Individual exposure tracking – Why and how?

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Summary

- Why tracking individual exposure?
  - Epidemiology
  - Data on high CED
  - Data on Chronic or recurrent patients
- How tracking individual exposure?

- Epidemiology

Atomic bomb survivors BEIR

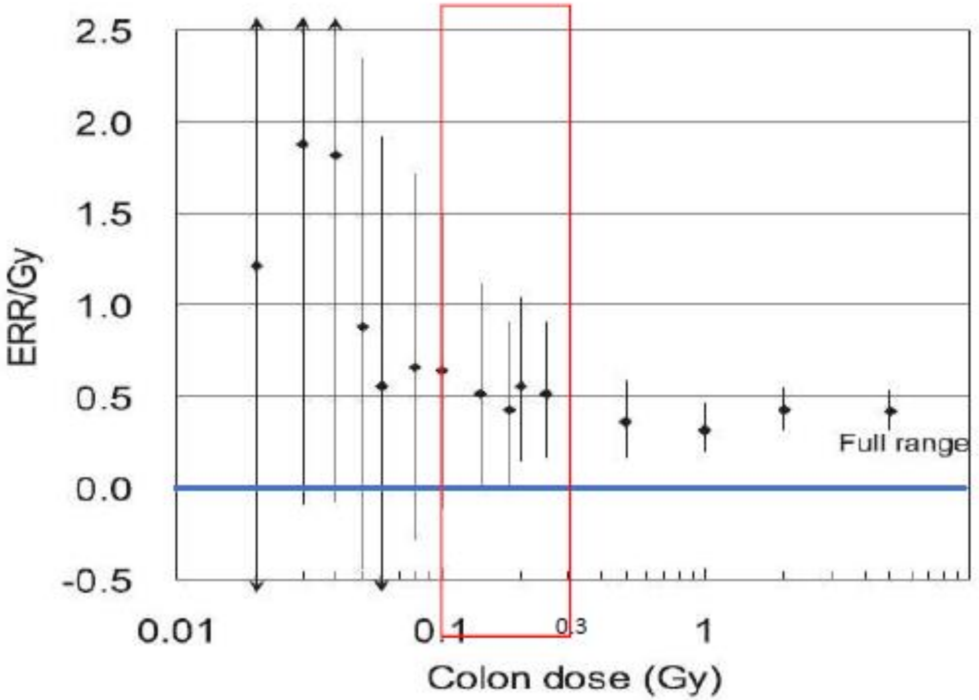

FIG. 5. Excess relative risk per Gy (ERR/Gy) for all solid cancer for selected dose ranges. The figure shows the ERR/Gy and 95% CI for a dose range from zero to a given dose based on the linear model for the full data that allowed for different ERRs below and above the given dose and taking radiation effect modifiers as common to the two dose ranges. The increased ERR/Gy in the low-dose levels less than 0.1 Gy corresponds to the estimates of ERR higher than the expected linear line in Fig. 4.

Osaza et al.
Studies of the mortality of atomic bomb survivors,
Report 14, 1950-2003: an overview of cancer and noncancer diseases.
Radiat. Res. 2012.

Nuclear Power plant workers

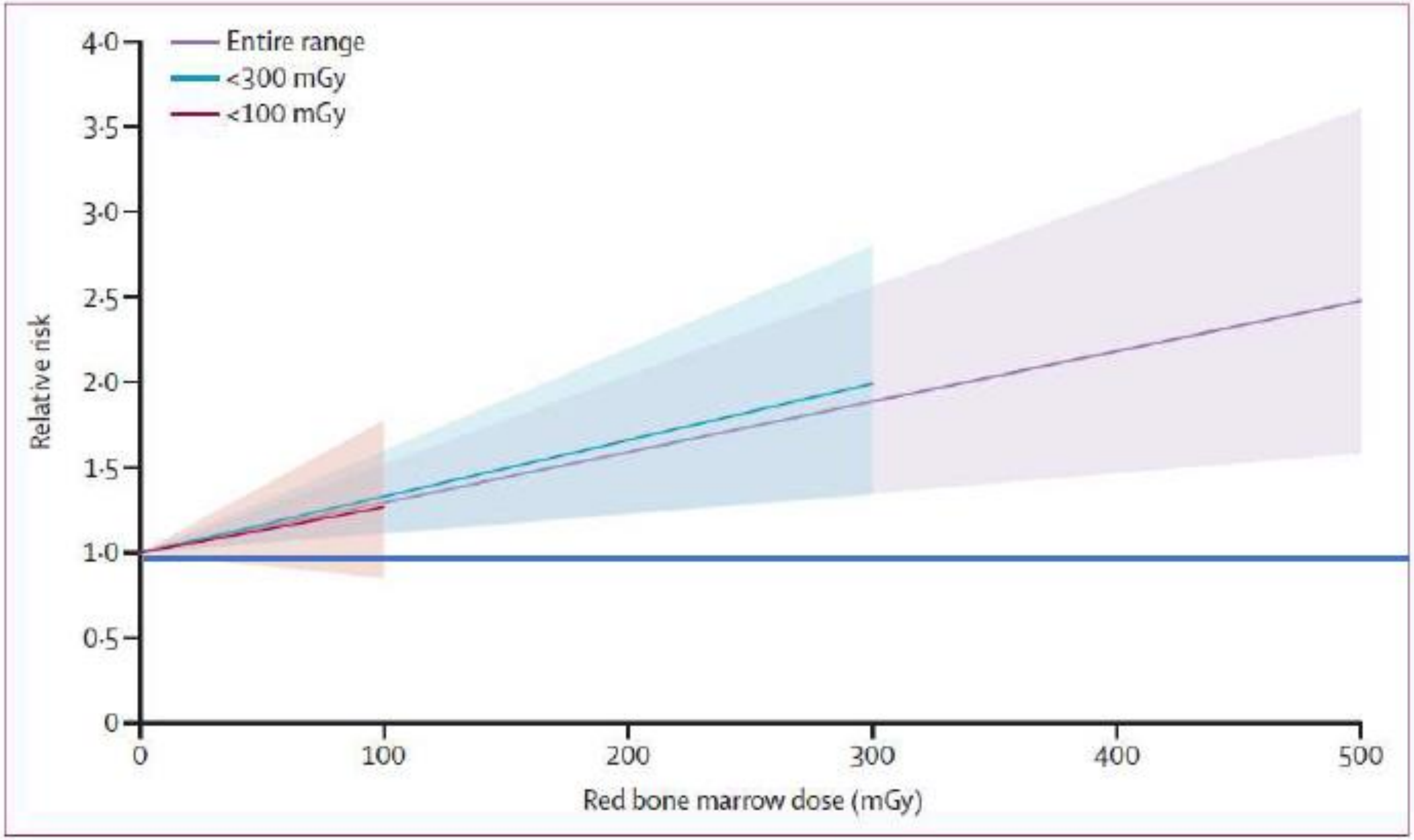

Figure: Relative risk of leukaemia excluding chronic lymphocytic leukaemia associated with 2-year lagged cumulative red bone marrow dose

The lines are the fitted linear dose–response model and the shading represents the 90% CIs.

Leuraud et al 2015

Medical Exposure –Pediatric CT studies

	Population size and age range	ERR/100mGy (95% CI)	
Pearce et al, 2012, Berrington et al al 2016 (UK)	178,604 CT patients 0-22 years old	**Leukaemia** (74 cases) 3.6 (0.5, 12) 3.3 (0. 4, 11.4) 3.7(0. 5, 12.5) **Brain tumours** (135 cases) 2.3 (1.0, 4.9) 1.2 (0.4, 3.1)	**Limitations - Organ-dose tables** - Overall - excluding previous cancers - excluding leukaemia related cond. - Overall - excluding previous cancers, conditions
Matthews et al, 2013 (Australia)	680,211 CT patients 0-19 years old	**Leukaemia** (246 cases) 3.9 (1.4, 7.0) **Brain tumours** (283 cases) 2.1 (1.4, 2.9)	**- Exposure misclassification** **- Increase for all cancer types**
Journy et al, 2014, 2015 (France)	67,274 patients 0-10 years old	**Leukaemia** (17 cases) 5.7 (-7.9, 19.3) 18.7 (NA) **Brain/CNS tumours** (22) 2.2 (-1.6, 6.1) 2.8 (NA)	**- Short follow-up (4 years), few cases** - Overall - excluding predisposing factors - Overall - excluding predisposing factors
Meulepas et al 2018 (Netherlands)	168,394 patients <18 years	**Leukaemia** – no association **Brain/CNS tumours** (84) 0.86 (0.20, 2.22)	

Which statements can be done on radiation risks above a certain threshold and with which level of confidence??? (epidemiologic perspective)

- In the last ten years many publications focused on the cancer induction due to radiations doses accrued in a long period of time .
- The quality of these studies is different, as are the estimates of ERR or EAR
- Nonetheless, there is enough concordance among the well designed studies with an elevated statistical power to conclude that, notwithstanding experimental error and uncertainties :

- Radiation dose levels, in the interval 100-300 mSv– are associated with a small increase in the risk of cancer

- Data on high CED

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

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Table 2. Data on cohort with cumulative effective dose (CED) ≥ 100 mSv*

Institution	Total number of patients with CED≥ 100 mSv (%)	Maximum CED mSv	Median CED mSv	Mean number of CT exams per patient	Median number of CT exams per patient	Maximum number of CT exams in any patient	Minimum days needed to get 100 mSv
A	8,952 (3.4%)	1185	146.9	21	19	109	1
B	5888 (1.4%)	785.7	129.9	12	11	57	1
C	12,198 (1.5%)	864.7	130.7	6.3	6	67	1
D	6,369 (0.64%)	800.3	125.5	7	6	89	1
	Total=33,407 (1.33%)	--	130.3	---	--	--	--

*Data collection period being different for different institution, last row not computed

M. Rehani Eur Radiol 2019 DOI: 10.1007/s00330-019-06523-y

Table 4 Number of patients with CED ≥ 100 mSv in the IAEA-MGH survey

Institution: single hospital (region)	Duration in years	Total number of patients undergoing CT in that period	Total number of patients with CED ≥ 100 mSv (%)
A (Africa)	1.0	1942	0 (0%)
B (Asia)	0.4	1878	0 (0%)
C (Europe)	0.5	5268	1 (0.02%)
D (Europe)	0.6	7096	1 (0.01%)
E (Europe)	1.0	11243	12 (0.11%)
F (Europe)	3.0	33636	58 (0.17%)
G (Europe)	3.1	34250	61 (0.18%)
H (Europe)	1.0	39728	101 (0.25%)
I (Europe)	1.8	35187	94 (0.27%)
J (Europe)	2.0	63757	126 (0.20%)
K (Europe)	2.0	58307	126 (0.22%)
L (Europe)	2.0	28750	262 (0.91%)
M (Europe)	3.3	113393	429 (0.38%)
N (Europe)	1.0	64785	451 (0.70%)
O (Europe)	6.1	101401	463 (0.46%)
P (Europe)	1.0	30000	550 (1.83%)
R (Europe)	2.3	30040	600 (2.00%)
S (Europe)	1.8	19539	976 (5.00%)
T (Europe)	2.0	9023	177 (1.96%)
U (Europe)	1.0	12982	92 (0.71%)
Total		702205	4580 (0.65%)

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

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Table 3 Cumulative radiation exposure and patients with CED > 100 mSv

Author	Condition	N. pts	X-ray procedures	Age (years), mean or median§	Patients with CED > 50 mSv	Patients with CED > 100 mSv	Follow-up (years)
Chen 2010 [17]	Pts with cardiac imaging	90121	Only cardiac procedures	51.1	3173 (3.5%)#	75 (0.08%)^	3
Einstein 2010 [18]	Pts with myocardial perfusion scan	1097	All medical imaging procedures	62.2		344 (31.4%)	20
Stein 2010 [19]	Cardiac disease	8656	All medical imaging procedures	65.9	533 (6.2%)		3
Kaul 2010 [20]	Acute myocardial infarction	64071	All medical imaging procedures	64.9§	1060 (1.7%)°		–
Eisenberg 2011 [21]	Acute myocardial infarction	82861	Only Cardiac Procedures	63.2§	15090 (18%)*		1
Lawler 2011 [22]	Acute myocardial infarction	11427	Only Cardiac Procedures	68.0§	825 (7.2%)*°		1
Kinsella 2010 [23]	Hemodialysis	100	All medical imaging procedures	58.9	26 (26%)	13 (13%)*	3.4 median
De Mauri 2011 [24]	Hemodialysis	106	All medical imaging procedures	65.3		17 (16%)	3.0 median
Coyle 2011 [25]	Hemodialysis	244	All medical imaging procedures	52.7	56 (23%)		4.0 median
	Kidney Transplant	150	All medical imaging procedures	45.7	12 (8%)		
De Mauri 2012 [26]	Kidney Transplant	92	All medical imaging procedures	52.4	26 (28%)	11 (12%)	4.1 median
Desmond 2012 [27]	Crohn's	354	All medical imaging procedures	32		55 (16%)*	15
Levi 2009 [28]	Crohn's ulcerative colitis	199; 125	All medical imaging procedures (no interventional)	39	23 (7%)		5.5; 5.0
Kroeker 2011 [29]	Crohn's	371	All medical imaging procedures	40	27 (7%)	12(3%)*	5
Butcher 2012 [30]	Crohn's	127	All medical imaging procedures (	45	8 (6%)		11.2
Estay 2015 [31]	Crohn's	82	All medical imaging procedures	36	16 (20%)		9.6
Chatu 2013 [32]	Crohn's	217	All medical imaging procedures	31	29 (13%)		8.3
Jung 2013 [33]	Crohn's	777	All medical imaging procedures	29	249 (35%)		15
Fuchs 2011 [34]	Crohn's	171	All medical imaging procedures	11 (pediatric)	14 (8%)		5.3
Sauer 2011 [35]	Crohn's	86	All medical imaging procedures	12 (pediatric)	6 (7%)		3.5
Huang 2011 [36]	Crohn's ulcerative colitis, indeterminate colitis	61; 32; 12	All medical imaging procedures	11§ (pediatric)	6 (6%)		5
Brambilla 2015 [37]	EVAR	71	All medical imaging procedures	74	71 (100%)	66 (93%)	1.8

*CED > 30 mSv

#CED > 60 mSv

*CED > 75

^CED > 150 mSv

°Per admission after acute myocardial infarction

Chronic or Recurrent Adult Patients

- End stage Kidney Disease (ESKD) including
  - Hemodialysis patients
  - Kidney transplant patients
- Inflammatory bowel disease (IBD) including
  - Chron's disease
  - ulcerative colitis
- Cardiology Patients
  - Cardiac disease
  - Patients with Acute myocardial Infarction
  - Patients with Congenital Heart Disease (adults and children)
  - Heart Transplant patients
- Endovascular Aortic Repair Patients
- Others (hydrocephalus, Pulmonary Tromboembolic, Renal Colic)

End stage Kidney Disease (ESKD)

- Patients on ESKD require ongoing care and often result in repeated imaging and repeated exposure to ionizing radiation for both diagnostic and therapeutic purposes.
- Hemodialysis patients are exposed to a considerable amount of imaging procedures because of their multiple comorbid conditions and for dialysis access-related procedures.
- Radiologic procedures are necessary in kidney transplant patients to allow specific treatment of the early and late graft complications, that were often present with non-specific signs and symptoms.

Estimated Radiation Exposure from Medical Imaging in Hemodialysis Patients

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Patient Population

The 106 study patients (63 men) were followed for a median of 3.0 years. During the study period, 23 patients (21.6%) died, whereas 6 (5.6%) underwent kidney transplantation. In these cases, the data were censored at the date of death or of transplantation. Thus, a total of 281 patient-years were available for follow-up.

The mean SD age at study entry was 65.3 ± 14.6 years. Among the subjects, 14 were in the 18- to 50-year age group, 41 were in the 50- to 70-year age group, and 51 were 70 years.

In all, 77% of the subjects were prevalent, with a median (interquartile range [IQR]) dialysis period of 4.0 (1.6 to 8.3) years, and the remaining 23% initiated dialysis during the study period.

J Am Soc Nephrol 22: 571–578, 2011. doi: 10.1681/ASN.2010070784

Results

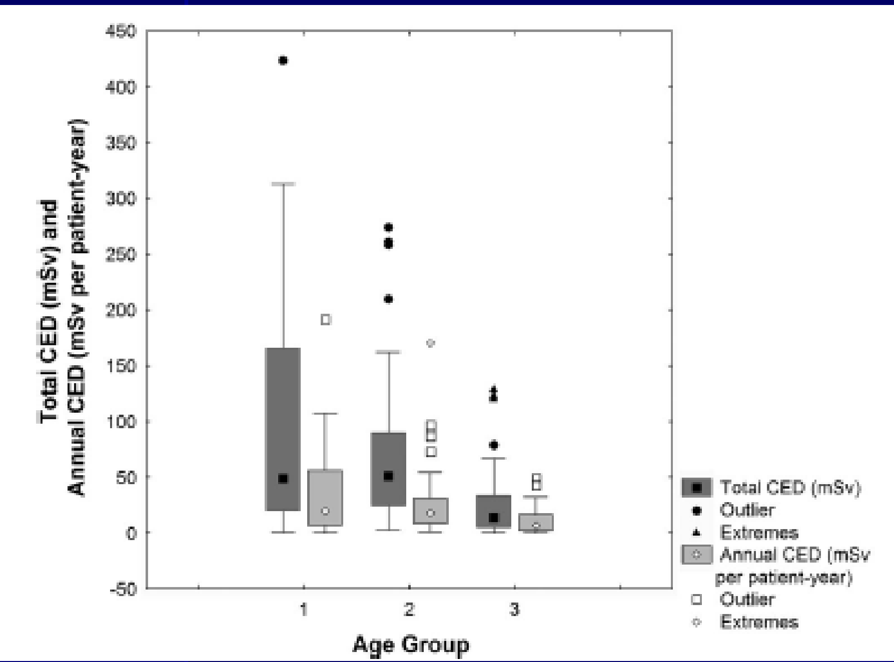

Table 1. Patient characteristics for the study population and comparison of average annual CED for gender, transplant waiting list status, and comorbid conditions including death

Patient Characteristics	Total [N (%)]	Annual CED (mSv per Patient-Year) (Mean ± SD)		*P*
		Yes	No	
Male	63 (59.4%)	22.0 ± 31.0	21.6 ± 32.0	0.44
Diabetes mellitus	26 (24.5%)	20.0 ± 18.6	22.5 ± 34.4	0.33
Ischemic heart disease	44 (41.5%)	21.1 ± 23.5	22.4 ± 35.9	0.30
Tumor	20 (18.9%)	25.8 ± 23.3	20.9 ± 328	0.11
Renal transplant eligible	30 (28.3%)	30.5 ± 40.0	18.4 ± 26.5	0.04
Death	23 (21.7%)	32.4 ± 45.2	18.9 ± 25.7	0.40

- The average radiation exposure was significantly associated to the younger-aged patients who were exposed to higher total CEDs ($P < 0.0001$) and annual CEDs ($P < 0.0002$) than the older patients (Fig. 1)
- Also the transplant waiting list status was associated with a significantly higher ($P = 0.04$) annual CED (Table 1)

Results

The median (IQR) total CED per subject over the study period was 27.3 mSv (9.8 to 60.0). The mean total CED was 55.7±73.6 mSv.
The mean levels are much higher than the median annual and total CED, which reflects the dramatic right-skew in this distribution of patients with increasing CED.

Table 2. Number of radiologic procedures and annual and total CED by procedure type

Procedure	Number of Examinations [*N* (%)]	Annual CED (mSv per Patient-Year) [Median (IQR)]	Annual CED (mSv per Patient-Year) (mean ± SD)	Total CED mSv (%)
Overall total	1303 (100%)	11.7 (4.3 to 24.7)	21.9 ± 31.2	5901.4 (100%)
Conventional diagnostic radiology	848 (65.0%)	1.4 (0.7 to 2.7)	1.9 ± 1.5	488.7 (8.3%)
CT	248 (19.0%)	6.5 (0 to 18.6)	16.6 ± 29.2	4484.0 (76.0%)
Nuclear medicine	108 (8.2%)	0.0 (0 to 2.8)	1.6 ± 1.3	451.1 (7.6%)
Interventional	99 (7.6%)	0.0 (0 to 2.3)	1.8 ± 1.5	477.5 (8.1%)

IQR, intraquartile range.

CT examinations accounted for 76% of the total CED, while accounting for only 19% of the total number of radiological procedures.
Conventional diagnostic radiology, nuclear medicine, and interventional procedures accounted for 65, 8.2, and 7.6% of the frequency in procedures and for 8.3, 7.6, and 8.1% of total CED, respectively.

Discussion

- This study showed that within 3 years, a significant fraction of surviving hemodialysis patients received estimated radiation doses that may put them at an increased risk of cancer.

- The cumulative radiation exposure was significantly higher in relatively younger patients and in those who are transplant eligible. This is of particular concern given the anticipated life expectancy of these subjects and the ongoing use of immunosuppressive agents in the latter.

- Although the retrospective nature of this study does not allow us to draw conclusive inferences about the percentage of CT studies that could have been avoided, the significant number of examinations that resulted in non notable findings or in negative results points toward the need of a more stringent process of justification of CT referral.

Cumulative Radiation Dose from Medical Imaging in Kidney Transplant Patients

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Patient Population

The 92 study patients (62 males) were followed for a median of 4.1 years (mean 3.6 years; range 0.8-4.1 years). During the study period 2 patients (2.1%) died, while 3 (3.2%) returned to dialysis. In these cases the data were censored at the date of death or of dialysis. Thus, a total of 335 patient-years was available for follow-up.

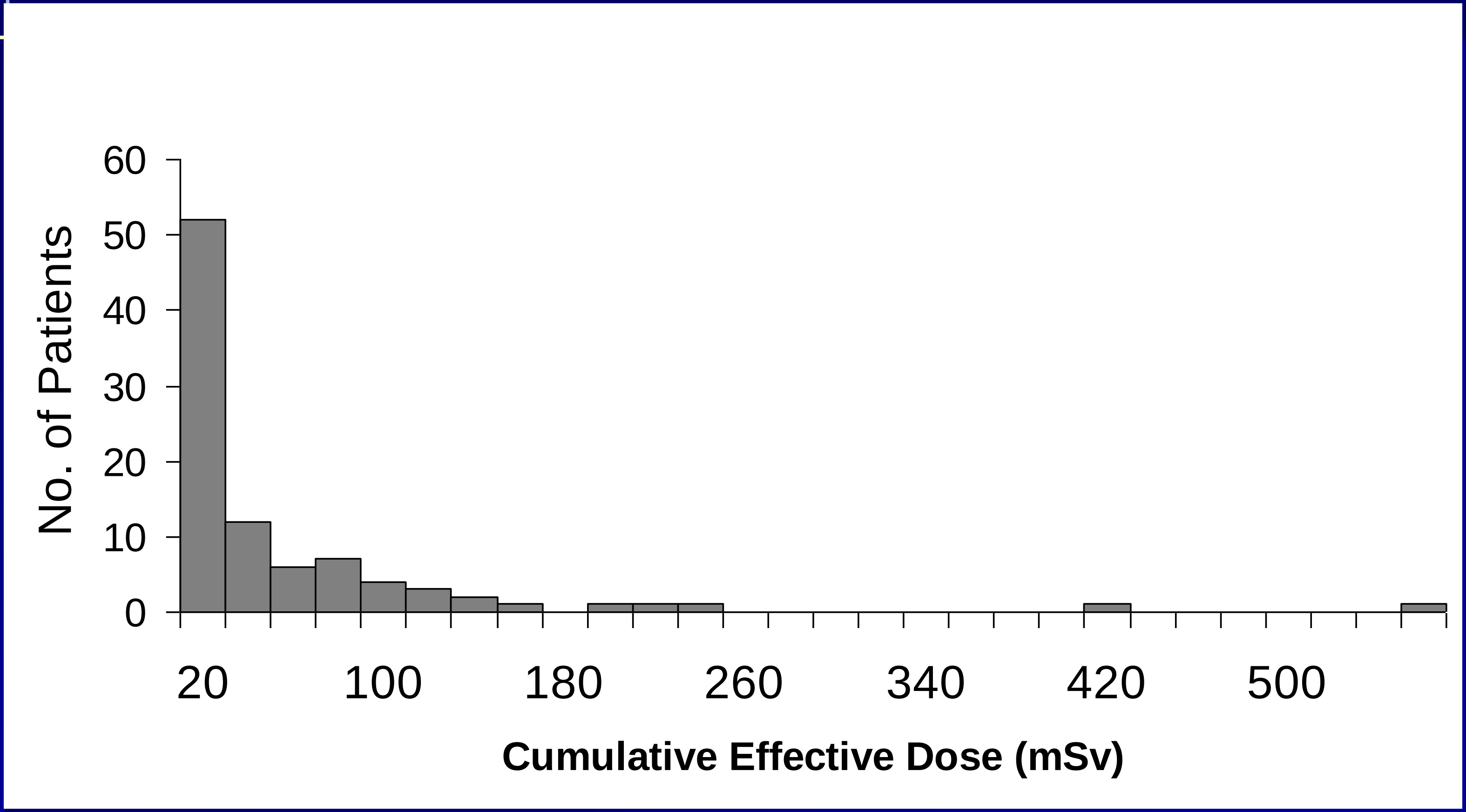
The mean ± SD age at study entry was 52.4 ± 14.0 years. Among the subjects 39 were in the 18-50 years age group, 30 were in the 51-65 years age group and 23 were older than 65 years.

In all, 71 subjects were prevalent with a median (IQR) period elapsed since transplant of 4.3 (1.7-9.9) years, and the remainder 21 underwent transplant during the study period.

Nephrol Dial Transplant. 2012 Sep;27(9):3645-51

Results

The distributions of total CED for all radiological procedures are shown in Figure 1



Results

The median (IQR) total CED per subject over the study period was 17.3 mSv (7.8 - 57.7). The mean total CED was 46.1 ± 80.6 mSv. The mean levels are much higher than the median annual and total CED which reflects the right-skew in this distribution of patients with increasing CED.

Table 4. Number of radiological procedures, and annual and total CED by procedure type.

Procedure	Number of examinations N (%)	Annual CED (mSv per patient-year) median (IQR)	Annual CED (mSv per patient-year) mean ± SD	Total CED mSv (%)
Overall total	1472 (100%)	4.2 (1.9-18.2)	16.3±29.9	4256.8 (100%)
Conventional diagnostic radiology	1239(84.2%)	2.0 (1.3-2.8)	2.4±1.8	711.8 (16.8%)
Computed Tomography	152 (10.3%)	0.5 (0.0-12.1)	12.1±27.1	3097.0 (72.7%)
Nuclear Medicine	67 (4.5%)	0.0 (0.0-1.8)	1.1±1.7	302.5 (7.1%)
Interventional	15 (1.0%)	0.0 (0.0-0.0)	0.6±2.5	145.4 (3.4%)

Abbreviations: CED, cumulative effective radiation dose; IQR, intra-quartile range. SD, Standard Deviation

Accounting for only 10.3% of the total number of radiological procedures, CT examinations accounted for 73% of the total CED.

The proportion of total CED to different types of CT examinations is shown in Table 5. Although comprising only 44.7% of the CT procedures, abdominal/pelvic examinations resulted in 80.2% of the CT radiation exposure and 58.4% of the total CED.

Table 5. Number of CT examinations, CT scans and related total CED.

Procedure	Number of examinations, N (%)	Number of scans (average N of scans per examination)	Total CED mSv(%)
Overall total	152(100%)	315 (2.1)	3097 (100%)
Head/Neck	41 (27.0%)	52 (1.3)	123 (4.0%)
Chest	43 (28.3%)	70 (1.6)	490 (15.8%)
Abdomen/Pelvis	68 (44.7%)	193 (2.8)	2484 (80.2%)

Abbreviations: CED, cumulative effective radiation dose;

J Nephrol
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CrossMark

ORIGINAL ARTICLE

Radiation exposure from medical imaging in dialyzed patients undergoing renal pre-transplant evaluation

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Received: 22 September 2015 / Accepted: 30 January 2016

Results

Follow-up time: 1.9 ± 1.5 years

The median total CED per subject over the study period was 32 mSv. The mean total CED was 72 mSv.

The median annual CED per subject over the study period was 7 mSv. The mean annual CED was 35 mSv.

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Cumulative Radiation Dose from Medical Imaging in Chronic Adult Patients

Table 2 Cumulative Radiation Exposure in Patients with ESKD

Study (First Author)	Condition	Patients n	Radiograph Procedures	ED Estimation Method	Age (Years) Mean	Annual CED (mSv/Year) Mean and/ or Median*	CED (mSv) Mean and/ or Median*	Patients with CED > 50 mSv or > 75 mSv†	Follow-up (Years) Median
Kinsella[18]	Hemodialysis	100	All medical imaging procedures	Look-up tables	58.9	6.9*	34.2-21.7*	26%-13%†	3.4
De Mauri[19]	Hemodialysis	106	All medical imaging procedures	Patient specific	65.3	21.9-11.7*	55.7-27.3*	35%-23%†	3.0
Coyle[20]	Hemodialysis	244	All medical imaging procedures	Look-up tables	52.7	5.8*	33.4-15.1*	23%	4.0
	Kidney transplant	150			45.7	0.5*	15.8-2.9*	8%	
De Mauri[21]	Kidney transplant	92	All medical imaging procedures	Patient specific	52.4	16.3-4.2*	46.1-17.3*	28%-12%†	4.1

ESKD = end-stage kidney disease.
*Median.
†CED (cumulative effective dose) >75 mSv.

M Brambilla The American Journal of Medicine (2013) 126, 480-486

End stage Kidney Disease (ESKD)

- ESKD, besides being such a chronic condition, is associated with an increased incidence of cancer of unclear aetiology.

- ESKD patients have a 4 fold higher risk of cancer compared to the general population, but the cancer risk is different according to the renal replacement therapy: there is an increase of 1-1.5 times during dialysis and 2.5-5 times after kidney transplantation, for both uremia and drug-related immunosuppression.

- The excess risk of cancer associated with radiation exposure adds in these patients to the increased incidence of cancer due to the inherent pathology and must be taken into careful consideration particularly in younger patients and in those eligible for kidney transplantation.

- Another concern is the potential synergistic effect of immunosuppressive drugs and radiation in kidney transplant patients but no data are available to make any conclusion about this risk.

Cardiology

- The studies included in this disease category evaluated different populations with different methodologies: for instance one study evaluated radiation exposure from cardiac imaging in a large population of insured individuals, another evaluated radiation exposure from all imaging in individuals who underwent MPI, and another three assessed radiation exposure during hospitalization for AMI.

- The main reason for the variation in radiation dose is that the denominator populations were different, ranging from an outpatient population, patients only imaged with MPI, patients with AMI, congenital heart disease and heart transplant.

- Moreover, only two studies contained dose estimates based on patient-specific data, whereas the others relied on typical effective radiation doses from the published literature.

Cardiology

Table 1 Cumulative Radiation Exposure in Cardiology

Study (First Author)	Condition	Patients n	Radiograph Procedures	ED Estimation Method	Age (Years) Mean or Median*	Annual CED (mSv/year) Mean and/or Median*	CED (mSv) Mean and/ or Median*	Patients with CED >50 mSv or >75 mSv†	Follow-up (Years)
Bedetti[12]	Pts admitted to cardiology ward	50	All medical imaging procedures	Look-up tables	66.7	NA	61.0§	28%	36
Kaul[13]	Acute myocardial infarction	64,071	All medical imaging procedures	Look-up tables	64.9§	NA	14.6-15.0‡	2%‡	—
Chen[9]	Pts with cardiac imaging	90,121	Only cardiac procedures	Look-up tables	51.1	NA	23.1-15.6*	3.3%	3
Einstein[10]	Pts with myocardial perfusion scan	1097	All medical imaging procedures	Patient-specific	62.2	NA	96.5-64.0*	31.4%†	20
Stein[11]	Cardiac disease	11,072	All medical imaging procedures	Look-up tables	65.9		14.0	6.2†	3
Eisenberg[14]	Acute myocardial infarction	82,861	Only cardiac procedures	Look-up tables	63.2§	14.1§	NA	NA	≥1
Lawler[15]	Acute myocardial infarction	106,803	Only cardiac procedures	Look-up tables	68.0§	NA	19.1	NA	3
Hoffmann[16]	Congenital heart disease	4110	All medical imaging procedures	Look-up tables	32.0	0.46	NA	NA	5
Noor[17]	Heart transplant	202	All medical imaging procedures	Patient-specific	46.0	35.3 (1st y post TX 5.5 (thereafter)	84	NA	10

*Median.
†CED (cumulative effective dose) >75 mSv.
‡Per admission.
§Estimated mean in the first year after admission.

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Cumulative Exposure to Ionizing Radiation From Diagnostic and Therapeutic Cardiac Imaging Procedures

A Population-Based Analysis

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Objectives The purpose of this study was to describe radiation exposure from cardiac imaging procedures over time in a general population.

Background Cardiac imaging procedures frequently expose patients to ionizing radiation, but their contribution to effective doses of radiation in the general population is unknown.

Methods We used administrative claims to identify cardiac imaging procedures performed from 2005 to 2007 in 952,420 nonelderly insured adults in 5 U.S. health care markets. We estimated 3-year cumulative effective doses of radiation in millisieverts from these procedures We then calculated population-based annual rates of radiation exposure to effective doses ≤3 mSv/year (background level of radiation from natural sources), >3 to 20 mSv/year, or >20 mSv/year (upper annual limit for occupational exposure averaged over 5 years).

Results A total of 90,121 (9.5%) individuals underwent at least 1 cardiac imaging procedure using radiation. Among patients who underwent ≥1 cardiac imaging procedures, the mean cumulative effective dose over 3 years was 23.1 mSv (range 1.5 to 543.7 mSv). Myocardial perfusion imaging accounted for 74% of the cumulative effective dose. Overall, 47.8% of cardiac imaging procedures were performed in physician offices; this proportion was higher for myocardial perfusion imaging (74.8%) and cardiac computed tomography studies (76.5%). The annual population-based rate of receiving an effective dose of >3 to 20 mSv/year was 89.0 per 1,000; and 3.3 per 1,000 for cumulative doses >20 mSv/year. Annual effective doses increased with age and were generally higher among men.

Conclusions Cardiac imaging procedures lead to substantial radiation exposure and effective doses for many patients in the U.S. (J Am Coll Cardiol 2010;56:702–11)

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

Context Myocardial perfusion imaging (MPI) is the single medical test with the highest radiation burden to the US population. Although many patients undergoing MPI receive repeat MPI testing, or additional procedures involving ionizing radiation, no data are available characterizing their total longitudinal radiation burden and relating radiation burden with reasons for testing.

Objectives To characterize procedure counts, cumulative estimated effective doses of radiation, and clinical indications for patients undergoing MPI.

Design, Setting, and Patients A retrospective cohort study of 1097 consecutive patients undergoing index MPI during the first 100 days of 2006 (January 1-April 10) at Columbia University Medical Center, New York, New York, that evaluated all preceding medical imaging procedures involving ionizing radiation undergone beginning October 1988, and all subsequent procedures through June 2008, at the center.

Main Outcome Measures Cumulative estimated effective dose of radiation, number of procedures involving radiation, and indications for testing.

Results Patients underwent a median of 15 (interquartile range [IQR], 6-32; mean, 23.9) procedures involving radiation exposure; of which 4 (IQR, 2-8; mean, 6.5) were high-dose procedures (≥3 mSv; ie, 1 year's background radiation), including 1 (IQR, 1-2; mean, 1.8) MPI study per patient. A total of 344 patients (31.4%) received cumulative estimated effective dose from all medical sources of more than 100 mSv. Multiple MPIs were performed in 424 patients (38.6%), for whom cumulative estimated effective dose was 121 mSv (IQR, 81-189; mean, 149 mSv). Men and white patients had higher cumulative estimated effective doses. More than 80% of initial and 90% of repeat MPI examinations were performed in patients with known cardiac disease or symptoms consistent with it.

Conclusion In this institution, multiple testing with MPI was common and in many patients associated with high cumulative estimated doses of radiation.

Andrew J. Einstein, MD, PhD

For MPI and nuclear medicine tests, the radiopharmaceuticals used and corresponding administered activities (mCi) were generally recorded; effective dose was estimated by multiplying administered activity by a radiopharmaceutical-specific conversion factor, as specified in ICRP 80

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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

Background—Invasive and noninvasive cardiovascular imaging is beneficial in the care of patients admitted with acute myocardial infarction. Little is known about patients' cumulative radiation exposure.

Methods and Results—All patients admitted with an acute myocardial infarction to any of 49 University HealthSystem Consortium member hospitals from 2006 to 2009 were reviewed for inpatient procedures involving ionizing radiation that included chest radiograph, computed tomogram scans, radionuclide imaging, diagnostic cardiac catheterization, and percutaneous coronary intervention. The average cumulative effective radiation dose per patient was estimated on the basis of published typical effective radiation doses for imaging procedures. Patients (n=64 071) admitted for acute myocardial infarction had a median age of 64.9 years. A total of 276 651 procedures involving ionizing radiation were performed during the study period, a median of 4.3 procedures per patient per admission. The majority of patients had invasive catheterization (77%), followed by computed tomogram scans (52%), mostly body examinations. The median cumulative effective radiation dose delivered was 15.02 mSv per patient per acute myocardial infarction admission. Postprocedural bleeding was a significant predictor of radiation exposure (odds ratio, 2.01; 95% confidence interval, 1.85 to 2.18), together with postprocedural mechanical complications resulting from device implantation (odds ratio, 2.86; 95% confidence interval, 2.61 to 3.13). Patients with higher underlying clinical complexity (defined by severity of illness scores) had higher radiation exposure and higher mortality ($P<0.0001$). There was also significant geographic variation in radiation exposure; patients in New England received the lowest cumulative exposure (odds ratio, 0.78; 95% confidence interval, 0.74 to 0.81).

Conclusions—Acute myocardial infarction inpatients are exposed to an approximate median radiation dose of 15 mSv. This exposure is a result of multiple cardiovascular and noncardiovascular procedures. Efforts should be made to understand the risks and benefits of radiation exposure per episode of care for acute myocardial infarction. (*Circulation*. **2010;122:2160-2169.**)

Cardiology

Notwithstanding this heterogeneity, some useful and common aspects can be summarized:

- The cumulative exposure is moderate in cardiac patients, with a mean annual CED averaging two to three times that of annual background radiation. This also applies to heart-transplant patients and to patients admitted for AMI in the chronic phases, while the CED incurred in the first year after transplantation averaged 35 mSv and in the acute post-AMI phase (< 1 month) averaged 12 mSv.

- Exposures exceeding 75-100 mSv of CED occur in about one-third of these patients but only after a long follow-up period (> 10 years).

- On the contrary, patients with congenital heart disease have only a low exposure to radiation (0.5 mSv per patient/year).

Cardiology

- These findings must also be interpreted in light of the advanced age of patients at study entry (average age 62-68 years).

- Notwithstanding the advanced age of patients in the cohorts examined (> 60 years), some studies showed that there are sizeable groups of patients aged 35-54 years, many of whom will live long enough for such long-term complications to develop.

- The largest contributor to the CED in cardiac patients is MPI, which is responsible for about 66-75% of the CED, with the exception of patients with acute myocardial infarction, where the largest contribution to CED is due to invasive catheterization procedures.

- Although most cardiac patients received low or moderate radiation from medical procedures, there exist certain groups of patients who receive high CED in a short time period. Patients admitted to hospitalization for AMI and patients undergoing heart transplant are two such groups.

Efforts to reduce cumulative radiation dose should be especially aimed at such groups.

Inflammatory Bowel Disease (IBD)

- Chron's disease and ulcerative colitis are chronic disease states with inflammation and ulceration of gastrointestinal tract. Diagnostic medical imaging are routinely used in the initial diagnosis and ongoing evaluation of patients with IBD and its complications.
- IBD patients have increased risk of gastrointestinal malignancies including colon cancer, adenocarcinoma and lymphoma of the small intestine because of chronic inflammation. The use of immunosuppressive agents also increases the risk of lymphoma.

Inflammatory Bowel Disease (IBD)

Table 3 Cumulative Radiation Exposure in Patients with IBD

Study (First Author)	Condition	Patients n	Radiograph Procedures	ED Estimation Method	Age (Years) Mean or Median*	Annual CED (mSv/year) Mean and/or Median*	CED (mSv) Mean and/or Median*	Patients with CED >50 mSv or >75 mSv†	Mean Follow-up (Years)
Newnham[24]	IBD	100	All medical imaging procedures	Look-up tables	39*	5.4*	10.0*	11%-3%†	~ 2
Peloquin[25]	Crohn	103	All medical imaging procedures	Patient specific	39	3.1*	27.6*	NA	9
	Ulcerative colitis	112			39	1.2*	10.5*	NA	9
Desmond[26]	Crohn	354	All medical imaging procedures	Look-up tables	32	NA	36.0	16%†	15
Desmond[27]	Crohn	445	All medical imaging procedures	Look-up tables	40	7.6	30.1	10%	10
	Ulcerative colitis	453				2.5	11.7		
Levi[28]	Crohn	199	All medical imaging procedures (no interventional)	Look-up tables	39	4.2	21.1	8%	5.5
	Ulcerative colitis	125			46	3.0	15.1		5
Kroeker[29]	Crohn	371	All medical imaging procedures	Patients specific	40	2.8	14.3-3.0*	7%-3%†	5
	Ulcerative colitis	182			39	1.2	5.9-1.0*	0.005%	
Butcher[30]	IBD	280	All medical imaging procedures (no interventional)	Look-up tables	49	—	10.2-4.1*	3%	
	Crohn	127			45	—	16.1-10.9*	6%	11.2
	Ulcerative colitis	144			51	—	4.9-1.5*	—	8.3

IBD = irritable bowel syndrome.
*Median.
†CED (cumulative effective dose) >75 mSv.

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Inflammatory Bowel Disease (IBD)

Cumulative exposure is intermediate in patients with Crohn's disease, with an annual CED more than twofold the background radiation.

Exposures exceeding 50-100 mSv of total CED are not uncommon in this study cohort, occurring in almost 10% of subjects who underwent imaging.

Patients with IBD are young (reported mean age 32-46 years) so that the risk of developing radiation-induced cancer may be of clinical relevance.

The largest contributor to the CED in IBD patients is CT, which is responsible for about 50-75% of the CED.

Inflammatory Bowel Disease (IBD)

Children with Crohn's disease demonstrate a moderate exposure to ionizing radiation due to medical imaging. The yearly rate of medical imaging radiation exposure stands at approximately 3-5 mSv/year, which is only slightly higher than typical background radiation. However, this extra yearly radiation exposure accrue over the entire lifetime and increases with increasing attained age.

Table 1. Cumulative radiation exposure in paediatric patients with inflammatory bowel disease..

Author [Ref.]	Condition	N. Pts	X-ray procedures	Effective Dose estimation method	Age (years) Mean or Median§	Annual CED (mSv/year) Mean and/or Median§	CED (mSv) Mean and/or Median§	Patients with CED > 50 mSv or > 75 mSv^	Mean Follow-up (years)
Fuchs [14]	Crohn's	171	All medical imaging procedures	Patient specific	11.5	3.9	20.5	8%	5.3
	Ulcerative colitis	86			10.5	2.1*	11.7	1%	5.4
Sauer [15]	Crohn's disease	86	Conventional X-ray and CT	Look-up tables	12.4	4.3§	15.0§	7%	3.5
	Ulcerative colitis	31			10.5	2.2§	7.2§	0%	3.3
Huang [16]	Inflammatory bowel disease	105	All medical imaging procedures	Look-up tables	11§	NA	15 – 7§	6%	5

CED= Cumulative Effective Dose; NA= Not available; § median; ^ CED > 75 mSv.

It is likely that the majority of subjects diagnosed with Crohn's disease at age of 10 years will eventually accrue more than 100 mSv at the age of 30 years and more than 200 mSv at the age of 50 years,

Endovascular aortic repair (EVAR)

Endovascular aortic aneurysm repair (EVAR) has become an integral part of vascular surgery as an established less invasive treatment option for the repair of abdominal aortic aneurysms. The use of fluoroscopy is common in EVAR procedures. Moreover, the life-long follow-up often includes computed tomography imaging, a modality that requires a substantial radiologic burden.

Available estimates of radiation exposure to the patients submitted to EVAR are based on the original protocols of the EVAR trials with a prevision of a CT preoperatively and then during postoperative follow-up at 4-6 weeks, 3-6 months and 12 months and annually thereafter, assuming an average dose for each CT examination

Endovascular aortic repair (EVAR)

Table 4 Cumulative Radiation Exposure in EVAR

Study (First Author)	Condition	Patients n	Radiograph Procedures	ED Estimation Method	CED (mSv) Mean or Median*	Patients with ESD >2 Gy	Follow-up (Years)
Weerakkody[33]	EVAR	96	Angiographic and CT	Look-up tables	79*	30%	1
Kalef-Ezra[34]	EVAR	62	Angiographic and CT	Look-up tables	62	0%	1
Jones[35]	EVAR	320	Angiographic and CT	Look-up tables	45.5	NA	1

EVAR = endovascular aortic repair; CED = cumulative effective dose; ESD = Entrance skin dose.
*Median.

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- Radiation exposure is a risk factor for developing cancer but it is associated with a latency period of between 10-20 years. The mean age of patients in these studies of 75 years represents most EVAR patients, and therefore, this risk may not be of significant clinical importance.
- The other associated risk of radiation exposure is acute skin injury, which can be usually seen with skin dose > 2 Gy and is associated with the fluoroscopy guided interventional procedure.

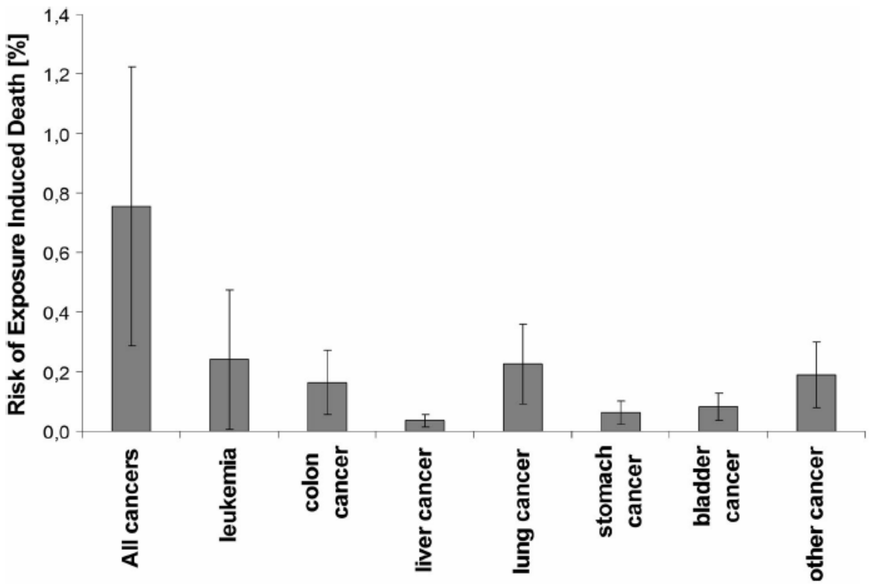
Cumulative radiation dose and radiation risk from medical imaging in patients subjected to endovascular aortic aneurysm repair

- To quantify the cumulative effective dose (CED) of radiation and the dose to relevant organs in endovascular aortic repair (EVAR) patients, to assess radiation risks and to evaluate the clinical usefulness of multi-detector computed tomography (MDCT) follow-up.
- The radiation exposures were obtained from a retrospective study of 71 consecutive EVAR patients with a follow-up duration ≥1 year (mean 2.7 years). Effective dose and organ dose were estimated on an individual basis. Radiation risk was expressed as risk of exposure-induced death (REID) (%).

- The average annual CED was 129 mSv/patient year

- The average REID was 0.8% (i.e. odds 1 in 130) and the median REID was 0.65%.

- The excess cancer risk attributable to radiation exposure is not negligible.



M Brambilla, et al *Radiol Med* 2015;

Conclusions

Altogether, these findings emphasize the need to begin tracking at least the CT-related exposure, as suggested by the American College of Radiology, to develop and increment alternative strategies to reduce patient-specific radiation burden.

As institutions begin to implement radiation reduction and exposure tracking programs, special attention should be paid not only to individuals but also to cohorts, such as the ESKD patients or Crohn's patients. This will also aid in incrementing the awareness of the medical community (including radiologists and emergency room physicians) of the much higher radiation burden associate with CT examinations in comparison with other radiologic procedures

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Review paper

Cumulative radiation dose estimates from medical imaging in paediatric patients with non-oncologic chronic illnesses. A systematic review

CrossMark

Marco Brambilla [a,*], Andreana De Mauri [b], Domenico Lizio [a], Lucia Leva [c], Alessandro Carriero [d], Clara Carpeggiani [e], Eugenio Picano [e]

- Inflammatory bowel disease (IBD) including
  - Chron’s disease
  - ulcerative colitis
- Congenital Heart Disease
- Cystic fibrosis
- Hydrocephalus shunt
- Hemophilia
- Dysraphism

Author year [Ref.]	Condition	N. pts	X-ray procedures	Effective dose estimation method	Age (years) mean or median[b]	Annual CED (mSv/year) mean and/ or median[b]	CED (mSv) mean and/ or median[b]	Patients with CED >50 mSv	Mean follow-up (years)
Fuchs 2011 [16]	Crohn's Ulcerative colitis	171 86	X-rays Contrast X-rays NM scans CT	Patient specific	11.5 10.5	3.9 2.1	20.5 11.7	8% 1%	5.3 5.4
Sauer 2011 [17]	Crohn's disease Ulcerative colitis	86 31	X-rays Contrast X-rays CT	Look-up tables	12.4 10.5	4.3[b] 2.2[b]	15.1[b] 7.2[b]	7% 0%	3.5 3.3
Huang 2011 [18]	Crohn's Ulcerative or indeterminate colitis	61 44	X-rays Contrast X-rays ERCP NM scans CT	Look-up tables Look-up tables	11[b]	NA	15 – 7[b]	6%	5
Donadieu 2007 [19]	Cystic fibrosis	80	CT	Patient specific	9.4–6.6[b]	NA	19.5	NA	15.4
O'Reilly 2010 [20]	Cystic fibrosis	77	All imaging procedures	Look-up tables	9.5	NA	6.2	0%	8.5
O'Connel 2012 [21]	Cystic fibrosis	230	X-rays Contrast X-rays Interventional NM scans CT	Look-up tables	21.5[a]	1.7	15 – 7[b]	NA	9.7
Onnasch 2007 [22]	Congenital heart disease	211	Cardiac catheterization	Patient specific	NA	NA	18.7 – 8.0[b]	NA	12
Ait-Ali 2010 [23]	Congenital heart disease	59	X-rays Cardiac catheterization CT	Look-up tables	2.8	NA	7.7[b]	0%	Lifetime
Holmedal 2007 [24]	Hydrocephalus shunt	13	CT	Patient specific	<1	NA	19	0%	>10
Vila Perez 2012 [25]	Hydrocephalus shunt	36	X-rays CT	Look-up tables	0.5	NA	6.9[b]	0%	NA
Crawford 2012 [27]	Severe haemophilia	35	X-rays NM Scans CT	Patient specific and look-up tables	3.8	2 – 0.4[b]	NA	10%	9
van Aalst 2013 [28]	Spinal dysraphism	135	X-rays Fluoroscopy NM Scans CT	Patient specific and look-up tables	3.2	NA	23	4.4%	10

Contrast X-ray includes: upper gastrointestinal series with or without small bowel follow-through, barium enema, ERCP = endoscopic retrograde cholangiopancreatography; NM = nuclear medicine; NA = not available.

[a] Age at the end of the study.

[b] Median.

Conclusions

- The literature over cumulative radiation exposure form medical imaging in patients with non oncologic chronic illnesses is scarce:
  - all the studies were retrospective;
  - The sample size is low for each cohort;
  - some of the source materials refer to very small number of children and some of the children in the source material were followed for a relatively short time period.
- Risk/benefit of medical imaging depends on a number of factors:
  - severity of underlying condition,
  - performance of the screening test in that specific population,
  - life expectancy of the patient population.

These considerations suggest the need of prospective studies enrolling a greater number of patients, followed for longer period of time and able to control confounding variables in order to provide better estimates of the cumulative exposure to radiation, which, in turn, should be increasingly expressed in terms of organ dose instead than effective dose.

Recommendations

- There should be models for predicting patients with different clinical conditions who are likely to reach high cumulative dose range. Professional medical societies should develop or adopt appropriateness criteria/referral guidelines for patients who require multiple and/or long-term imaging studies.
- When a series of procedures can be reasonably foreseen, the risks and benefits of the entire series should be considered in the justification process.
- There is an urgent need for inclusion of the concept of patient cumulative radiation exposure in radiation protection framework and standards.
- Alert values for cumulative radiation exposures of patients should be set up and introduced in dose management systems with suitable cautions provided to avoid misuse.

- How tracking individual exposure?

Look up Tables For specific CT examinations

ED_{DLP} Conversion Factors

E = DLP x k

k values region specific

Guidelines EUR16262EN

Region of body	Normalized Effective Dose E_{DLP} (mSv mGy^{-1} cm^{-1})
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Estimation of Patient Organ dose
Cardiac CT -Adult patients

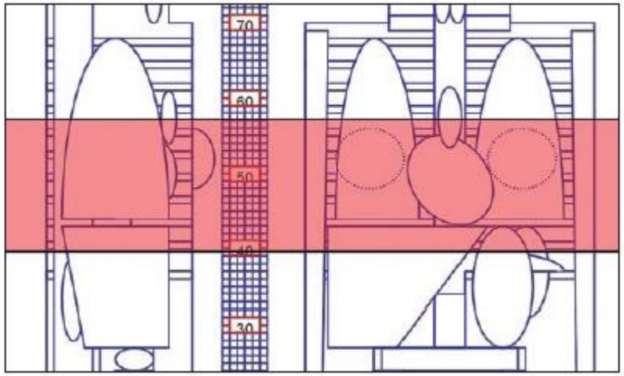

TABLE 4: Radiation Dose Statistics for All 100 Patients Included in This Study

Statistic	$CTDI_{vol}$ (mGy)	DLP (mGy-cm)	Scan Length (cm)	Effective Dose (mSv)	Male Cancer Incidence Risk per 100,000	Female Cancer Incidence Risk per 100,000
Minimum	44	574	13	12	29	90
10th percentile	58	958	15	20	44	126
25th percentile	61	1,024	16	22	55	143
Median	62	1,084	17	24	65	166
75th percentile	64	1,182	19	27	77	205
90th percentile	69	1,362	22	31	86	258
Maximum	71	1,687	29	42	98	308

TABLE 2: Values of D'_{organ} for the 17-cm Cardiac CT Scan Shown in Figure 1[a]

Organ	D'_{organ}[b]
Red Bone Marrow	0.26
Lung	1.11
Stomach	0.31
Breast	1.15
Liver	0.48

[a]Scan was done on a Seimens Healthcare Sensation 64 MDCT-Scanner Using the ImPACT CT Patient Dosimetry Calculator [18].
[b]Organ dose divided by $CTDI_{vol}$.

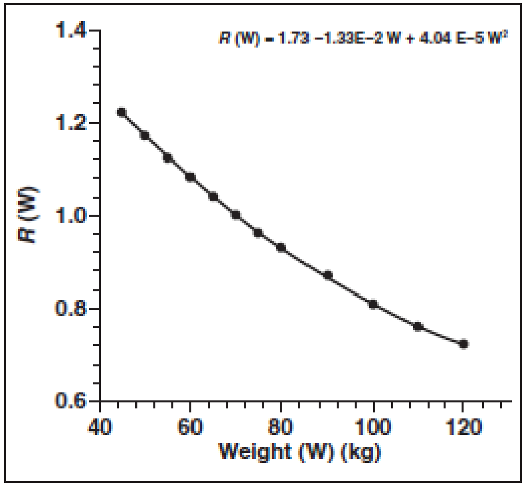

Fig. 2—Relative dose, R(W), plotted as function of patient weight where R(W) is equal to 1.0 for standard-size adult patient who weighs 70 kg. Data points are from [19]; curve obtained using least squares fit to second order polynomial ($r^2 > 0.99$).

TABLE 3: Curve Fit Coefficient Where the Cancer Induction Risk for Individuals Age Y Years is Given by the Expression ($b_o + b_1 Y + b_2 Y^2 + b_3 Y^3$)

Organ	Sex	b_0	b_1	b_2	b_3	r^2
RBM	M	153	−4.99	0.116	−8.80E-4	0.998
	F	80.6	−1.35	0.0345	−3.06E-4	0.996
Lung	M	88.5	0.516	0.0102	−3.15E-4	0.999
	F	190	2.30	−3.53E-3	−5.37E-4	0.999
Stomach	M	13.4	0.954	−0.0174	5.56E-5	0.999
	F	18.8	1.13	−0.0205	6.48E-5	0.999
Liver	M	−1.76	1.58	−0.0309	1.48E-4	0.999
	F	3	0.448	−7.98E-3	2.78E-5	0.999
Breast	F	941	−33.8	0.414	−1.72E-3	> 0.999

Note—Data were taken from BEIR VII, and fitted for adult men and women between the ages of 30 and 80 [20]. RBM = red bone marrow.

$$E(mSv) = DLP \times 0.026 \times R(W)$$

Huda W AJR 2011;196: W159-W165

Estimation of Patient Organ dose CT –Pediatric patients

TABLE III. $CTDI_{vol}$– and 100 mAs-normalized organ absorbed doses (mGy/100 mAs mGy) and effective doses (mSv/100 mAs mGy) based on tissue weighting factors from either ICRP 60 (ED_{60}) or ICRP 103 (E_{103}) for the newborn, 1-year, 5-year, 10-year, and 15-year male and female reference phantoms for **head examinations** at tube potentials of 80, 100, and 120 kVp.

Head scan	Newborn[a]			1-year[a]			5-year[a]			10-year[a]			15-year female			15-year-male		
Tube potential (kVp)	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp
Brain	1.021	1.025	1.051	0.818	0.861	0.925	0.713	0.773	0.854	0.689	0.751	0.834	0.656	0.722	0.808	0.619	0.685	0.772
Pituitary gland	0.866	0.906	0.978	0.627	0.711	0.811	0.632	0.702	0.788	0.600	0.672	0.766	0.589	0.672	0.780	0.498	0.601	0.707
Lens	1.107	1.069	1.063	0.976	0.952	0.943	0.931	0.922	0.919	0.892	0.884	0.888	1.000	0.990	0.990	0.948	0.933	0.936
Eye balls	1.026	1.019	1.028	0.985	0.983	0.989	0.885	0.897	0.924	0.852	0.869	0.900	0.893	0.906	0.934	0.887	0.895	0.921
Salivary glands	0.536	0.548	0.572	0.436	0.460	0.498	0.694	0.726	0.775	0.611	0.639	0.683	0.679	0.714	0.768	0.696	0.735	0.795
Oral cavity	0.363	0.378	0.402	0.658	0.706	0.777	0.623	0.685	0.777	0.583	0.646	0.727	0.432	0.486	0.555	0.420	0.471	0.540
Spinal cord	0.044	0.047	0.050	0.053	0.057	0.062	0.059	0.065	0.072	0.027	0.029	0.032	0.103	0.114	0.128	0.116	0.128	0.145
Thyroid	0.161	0.167	0.175	0.098	0.108	0.122	0.080	0.092	0.107	0.064	0.074	0.085	0.041	0.048	0.057	0.036	0.043	0.051
Esophagus	0.042	0.048	0.052	0.068	0.075	0.087	0.040	0.045	0.054	0.022	0.027	0.032	0.011	0.014	0.018	0.012	0.015	0.019
Trachea	0.060	0.067	0.074	0.089	0.097	0.112	0.049	0.059	0.068	0.033	0.041	0.047	0.018	0.022	0.027	0.020	0.024	0.031
Thymus	0.049	0.053	0.058	0.042	0.047	0.054	0.027	0.032	0.038	0.019	0.023	0.028	0.017	0.020	0.024	0.012	0.016	0.020
Lungs	0.033	0.035	0.039	0.026	0.029	0.034	0.024	0.027	0.032	0.011	0.013	0.017	0.008	0.010	0.012	0.007	0.008	0.010
Breast	0.016	0.015	0.021	0.011	0.012	0.013	0.006	0.008	0.009	0.004	0.004	0.005	0.002	0.003	0.003	0.002	0.002	0.002
Heart wall	0.028	0.030	0.033	0.020	0.022	0.026	0.012	0.014	0.017	0.006	0.008	0.010	0.004	0.005	0.007	0.003	0.004	0.005
Stomach wall	0.008	0.009	0.011	0.006	0.007	0.009	0.004	0.004	0.005	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Liver	0.013	0.014	0.015	0.007	0.008	0.010	0.004	0.005	0.006	0.002	0.002	0.003	0.001	0.001	0.002	0.001	0.001	0.001
Gall bladder	0.006	0.007	0.007	0.003	0.004	0.006	0.002	0.002	0.003	0.001	0.001	0.002	0.000	0.001	0.001	0.000	0.000	0.001
Adrenals	0.010	0.011	0.012	0.009	0.010	0.012	0.004	0.005	0.006	0.002	0.002	0.003	0.001	0.001	0.001	0.001	0.001	0.001
Spleen	0.012	0.013	0.015	0.008	0.010	0.012	0.004	0.005	0.006	0.002	0.003	0.003	0.001	0.001	0.002	0.001	0.001	0.001
Pancreas	0.007	0.008	0.010	0.003	0.004	0.005	0.002	0.002	0.003	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.001
Kidney	0.007	0.007	0.008	0.005	0.006	0.007	0.002	0.003	0.004	0.001	0.001	0.002	0.001	0.001	0.001	0.000	0.001	0.001
Small intestine wall	0.003	0.004	0.005	0.001	0.002	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Colon wall	0.005	0.005	0.006	0.002	0.002	0.002	0.001	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Rectosigmoid wall	0.002	0.003	0.004	0.001	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Urinary bladder wall	0.001	0.001	0.002	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Prostate[b]	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	NA[d]	NA	NA	0.000	0.000	0.000
Uterus[b]	0.001	0.001	0.002	0.001	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	NA	NA	NA
Testes[b]	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	NA	NA	NA	0.000	0.000	0.000
Ovaries[b]	0.002	0.002	0.002	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	NA	NA	NA
Skin	0.233	0.227	0.223	0.197	0.195	0.195	0.139	0.139	0.140	0.095	0.094	0.095	0.075	0.074	0.075	0.068	0.068	0.069
Muscle	0.053	0.054	0.055	0.027	0.029	0.032	0.012	0.013	0.015	0.014	0.015	0.016	0.013	0.014	0.015	0.011	0.012	0.013
Active marrow	0.262	0.282	0.314	0.295	0.325	0.368	0.235	0.266	0.312	0.126	0.144	0.169	0.075	0.086	0.103	0.084	0.097	0.116
Shallow marrow	0.427	0.455	0.498	0.237	0.262	0.296	0.215	0.243	0.280	0.136	0.154	0.179	0.104	0.119	0.138	0.108	0.124	0.144
ED_{60}[c]	0.081	0.085	0.092	0.074	0.081	0.090	0.060	0.067	0.077	0.041	0.046	0.053	0.031	0.035	0.041			
ED_{103}[c]	0.075	0.079	0.086	0.072	0.079	0.088	0.061	0.068	0.078	0.042	0.047	0.053	0.032	0.036	0.041			

[a]Gender-independent organ doses for newborn, 1-year, 5-year, and 10-year phantoms were tabulated from male phantom since male and female phantoms have identical anatomy except gender-specific organs.
[b]Gender-specific organ doses were calculated separately from male and female phantoms.
[c]Effective doses were calculated using male and female organ doses as recommended by ICRP. Effective dose for 15-year phantoms was tabulated in 15-year female columns.
[d]Male organ doses are not available (NA) for 15-year female phantom. Female organ doses are not available for 15-year male phantom.

Choonsik L W Med Phys 2012;39

Estimation of Patient Organ dose

Look up Table Example: Chest CT -Adult patients

TABLE III. Average value of f_{organ} for scan lengths ranging from 4 to 32 cm performed at 120 kV.

Scan from z=40 cm to z=	f_{breast}	f_{lung}	$f_{thyroid}$	f_{thymus}	f_{heart}	f_{rbm}	f_{liver}	$f_{stomach}$
44	0.03	0.12	0.0	0.02	0.14	0.05	0.31	0.18
48	0.07	0.42	0.01	0.07	0.63	0.11	0.39	0.24
52	0.62	0.72	0.01	0.16	1.08	0.16	0.44	0.27
56	1.16	0.98	0.02	0.61	1.29	0.23	0.46	0.28
60	1.21	1.23	0.04	1.39	1.37	0.28	0.47	0.29
64	1.23	1.39	0.09	1.58	1.41	0.35	0.47	0.29
68	1.25	1.47	0.20	1.64	1.43	0.41	0.48	0.30
72	1.25	1.50	1.07	1.67	1.43	0.44	0.48	0.30

$$f_{organ} = \text{Organ dose}/\text{CTDI}_{vol}.$$

Organs that are directly in the x-ray beam, and are completely irradiated, generally had f_{organ} values for a complete chest CT scan that were well above 1 i.e., breast, lung, heart, and thymus. Organs that are not completely irradiated in a total chest CT scan generally had f_{organ} values that were less than 1 e.g., red bone marrow, liver, and stomach.

Huda W Med Phys 2010; 37:842-47

Look up Tables For Interventional procedures

Estimation of Patient Organ dose

Coronary Angiography and Percutaneous Coronary Intervention

TABLE VI. Conversion factors between DAP and equivalent doses $H_T/\mathrm{DAP}_{\mathrm{CA}}$ and $H_T/\mathrm{DAP}_{\mathrm{PCI}}$ (with Pearson's correlation coefficients r_{CA} and r_{PCI}) for CA and PCI procedures.

Parameter	$H_T/\mathrm{DAP}_{\mathrm{CA}}$ (mSv Gy^{-1} cm^{-2})	r_{CA}	$H_T/\mathrm{DAP}_{\mathrm{PCI}}$ (mSv Gy^{-1} cm^{-2})	r_{PCI}
$H_{T,\mathrm{bone}}$	0.0022 ± 0.0002	0.98	0.0025 ± 0.0005	0.92
$H_{T,\mathrm{colon}}$	0.008 ± 0.002	0.91	0.011 ± 0.003	0.84
$H_{T,\mathrm{esophagus}}$	0.35 ± 0.06	0.96	0.43 ± 0.11	0.85
$H_{T,\mathrm{heart}}$	0.31 ± 0.06	0.94	0.40 ± 0.11	0.83
$H_{T,\mathrm{liver}}$	0.15 ± 0.03	0.94	0.17 ± 0.05	0.85
$H_{T,\mathrm{lung}}$	0.40 ± 0.06	0.94	0.50 ± 0.14	0.85
$H_{T,\mathrm{red\ bone\ marrow}}$	0.09 ± 0.02	0.94	0.11 ± 0.03	0.85
$H_{T,\mathrm{skin}}$	0.065 ± 0.005	0.99	0.064 ± 0.014	0.91
$H_{T,\mathrm{stomach}}$	0.09 ± 0.02	0.87	0.13 ± 0.05	0.70
$H_{T,\mathrm{thyroid}}$	0.053 ± 0.012	0.93	0.07 ± 0.02	0.85

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Conversion factors of effective and equivalent organ doses with the air kerma area product in patients undergoing coronary angiography and percutaneous coronary interventions

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Table 6
Conversion factors between DAP and equivalent doses H_T /DAP$_{CA}$ and H_T /DAP$_{PCI}$ with Pearson's correlation coefficients r_{CA} and r_{PCI} for CA and PCI procedures.

Parameter	H_T/DAP$_{CA}$ mSv Gy^{-1} cm^{-2}	r_{CA}	H_T/DAP$_{PCI}$ mSv Gy^{-1} cm^{-2}	r_{PCI}
$H_{T,active\ bone\ marrow}$	0.38 ± 0.10	0.99	0.39 ± 0.20	0.86
$H_{T,breasts\ (Female)}$	0.11 ± 0.05	0.87	0.12 ± 0.04	0.81
$H_{T,colon}$	0.007 ± 0.003	0.95	0.009 ± 0.005	0.74
$H_{T,heart}$	1.28 ± 0.40	0.99	1.31 ± 0.62	0.91
$H_{T,liver}$	0.20 ± 0.09	0.92	0.26 ± 0.15	0.71
$H_{T,lungs}$	1.07 ± 0.32	0.99	1.00 ± 0.49	0.83
$H_{T,oesophagus}$	0.97 ± 0.28	0.99	1.07 ± 0.51	0.95
$H_{T,skeleton}$	0.57 ± 0.15	0.99	0.52 ± 0.25	0.91
$H_{T,skin}$	0.13 ± 0.03	1.00	0.13 ± 0.05	0.98
$H_{T,stomach}$	0.08 ± 0.02	0.97	0.09 ± 0.06	0.73
$H_{T,thyroid}$	0.03 ± 0.01	0.98	0.03 ± 0.04	0.64

Table 7
Conversion factors between E/ DAP$_{CA}$ and E/ DAP$_{PCI}$ found in literature.

Author year [Ref.]	E/DAP$_{CA}$ mSv Gy^{-1} cm^{-2}	E/DAP$_{PCI}$ mSv Gy^{-1} cm^{-2}
Compagnone 2011 [9,11]	0.18	0.20
Compagnone 2011 [9,21]	0.11	0.13
Bor 2009 [24]	0.26	0.25
Bogaert 2008 [24]	0.18–0.21	
Struelens 2012 [26]	0.30	
Varghese 2016 [25]	0.35	
Present Study 2016	0.30	0.33

NA = Not available.

Dependence of conversion factors from added filtration

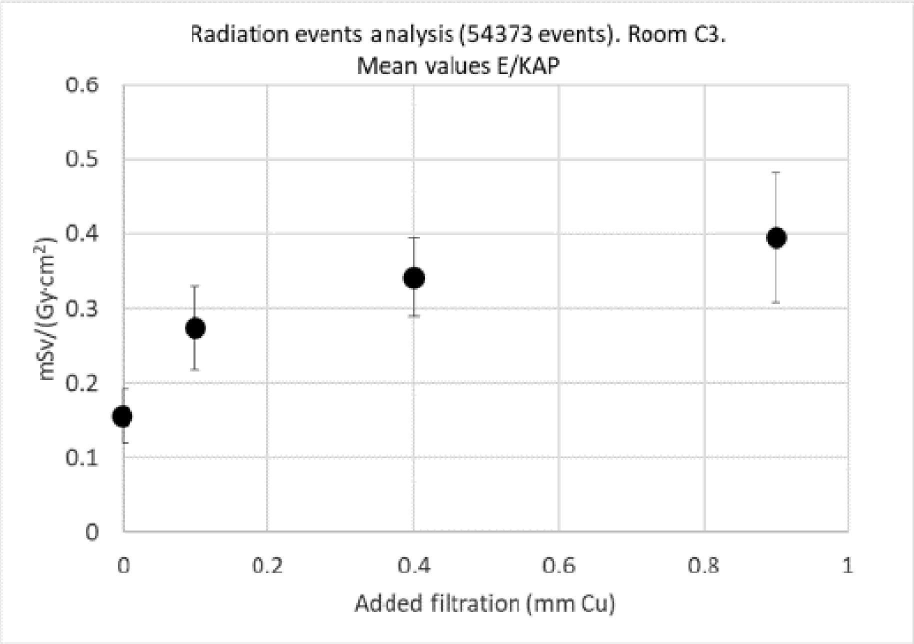

Fig. 5 Conversion factors from KAP to effective dose by added copper filtration. The error bars represent the standard deviation of the sample.

For X-ray systems without Copper filtration in cine
Effective dose (mSv) = KAP (Gy.cm^2) x 0.21
For X-ray systems with "dose reduction techniques" using 0.4 mm of Cu filtration in cine
Effective dose (mSv) = KAP (Gy.cm^2) x 0.29
NOTES: KAP values should be corrected by the local calibration factor and by the attenuation of the table and mattress. The "conversion factors" (0.21 and 0.29) should be refined according to the Copper filtrations used in the local protocols.

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Conclusions

- Conversion factors
  - E/KAP for interventional radiology
  - E/administered activity and type of Radiopharmaceutical for NM
  - E/DLP for CT

Seems the most simple and efficient way to manage the radiation exposure tracking of individual patients.

- Alert values could be set at a value of 100 mSv of CED accrued