18
H5	9777	3458	35.3	268	2.7	8.4	310	2.7	23.8	2.3	16
H7	8623	2329	26.7	748	8.7	15.9	628	7.1	45.4	1.4	12
H8	6125	1961	32.0	469	7.7	16.3	447	4.2	47.0	2.0	13

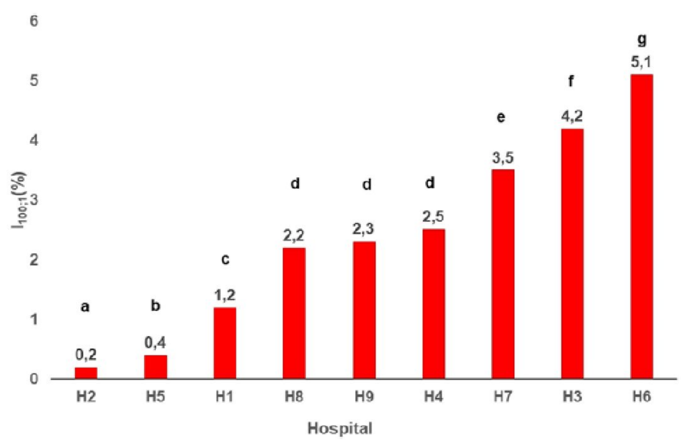


Fig. 1 Histogram distribution of the yearly incidence $I_{100;1}$ (%) in 2021 or 2022 (for H6 and H9). Different letters above bars indicate statistically significant differences (*Z*-test; $p < 0.01$)

Median $I_{100:1}$ (%)
2.4%

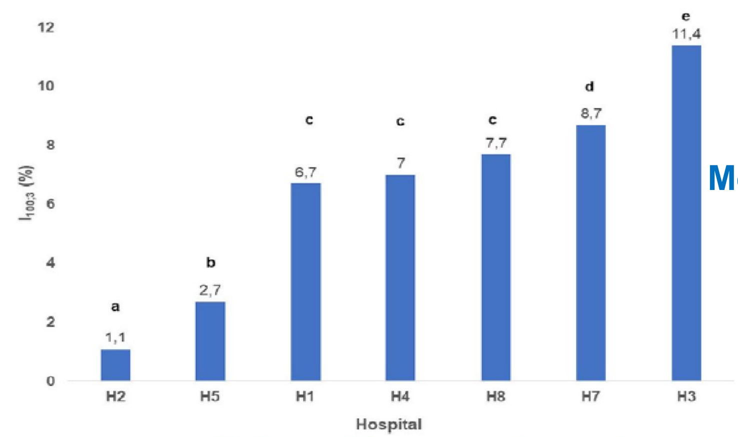


Fig. 3 Histogram distribution of the 3-year cumulative incidence $I_{100;3}$ (%). Different letters above bars indicate statistically significant differences (*Z*-test; $p < 0.01$)

Median $I_{100:3}$ (%)
7 %

$$I_{100;1}(\%) = \frac{N.\ \text{of patients with CED} \geq 100\ \text{mSv in year } i}{N.\ \text{of patients receiving a CT exam in year } i} \times 100$$

$$I_{100;3}(\%) = \frac{N.\ \text{of patients in 2021 with CED} \geq 100\ \text{mSv in 3 cumulative years } (2020-2022)}{N.\ \text{of patients receiving a CT exam in 2021}} \times 100$$

Brambilla et al Optimisation of protection in the medical exposure of recurrent adult patients due to computed tomography procedures: development of recurrent exposures reference levels Eur Radiol 2024

Recurrent patients with high CED due to repeated CT scans

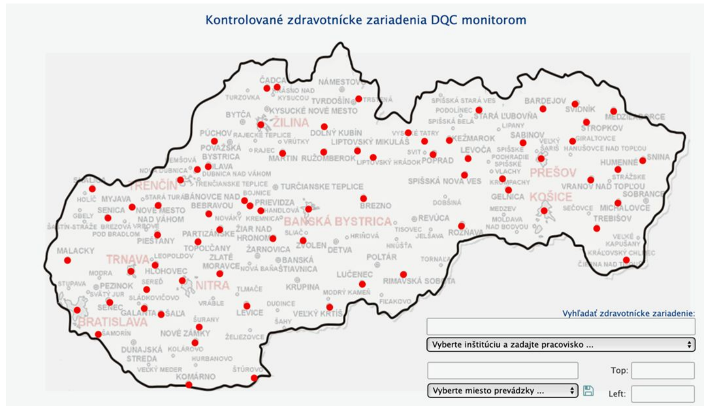
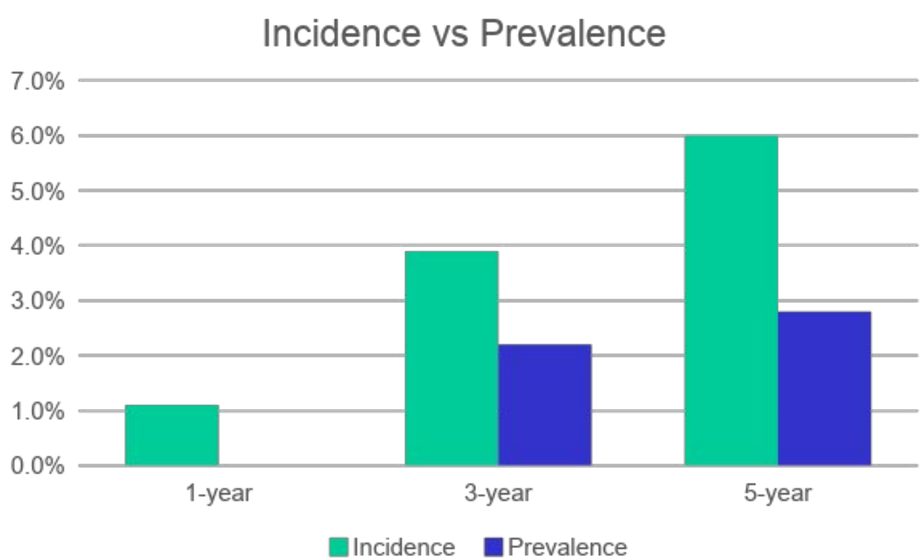
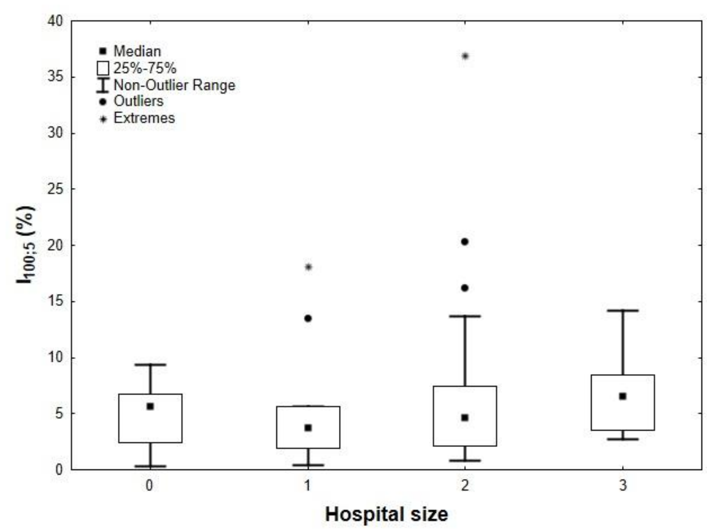


Figure 1. Map of healthcare centres with CTs monitored by Slovakian Institute of Radiation Protection





Brambilla et al Establishment of recurrent exposures reference levels for repeated computed tomography examinations in adult patients on a nationwide level in Slovakia. Eur Radiol 2024 accepted for publication

- There is no meaningful way to incorporate cumulative doses into actionable risk-benefit decisions.
- There is no scientific or medical consensus on what to do when a specific cumulative effective or organ dose is reached.

A workable system to introduce the concept of cumulated dose into the framework of patient radiation protection

Directions

- Harmonization of referral guidelines for **patients who need recurrent imaging** keeping into account the CED expectancy.

- **Recurrent Exposures reference levels (RERL)** for optimization of imaging in patients with recurrent exposures.

Which patients undergo imaging with high CED?

Patients undergoing recurrent CT exams: assessment of patients with non-malignant diseases, reasons for imaging and imaging appropriateness

Nearly 90% of patients with CED> 100 mSv (n = 8,091; 90.4%) had malignant diagnoses and only 10% (n = 861; 9.6%) had non-malignant diagnoses.

Rehani M et al Eur Radiol 30 (2020)

Patients undergoing multiphase CT scans and receiving a cumulative effective dose of ≥100 mSv in a single episode of care

The patient's clinical indication for referral together with the estimated CED values included cancer in 132 patients (31%).

Brambilla M et al Eur Radiol 31 (2021)

Which patients undergo imaging with high CED?

Which patients are prone to undergo disproportionate recurrent CT imaging and should we worry?

56 patients who underwent > 40 CT in 10 years (0.06% of the total number of patients scanned with CT).

All patients were oncological. All but one with metastatic disease

79 % major surgery	**68% targeted therapy**	**63% radiotherapy**	**61% involved in clinical trials**

median CT number = 47

mean CED = 187 mSv

Mean $LAR_{incidence}$ = 1%

Mean $LAR_{mortality}$ = 0.7%

The vast majority of CT scans were performed for therapy response assessment or surveillance imaging.

Kwee T et al EJR 125 (2020)

Cohorts of non-oncological recurrent patients with high CED

- Multiple higher dose imaging procedures (CT, interventional, hybrid, etc.) on the same patient
- Cumulative dose above 100 mSv in a few years/ weeks/ days

Magnitude of the phenomenon in selected cohorts of patients

ESKD- Dialysis – Kid Int 2010

Maintenance hemodialysis patients have high cumulative radiation exposure

Sinead M. Kinsella[1], Joe P. Coyle[2], Eva B. Long[1], Sebastian R. McWilliams[2], Michael M. Maher[2], Michael R. Clarkson[1] and Joseph A. Eustace[1]

[1]Department of Nephrology, Cork University Hospital, Wilton, Cork, Ireland and [2]Department of Radiology, Cork University Hospital, Wilton, Cork, Ireland

ESKD- Dialysis – JASN 2011

Estimated Radiation Exposure from Medical Imaging in Hemodialysis Patients

Andreana De Mauri,* Marco Brambilla,† Doriana Chiarinotti,* Roberta Matheoud,† Alessandro Carriero,‡ and Martino De Leo*

*Nephrology Department, †Medical Physics Department, and ‡Radiology Department, University Hospital "Maggiore della Carità," Novara, Italy

ESKD- Transplant –NDT 2012

Nephrol Dial Transplant (2012) 0: 1–6
doi: 10.1093/ndt/gfs145

Original Article

Cumulative radiation dose from medical imaging in kidney transplant patients

Andreana De Mauri[1], Marco Brambilla[2], Cristina Izzo[3], Roberta Matheoud[2], Doriana Chiarinotti[1], Alessandro Carriero[4], Piero Stratta[3] and Martino De Leo[1]

Cardiac – JAMA 2010

Multiple Testing, Cumulative Radiation Dose, and Clinical Indications in Patients Undergoing Myocardial Perfusion Imaging

Andrew J. Einstein, MD, PhD
Shepard D. Weiner, MD

Context Myocardial perfusion imaging (MPI) is the single medical test with the highest radiation burden to the US population. Although many patients undergoing MP

Myocardial Infarction – Circ 2010

Ionizing Radiation Exposure to Patients Admitted With Acute Myocardial Infarction in the United States

Prashant Kaul, MD; Sofia Medvedev, PhD; Samuel F. Hohmann, PhD; Pamela S. Douglas, MD; Eric D. Peterson, MD, MPH; Manesh R. Patel, MD

Heart Transplant – *J Heart Lung Transplant* 2011

The Journal of Heart and Lung Transplantation
http://www.jhltonline.org

Radiation exposure after heart transplantation: Trends and significance

Mumin Noor, MRCP,[a] Jane Shekhdar, MIPEM,[b] and Nicholas R. Banner, FRCP[a,c]

Chronic – JACR 2010

Radiation Exposure From Medical Imaging in Patients With Chronic and Recurrent Conditions

Evan G. Stein, MD, PhD[a,b], Linda B. Haramati, MD, MS[a], Eran Bellin, MD[c,d], Lori Ashton, BA[c], Gus Mitsopoulos, MD[a], Alan Schoenfeld, MS[a], E. Stephen Amis Jr, MD[a]

Crohn's Disease – Gut 2008

Crohn's disease: factors associated with exposure to high levels of diagnostic radiation

A N Desmond,[1] K O'Regan,[2] C Curran,[1] S McWilliams,[1] T Fitzgerald,[3] M M Maher,[2] F Shanahan[1]

EV Aortic Repair- Radiol Med 2015

Radiol med (2015) 120:563–570
DOI 10.1007/s11547-014-0485-x

MEDICAL PHYSICS

Cumulative radiation dose and radiation risk from medical imaging in patients subjected to endovascular aortic aneurysm repair

Marco Brambilla · Paolo Cerini · Domenico Lizio · Luca Vigna · Alessandro Carriero · Rita Fossaceca

Lymphoma –BJR - 2021

Cumulative radiation doses due to nuclear medicine examinations: a systematic review

[1,2]MARCO BRAMBILLA, MSc, [3]AGNIESZKA KUCHCIŃSKA, MSc, [2]ROBERTA MATHEOUD, MSc and [4]ALFREDO MUNI

HCC–Liver transplant –EJR - 2023

Radiation exposure from radiological procedures in liver transplant candidates with hepatocellular carcinoma

Numan Kutaiba[a,b,*], Joshua G Varcoe[c,d], Peter Barnes[d], Natalie Succar[a], Eddie Lau[a,]

CED > 100 mSv Transplanted patients

Kidneys

ESKD- Dialysis – JASN 2011

Estimated Radiation Exposure from Medical Imaging in Hemodialysis Patients

Andreana De Mauri,* Marco Brambilla,† Doriana Chiarinotti,* Roberta Matheoud,† Alessandro Carriero,‡ and Martino De Leo*

*Nephrology Department, †Medical Physics Department, and ‡Radiology Department, University Hospital "Maggiore della Carità," Novara, Italy

No of patients: 106
Fu duration: 3 years
(>100 mSv): 16%
Annual CED: 22 mSv
Mean Age: 65 years

ESKD- Wait list –CJASN 2013

Ionizing Radiation Exposure among Kidney Transplant Recipients Due to Medical Imaging during the Pretransplant Evaluation

Kim N. Nguyen, Anup M. Patel,* and Francis L. Weng*†*

No of patients: 172
Fu duration: 3.7 years
(>100 mSv): 13%
Annual CED: 13 mSv
Mean Age: 51 years

ESKD- Transplant –NDT 2012

Nephrol Dial Transplant (2012) 0: 1–6
doi: 10.1093/ndt/gfs145

NDT
Nephrology Dialysis Transplantation

Original Article

Cumulative radiation dose from medical imaging in kidney transplant patients

Andreana De Mauri[1], Marco Brambilla[2], Cristina Izzo[3], Roberta Matheoud[2], Doriana Chiarinotti[1], Alessandro Carriero[4], Piero Stratta[3] and Martino De Leo[1]

No of patients: 92
Fu duration: 4 years
(>100 mSv): 12%
Annual CED: 16 mSv
Mean Age: 52 years

Heart

P Heart Transplant – *J Heart Lung Transplant* 2014

Radiol med (2015) 120:563–570
DOI 10.1007/s11547-014-0485-x

CrossMark

MEDICAL PHYSICS

Cumulative radiation dose and radiation risk from medical imaging in patients subjected to endovascular aortic aneurysm repair

Marco Brambilla · Paolo Cerini · Domenico Lizio · Luca Vigna · Alessandro Carriero · Rita Fossaceca

No of patients: 31
Fu duration: 1 year
Median CED: 53 mSv
Annual CED: 53 mSv
Mean Age: 13 years

Heart Transplant – *J Heart Lung Transplant* 2011

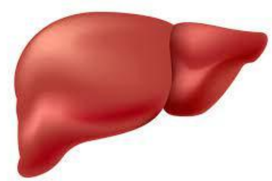
ELSEVIER

The Journal of Heart and Lung Transplantation
http://www.jhltonline.org

Radiation exposure after heart transplantation: Trends and significance

Mumin Noor, MRCP,[a] Jane Shekhdar, MIPEM,[b] and Nicholas R. Banner, FRCP[a,c]

No of patients: 202
Fu duration: 10 years
Mean CED: 84 mSv
Annual CED: 8 mSv
Mean Age: 46 years



Liver

Liver- Transplant –EJR 2023

Radiation exposure from radiological procedures in liver transplant candidates with hepatocellular carcinoma

Numan Kutaiba[a,b,*], Joshua G Varcoe[c,d], Peter Barnes[d], Natalie Succar[a], Eddie Lau[a]

No of patients: 179
Fu duration: 7 years
(>100 mSv): 85%
Annual CED: 56 mSv
Median Age: 58 years

CED > 100 mSv Lymphoma patients

Hodgkin Lymphoma– Cancer 2015

Very Low Utility of Surveillance Imaging in Early-Stage Classic Hodgkin Lymphoma Treated With a Combination of Doxorubicin, Bleomycin, Vinblastine, and Dacarbazine and Radiation Therapy

Neetha Gandikota, MD[1], Sidonie Hartridge-Lambert, MBBS[2], Jocelyn C. Migliacci, BS[2],

No of patients: 78
Fu duration: 3.8 years
(>100 mSv): NR
Total CED: **139 mSv**
Median Age: 43 years

Lymphoma– Eur J Radiol 2014

Estimated radiation exposure and cancer risk from CT and PET/CT scans in patients with lymphoma

Ravi Guttikonda[a,1], Brian R. Herts[a,b,*], Frank Dong[a], Mark E. Baker[a,b],

No of patients: 76
Fu duration: 2.6 year
(>100 mSv): 22 %
Total CED: **71 mSv**
Mean Age: 53 years

Lymphoma– Clin Transl Oncol 2016

Ionizing radiation exposure as a result of diagnostic imaging in patients with lymphoma

M. P. Crowley[1] · S. B. O'Neill[2] · B. Kevane[3] · D. C. O'Neill[2] · J. A. Eustace[4] ·

No of patients: 486
Fu duration: 3.6 years
(>100 mSv): 14%
Total CED: **69 mSv**
Annual CED: 48 mSv
Mean Age: 59 years

British J Radiol 2023

Cumulative radiation exposure from radiological imaging in patients with Hodgkin and diffuse large b-cell lymphoma not submitted to radiotherapy

[1]MARCO BRAMBILLA, PhD, [1]ROBERTA MATHEOUD, PhD, [2]GLORIA MARGIOTTA-CASALUCI, MD, [1]BARBARA CANNILLO, PhD, [1]ANDREA D'ALESSIO, PhD, [3]CHIARA SICILIANO, BsC, [3]ALESSANDRO CARRIERO, MD and [2]GIANLUCA GAIDANO, MD, PhD

Hodgkin Lymphoma

No of patients: 51
Fu duration: 3.5 years
(>100 mSv): 49%
Total CED: **114 mSv**
Annual CED: 40mSv
Median Age: 47 years

DLBC Lymphoma

No of patients: 83
Fu duration: 3.7 years
(>100 mSv): 67%
Total CED: **170 mSv**
Annual CED: 57 mSv
Median Age: 66 years

Which is the associate LAR for Lymphoma patients?

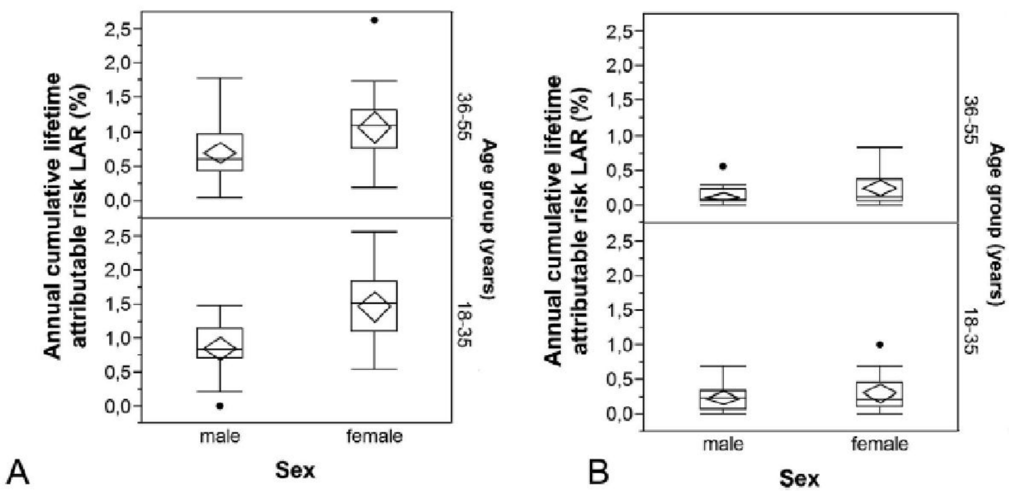


Figure 5. (A,B) Sex- and age-specific distribution of the average lifetime attributable risk of cancer incidence $\overline{LAR}$ cumulated over on year in (A) the first year after diagnosis and (B) each of the following years.

The average LAR for men and women associated to the diagnostic imaging procedures considered in the present study corresponds to about 1 excess cancer in 100 lymphoma patients from diagnostic imaging performed in the first year after diagnosis (mean LAR[1] ≈ 1%), and to an additional excess cancer case for imaging procedures carried-out during a follow-up period of 5 years ($LAR_{[2,6]}$ ≈ 0.23% per year)

The reported risk estimates overestimate the real risks to some extent since they were derived using life table data for the entire German population and not data specific for lymphoma patients with a reduced life expectancy.

The lifetime baseline cancer risk (incidence excluding non-melanoma skin cancer) of a 35-year-old man or woman in Germany is about 50 and 40%, respectively

Fabritius G et al Nature Sci Rep 2016

Justification and referral guidelines

Cancer. 2015 June 15; 121(12): 1985–1992. doi:10.1002/cncr.29277.

Very Low Utility of Surveillance Imaging in Early-Stage Classic Hodgkin Lymphoma Treated With a Combination of Doxorubicin, Bleomycin, Vinblastine, and Dacarbazine and Radiation Therapy

Neetha Gandikota, MD[1], Sidonie Hartridge-Lambert, MBBS[2], Jocelyn C. Migliacci, BS[2], Joachim Yahalom, MD[3], Carol S. Portlock, MD[2], and Heiko Schoder, MD[1]

The American Society of Hematology published the Choosing Wisely recommendations, which included a recommendation to limit CT surveillance in asymptomatic patients after curative-intent treatment for aggressive lymphoma

Hicks LK et al et al Blood 2013

Number and type of examinations recommended in German, US and European guidelines in 2016

Fabritius G et al Nature Sci Rep 2016

Justification and referral guidelines

Country	Type of Lymphoma (guidelines)	Initial workup	Number of examinations during		
			Therapy	Follow-up (5 years)	Refractory disease
Germany	HL	1 Chest X-ray 1 CT Neck/Thorax/Abdomen	2 CTs Neck/Thorax/Abdomen	Only in clinical relapse	1 CT Neck/Thorax/Abdomen
	DLBCL	1 CT Neck/Thorax/Abdomen	1 CT Neck/Thorax/Abdomen, 1 PET/CT or CT Neck/ Thorax/Abdomen	Not in routine follow-up	None
Italy	HL AIOM 2018	1 CT Neck/Thorax/Abdomen 1 PET/CT	1 CT Neck/Thorax/Abdomen, 1 PET/CT	1 CT Neck/Thorax/Abdomen,	1 CT Neck/Thorax/Abdomen, 1 PET/CT
	DLBCL AIOM 2018	1 CT Neck/Thorax/Abdomen 1 PET/CT	1 CT Neck/Thorax/Abdomen 1 PET/CT	1 CT Neck/Thorax/Abdomen, every six month (2 years)- yearly	
Europe	HL ESMO 2018	1 PET/CT and 1 CT Neck/Thorax/Abdomen	PET/CT	Only if clinical symptoms occur	Not specified
	DLBCL ESMO 2015	1 CT Neck/Thorax/ Abdomen and 1 PET/CT	PET/CT	Not in routine follow-up Option Neck/Thorax/Abdomen, 6,12 and 24 months	1 CT Neck/Thorax/ Abdomen and 1 PET/CT
USA	HL	1 Chest X-ray 1 PET/CT or CT Neck/Thorax/Abdomen	1-2 PET/CTs or CTs Neck/ Thorax/Abdomen	2-4 Chest-X-rays or CTs	1 PET/CT or CT
	DLBCL	1 CT Thorax/Abdomen and/ or 1 PET/CT	2 PET/CTs or 1 PET/CT and 1 CT Neck/Thorax/Abdomen	0-4 CTs Neck/ Thorax/Abdomen	None

Justification and referral guidelines

The significant CED in this category of patients should prompt a harmonization of guidelines to keep into consideration the CED expectancy according to different guidelines.

1. This principle could be followed in general for the clinical conditions in which it is known in advance that patient will likely be submitted to recurrent imaging

Conclusions

Although it may be controversial to incorporate CED into electronic medical record in the care of individual patients, one needs to acknowledge its benefits, such as:

- Effective dose is an appropriate dose metric to compare radiation burden of patient exams using different image modalities or in different anatomic regions.
- The concept of RERL could be easily introduced in the clinical practice following the consolidated methodology which lead to the establishment of DRLs
- Its utility for optimization of management of recurrent patients among different institutions and within the same institution
- Its utility in population research