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Cumulative Radiation Exposure from Medical Imaging in Two Hospital Systems – Implications for Medical Record Portability

Timothy B. Bullard[1], **Jay L. Falk**[1], **Mark S. Smith**[2], **Audrey Wegst**[3], **David H. Roseman**[2], **James S. Jelinek**[2], **Mihail Stojanovski**[1], **Ashley Waplinger**[1] **and Linda Papa**[1*]

[1]*Orlando Regional Medical Center, USA*

[2]*Washington Hospital Center, USA*

[3]*Diagnostic Technology Consultants Inc., USA*

[*]**Corresponding author:** Linda Papa, MD.CM, MSc, Department of Emergency Medicine, Orlando Regional Medical Center, 86 W. Underwood (S-200), Orlando, Florida, 32806, USA, Tel: 407-237-6329; Fax: 407-649-3083; E-mail: lpstat@aol.com

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Abstract

This study assessed the estimated cumulative effective ionizing radiation dose from diagnostic imaging studies performed on a sample of patients identified in two emergency departments (ED) from different hospital systems over 5 years. A random sample of patients was retrospectively identified from a cohort of patients receiving diagnostic imaging during their visit. All imaging diagnostic studies performed on the sample patients over a five year period were retrieved and assigned an effective radiation dose by a radiation physicist, using published reference tables. During the five year study period there were 13,387 radiological studies performed on 1,243 patients sampled from the two hospitals. The mean cumulative radiation dose per patient in milliseiverts (mSv) was 45.0 (SD ±71.4) (range 0.1-674.6) mSv. There were 150 patients (12%) exposed to over 100 mSv of ionizing radiation over 5 years. Although CT scans accounted for only 25.5% of tests performed, they contributed to over 53% of the entire estimated effective radiation dose to this population. Moreover, nuclear medicine tests accounted for 5.3% of all tests performed but contributed to 29.7% of the total estimated effective radiation. The study identified a substantial number of patients exposed to estimated cumulative effective doses of ionizing radiation that would put them at risk of developing cancer based on the Linear No-Threshold Model. The study demonstrates that it is important for physicians to know how much cumulative radiation exposure from medical imaging their patients have received. This is one more example of the urgent need for medical record portability and information sharing.

Keywords: Ionizing radiation; Diagnostic imaging; Linear No-threshold model; Cancer risk; Cumulative radiation; Medical record portability; Electronic medical record; Cumulative medical imaging

Introduction

Recent articles have suggested that cancer risk to the population may be increasing as a result of exposure to increasing levels of ionizing radiation from diagnostic radiology procedures [1-9]. Radiation exposure was first recognized as a safety hazard in the early and mid-1900s, when fluoroscopy was in vogue and health care workers, as well as patients, developed serious clinical sequelae from a combination of overexposure and inadequate protection from radiation [10]. In the latter half of the 1900's, awareness of the risks of exposure resulted in safety measures and changes in practice that substantially reduced these risks [11]. The success of these interventions resulted in the general belief that diagnostic radiology was safe for patients, and that healthcare workers were protected by regulations requiring monitoring of and limitations to their exposure [11].

With the explosion in the use of computerized tomography (CT) scanning experts in the field of radiation physics and radiology have again raised concerns about patient safety [1-3,7-9]. CT scanning delivers substantially higher doses of ionizing radiation than standard plain radiography [12,13]. One chest CT scan has been estimated to deliver the equivalent radiation of 100 plain chest radiographs (x-rays) [14]. Furthermore, newer generation multi-slice scanners currently on the market deliver even higher radiation doses than do the older single slice scanners [4]. Amid these concerns, CT scanning is rapidly replacing traditional plain radiography as the imaging modality of choice for a broad range of clinical conditions [15-17]. In the emergency department, current practice includes very liberal use of CT exams for evaluation of abdominal pain [18], including renal colic [19]. Head CT is routinely used for the evaluation of trauma, headache, seizures and suspected stroke. CT of the cervical spine has largely replaced plain radiography for the evaluation of spine injuries in trauma [20-24]. Protocols for patient assessment at trauma centers increasingly rely on more liberal CT use [25,26]. Chest CT with contrast is now the preferred diagnostic modality for the work-up of a suspected pulmonary embolus [27,28]. New protocols utilizing CT angiography are under investigation to assist in the diagnosis of acute coronary syndromes and stroke [29-31]. These changes in practice have resulted in a 600 - 850% increase in the use of CT in the United States over the last two decades [8,32]. Longitudinal data collected on populations exposed to low levels of ionizing radiation, particularly the survivors of Hiroshima and Nagasaki, suggest that exposure even to doses as low as 10 to 100 millisieverts can have deleterious effects [33]. Additional data are available from studies on nuclear workers and medical populations [3,5,34-39]. The Academy of Sciences Committee on the Biologic Effects of Ionizing Radiation continues to endorse the linear non-threshold model relating radiation exposure to cancer risk [33,39]. According to that model, there is no low level of radiation that is completely safe. The estimated lifetime chance of

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developing cancer from 10 millisieverts of effective radiation dose (one abdominal CT) ranges from 1 in 550 for a child to 1 in 1000 for an adult (BEIR VII, 2005). Additionally, a dose of 100 millisieverts would cause approximately 1 person in 100 to develop a solid cancer or leukemia in their lifetime [33].

The swift growth in CT scan usage does not automatically reflect an increased awareness in patients or health care providers of radiation dosages associated with these procedures or the potential associated cancer risks [7,28]. When the "quick and easy" becomes the "norm" the risks of overuse are often ignored [40], a limited survey of physician and patient knowledge of the radiation dose resulting from CT scanning revealed an alarming ignorance, even among radiologists [41]. Although the emphasis of most of the recent articles has been on CT, other diagnostic radiological procedures also need to be considered when studying radiation exposure. Accordingly, this study attempts to assess the radiation exposure risk among a random sample of patients undergoing radiologic diagnostic testing as part of their routine healthcare in two geographically distinct healthcare systems.

Materials and Methods

Study design/setting

This retrospective study randomly sampled a cohort of patients who received diagnostic imaging during their visit to one of two urban tertiary care emergency departments (ED's) during the month of March 2006. Orlando Regional Medical Center (ORMC), Orlando, Florida and Washington Hospital Center Hospital (WHC), Washington D.C. are each tertiary care, level one trauma centers with high volume, high acuity emergency department visits that are separated geographically. Orlando Regional Medical Center is licensed for 581 beds and its ED treats 85,000 patients annually. Washington Hospital Center is licensed for 923 beds and treats 81,500 patients in its ED.

Study participants

A sample of 20% of patients in the cohort was randomly selected for analysis using a random coding system. Sampling methodology was the same at both study sites. The medical record numbers of every ED patient 16 years or older who received a diagnostic imaging test during the study time period was sorted in ascending order. Each fifth medical record number was selected for the study, yielding a random sample of twenty percent of the ED patients. Because a medical record number and not a visit number was used as the sort key, every patient who was seen during the month of March had equal probability of being included in the sample, regardless of how many ED visits the patient had during the month. Each patient was only counted once.

Methods of measurement

The term "rad" is the amount of radiation absorbed per unit mass. The preferred term for absorbed dose is the gray (Gy) (energy absorbed per kilogram). One rad is equivalent to 0.01 Gy. However, different tissues absorb different doses and have unequal biological effects. The rem (or sievert per System International [SI] units) is a unit that accounts for the biological effect of radiation and is calculated by multiplying the rad (or seivert) by the radiation weighting factor. The weighting factor reflects differences for each type of radiation (e.g. alpha, beta, gamma). Therefore, the "effective" radiation dose for a given radiologic study (seivert) is calculated from the actual radiation dose measured in grays (energy absorbed per kilogram) multiplied by a weighting factor that reflects the radiation sensitivity of the organ systems included in the irradiated field. The sievert implies a "biological" dose and gives an index of potential harm to a particular tissue or organ.

All imaging diagnostic studies performed on the sample patients over a five year period were retrieved and were assigned an effective radiation dose by a radiation physicist, using published reference tables (Table 1) [7,13,42-48]. Table 1 contains the estimated effective radiation dose, expressed in millisieverts (mSv) and plain chest x-ray equivalents that were used in the calculation. Diagnostic imaging tests included plain radiography, fluoroscopic procedures, CT scans, diagnostic nuclear medicine examinations, and mammography. All other diagnostic tests (such as GI studies, catheter placement) were categorized as "special procedures." Therapeutic nuclear medicine administration, radiation therapy treatments, all interventional radiology procedures, and coronary angiograms were excluded from the cumulative exposure data. For flouoroscopic studies, estimated fluoroscope time based on procedure norms was used, since the fluoroscopy time of each actual study was not available. A standard industry reference for radiation dose per procedure was then used to assign an estimated effective radiation dose to each fluoroscopy procedure.

Diagnostic Test	***Dose Range (mSv) Reported in the literature**	**Effective Dose (mSv) Single view/scan used in analysis**	**Chest x-ray Equivalent**
Plain Radiography (X-ray)			
Chest AP	0.02-0.67	0.1	1
Abdomen	0.37-1.00	0.36	3.6
C-spine	0.06-0.27	0.20	8
T-spine	0.40-1.40	0.40	4
LS-Spin	0.80-2.40	1	40
Pelvis AP	0.70-0.86	1	10
Limbs (single view)	0.01-0.06	0.03	0.3

CT			
CT Head	1.50-2.30	2.60	26
CT Chest	4.10-8.00	9.00	90
CT Abdomen	7.60-16.0	10.0	100
CT Pelvis	10.0-13.0	10.0	100
CT C-Spine	3.0-10.0	5.0	50
CT T-Spine	6.0-10.0	8.0	80
CT L-Spine	6.0-10.0	7.0	70
Mammography			
Bilateral Mammogram	0.07-0.89	0.7	7
Nuclear Medicine			
Cardiac (ORMC/WHC)	15.6-71.9	30/63	300/630

Table 1: Table of effective doses and chest radiography equivalents

This table contains the estimated effective radiation dose, expressed in millisieverts (mSv) and plain chest x-ray equivalents that were used in the calculation of effective doses (Brenner, 2007) (Mettler, 2008) (Richards, 2008) (Smith-Bindman, 2009) (Wall, 1997) (Fazel, 2009) (Hendrick, 2011) (Diederich, 2000)(Mayo, 2003).

Outcome measures

The actual effective radiation dose delivered to a single patient may vary from the estimated effective radiation dose because of technique; factors include size of the patient and the exact extent of the exposed irradiated area. However, on a population basis, this variation of actual from estimated effective dose should normalize over the population. For each patient, the sum of the estimated effective radiation dose for each radiologic study that the patient received during the study period was calculated. This yielded a five year cumulative estimated effective radiation dose which can be translated into an overall cancer risk from radiation. Patient age was assigned on the basis of age at the time of presentation in the ED during March.

Primary data analysis

Data is described using means, standard deviations and range and was assessed for distribution and variance. Comparisons were made using the Mann Whitney U test, Kendall's tau-b and Kruskall Wallis test. Data was analyzed using statistical software SPSS 12.0. Significance was set at P<0.05.

Ethics/Institutional review board

The study was approved by both Orlando Health Institutional Review Board and the Washington Hospital Center Institutional Review Board with a waiver of informed consent. All data were analyzed anonymously.

Results

During the five year study period there were 13,387 radiological studies performed on 1,243 patients sampled from the two hospitals. Of these radiographic studies 8436 (63%) were plain films, 3413 (26%) were CT scans, 703 (5%) were nuclear studies, 311 (2%) were mammography, 202 (2%) were fluoroscopy and 319 (2%) were special procedures. Patients were a mean age of 51.7 (±19.0) years and age range of 16-97 years. The demographics of the study patients from the two hospitals in Table 2 are similar and show no statistically significant differences. The mean number of diagnostic examinations per patient over 5 years was 10.6 at ORMC and 10.9 at WHC.

Characteristics	**ORMC** **N=556**	**WHC** **N=687**	**Total** **N=1,243**	**P-Value**
Mean age in years (±SD) Range	51.8 (±19.7) (16-95)	51.6 (±18.3) (16-97)	51.7 (±19.0) (16-97)	0.84
Gender – Female/ Male	283/ 273 51% Female	364/ 323 53% Female	647/ 596 52% Female	0.49
Mean Cumulative Radiation per Patient in mSv (±SD) Range	49.4 (±76.8) (0.1-674.6)	41.4 (±66.6) (0.1-560.4)	45.0 (±71.4) (0.1-674.6)	0.06

Total number of studies	5912	7472	13,384	-
Total Radiation Dose (mSv)	26,682	30,175	56,857	-
Number of Patients with Cumulative Radiation (%) >100 msv >200 msv >300 msv >400 msv	76 (13.7) 30 (5.4) 10 (1.8) 5 (0.9)	74 (10.8) 20 (2.9) 10 (1.5) 4 (0.6)	150 (12) 50 (4) 20 (1.6) 9 (0.6)	0.08
Mean Radiation per Study per Modality in mSv (±SD) Plain Films Computed Tomography (CT) Fluoroscopy Nuclear Medicine Mammography Special Procedures	0.65 (±1.31) 10.33 (±7.10) 12.43 (±5.43) 16.46 (±12.22) 0.46 (0.30) 2.41 (±4.07)	0.60 (±1.29) 7.62 (±3.47) 9.66 (±4.20) 31.11 (±30.92) 0.56 (±0.26) 5.81 (±4.30)	0.62 (±1.30) 8.91 (±5.66) 11.7 (±5.27) 24.03 (±24.88) 0.52 (±0.28) 5.61 (±4.35)	0.02
Total Radiation Dose from Studies Contributing Most Radiation mSv (%) CT Abdomen/Pelvis Nuclear Medicine (Cardiac) CT Chest Fluoroscopy CT Head Plain Abdomen Plain L-S Spine Plain Chest CT C-Spine Nuclear Medicine (Bone)	9,370 (35.1) 4,335 (16.2) 4,034 (15.1) 1,865 (7.0) 910 (3.4) 855 (3.2) 420 (1.6) 350 (1.3) 404 (1.5) 580 (2.2)	9,170 (30.4) 10,164 (33.7) 2,576 (8.5) 478 (1.6) 1,159 (3.8) 663 (2.2) 789 (2.6) 448 (1.5) 389 (1.3) 202 (1.0)	18,540 (32.6) 14,499 (25.5) 6,610 (11.6) 2,343 (4.1) 2,070 (3.6) 1,518 (2.7) 1,209 (2.1) 799 (1.4) 793 (1.4) 782 (1.4)	0.16

Table 2: Patient characteristics of all patients included in the analysis and by site

The demographics of the study patients from the two hospitals are similar and show no statistically significant differences except for radiation dose from nuclear medicine scans.

A p-value <0.05 is considered significant.

The overall mean cumulative radiation dose per patient in milliseiverts (mSv) was 45.0 (SD ± 71.4) (range 0.1-674.6) mSv with 49.4 (SD ± 76.8) at ORMC and 41.4 (± 66.6) at WHS. The total effective radiation dose from all diagnostic studies at both sites was 56,857 mSv. Seventy percent of the total radiation exposure to the entire study population could be attributed to 3 diagnostic tests: CT scan of the abdomen/pelvis; nuclear cardiac testing; and CT scan of the chest.

Table 3 summarizes the test frequency and total radiation within each modality at each site. Although CT scans accounted for only 25.5% of tests performed, they contributed to over 53% of the entire radiation dose to this population. Moreover, nuclear medicine tests accounted for 5.3% of all tests performed but contributed to 29.7% of the total radiation. The distribution of effective radiation by imaging modality and by age groups is shown in (Figure 1). In the under 20-year age group, fluoroscopy and nuclear scans contributed the largest mean radiation dose.

	ORMC		**WHS**		**Total**	
Type of Imaging	Number of Studies (%)	Total Radiation mSv (%)	Number of Studies (%)	Total Radiation mSv (%)	Number of Studies (%)	Total Radiation mSv (%)

Plain Films	3,657 (61.9)	2,376 (8.9)	4,779 (64)	2,873 (9.5)	8,436 (63)	5,249 (9.2)
Computed Tomography	1,620 (27.4)	16,739 (62.7)	1,793 (24)	13,657 (45.3)	3,413 (25.5)	30,396 (53.5)
Fluoroscopy	150 (2.5)	1,865 (7.0)	52 (0.7)	503 (1.7)	202 (1.5)	2,368 (4.2)
Nuclear Medicine	340 (5.8)	5,597 (21.0)	363 (4.9)	11,296 (37.4)	703 (5.3)	16,893 (29.7)
Mammography	126 (2.1)	59 (0.2)	185 (2.5)	103 (0.3)	311 (2.3)	162 (0.3)
Special Procedures	19 (0.3)	46 (0.2)	300 (4.0)	1,744 (5.8)	319 (2.4)	1790 (3.1)
Total	5,912	26,682	7,472	30,175	13,384	56,857

Table 3: Summary of the number of studies (plain films, CT's, Fluoroscopies, Nuclear scans, Mammography and special procedures) and total cumulative dose within each modality by site

This table summarizes the test frequency and total radiation within each modality at each site. Although CT scans accounted for only 25.5% of tests performed, they contributed to over 53% of the entire radiation dose to this population. Moreover, nuclear medicine tests accounted for 5.3% of all tests performed but contributed to 29.7% of the total radiation.

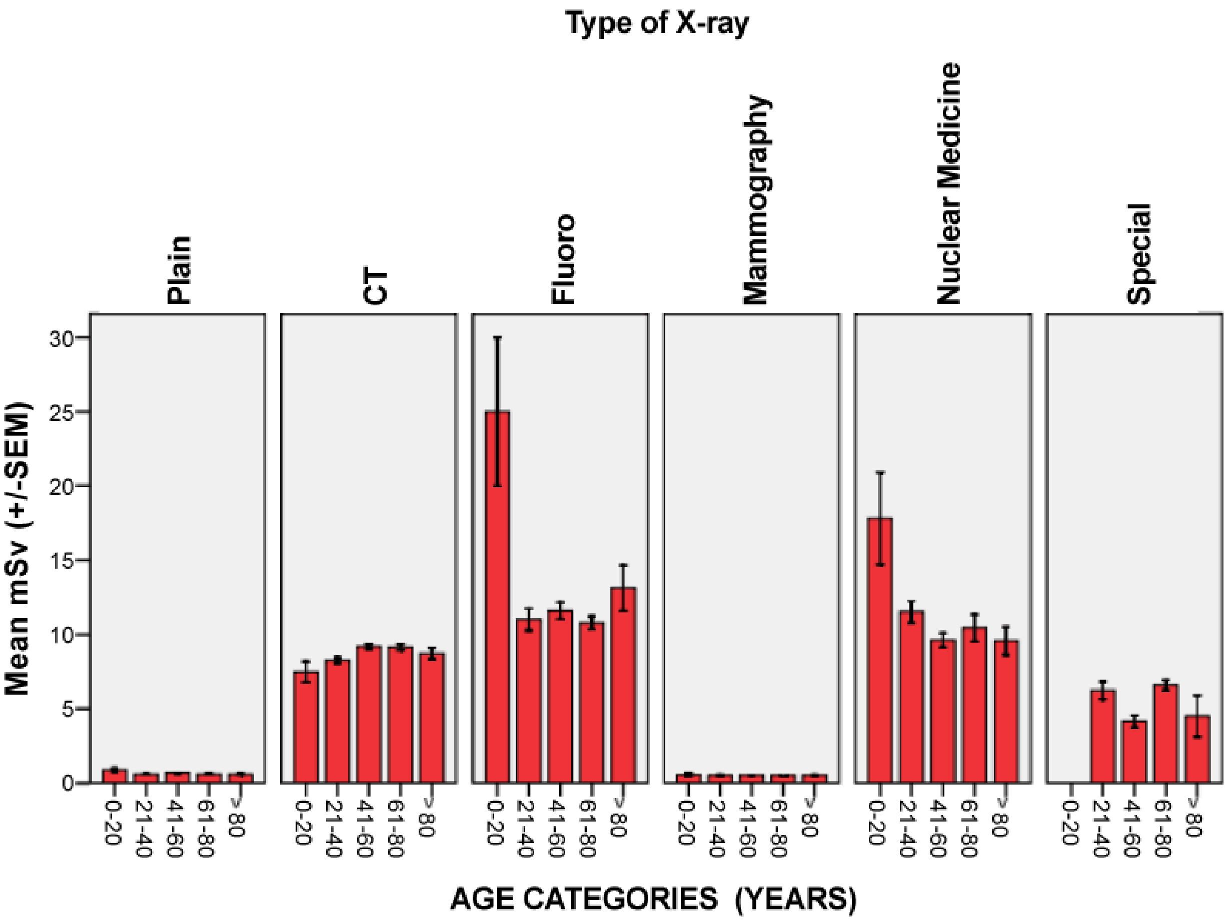

Figure 1: Mean effective radiation dose by type of imaging modality and by age group

The distribution of the type of radiological studies performed in each modality (Table 4) was similar for both institutions except for the modality of nuclear medicine where there were significant differences at ORMC versus WHC respectively in Bone Scans (22.5% vs 6.9%), Lung Scans (0.6% vs 21.5%) and PET scans (15% vs 6.1%). In both hospitals, however, Nuclear Cardiac Testing was the predominant study type with 48.2% and 51.2% at ORMC and WHS respectively.

Radiographic Study in order of Frequency	ORMC (%)	WHC (%)	Total (%)	P-Value
Plain Radiography	(N=3657)	(N=4779)	N= (8436)	0.13
1. Chest	2397 (65.5)	3149 (65.9)	5546 (65.7)	
2. Abdominal	378 (10.3)	437 (9.1)	815 (9.7)	
3. Pelvis/ Hip	123 (3.4)	165 (3.5)	288 (3.4)	
4. Foot	55 (1.5)	161 (3.4)	216 (2.6)	
5. LS-Spine	73 (2.0)	132 (2.8)	205 (2.4)	
6. Knee	67 (1.8)	125 (2.6)	192 (2.3)	
7. Ankle	73 (2.0)	86 (1.8)	159 (1.9)	
8. Hand	48 (1.3)	80 (1.7)	128 (1.5)	
9. Wrist/ Forearm	73 (2.0)	53 (1.1)	126 (1.5)	
10. Shoulder	50 (1.4)	69 (1.4)	119 (1.4)	
CT Scan	(N=1620)	(N=1793)	(N=3413)	0.16
1. Abdomen/ Pelvis	680 (42.0)	910 (50.8)	1590 (46.6)	
2. Head	341 (21.0)	439 (24.5)	780 (22.9)	
3. Chest	344 (21.2)	284 (15.8)	628 (18.4)	
4. C-Spine	70 (4.3)	66 (3.7)	129 (3.8)	
5. Maxillo-facial	45 (2.8)	59 (3.3)	111 (3.5)	
Nuclear Medicine	(N=340)	(N=363)	(N=703)	<0.001
Cardiac	164 (48.2)	186 (51.2)	350 (50.0)	
Bone	77 (22.5)	25 (6.9)	102 (14.5)	
Lung	2 (0.1)	78 (21.5)	80 (11.4)	
PET	51 (15.0)	22 (0.1)	73 (10.3)	
GI	32 (9.4)	29 (8.0)	61 (8.7)	
Mammography	(N=126)	(N=185)	(N=311)	0.21
Bilateral	71 (56.3%)	138 (74.6%)	209 (67.2)	
Dexa Skeleton	28 (22.2%)	28 (15.1%)	56 (18.0)	
Unilateral	18 (14.2%)	17 (9.2%)	35 (11.3)	

Table 4: Most frequently ordered studies within each modality, according to site

The distribution of the type of radiological studies performed in each modality was similar for both institutions except for nuclear medicine studies. There were significantly more Bone Scans 22.5% vs 6.9% ($p<0.001$) and PET scans 15% vs 6.1% ($p=0.001$) performed at ORMC than WHC. However, there were more Lung Scans 0.6% vs 21.5% ($p<0.001$) performed at WHC than ORMC. Nonetheless, in both hospitals, Nuclear Cardiac Testing was the predominant study type with 48.2% and 51.2% at ORMC and WHS respectively. A p-value <0.05 is considered significant.

There were 150 patients (12%) who received a five year effective dose of over 100 mSv of ionizing radiation, 76 (13.7%) at ORMC and 74 (10.8%) at WHS (Table 5). The mean age of this high exposure subgroup was 55.4 (±17.4) years with a range from 16-89. Of these 150 patients 50 (33%) were exposed to over 200 mSv of effective radiation, 20 (13%) were exposed to over 300 mSv and 9 patients (6%) were exposed to over 400 mSv of effective radiation. Of the total effective radiation dose of 56,867 mSv from all the diagnostic studies in the entire cohort, 29,900 mSv (52.6%) was accounted for by this subgroup of 150 patients with 14,796 (49%) mSv from ORMC and 15,104 (51%) mSv from WHC. Additionally, there were 5,563 diagnostic tests performed in those receiving more than 100mSv of effective cumulative radiation, accounting for 42% of all studies performed in the entire cohort. The mean number of diagnostic examinations per patient over 5 years was 36.0 at ORMC and 38.0 at WHC. This represents close to four times the number of radiological examinations performed in those with less than 100 mSv of cumulative radiation.

Characteristics	ORMC N=76	WHC N=74	Total N=150
Mean age in years (±SD)	60.1 (±15.5)	50.5 (±18.1)	55.4 (±17.4)

Range	(18-89)	(16-89)	(16-89)
Gender (female)	42 (55%)	35 (47%)	77 (51%)
Mean Radiation/Patient mSv (±SD) Range	201.3 (±111.1) (104.7 - 674.6)	191.7 (±99.1) (100.2 - 560.4)	196.6 (±105.1) (100.2 – 674.6)
Total number of studies	2734	2829	5563
Total Radiation Dose (mSv)	14,796	15,104	29,900
Number of studies by Modality Plain Radiography CT Fluoroscopy Nuclear Medicine Mammography Special Procedures	1505 (55.0) 891 (32.6) 83 (3.0) 208 (7.6) 32 (1.2) 15 (0.5)	1640 (58.0) 734 (25.9) 31 (1.1) 192 (6.8) 36 (1.3) 196 (6.9)	3145 (56.5) 1625 (29.2) 114 (2.0) 400 (7.2) 68 (1.2) 211 (3.8)
Most Frequent Study Type Plain Chest Radiography CT Abdomen/Pelvis Plain Abdominal Radiography CT Chest CT Head	1001 (36.6) 490 (17.9) 224 (8.2) 199 (7.4) 110 (4.0)	1050 (37.1) 473 (16.7) 246 (8.7) 112 (4.0) 106 (3.7)	2951 (36.9) 963 (17.3) 470 (8.4) 311 (5.6) 216 (3.9)
Total Radiation Dose from each Modality mSv (%) Plain Radiography CT Fluoroscopy Nuclear Medicine Mammography Special Procedures	1,125 (7.6) 9,667 (65.3) 1,044 (7.1) 2,909 (19.7) 18 (0.1) 34 (0.2)	1,110 (7.3) 6,223 (41.2) 306 (2.0) 6,246 (41.4) 16 (0.1) 1,204 (8.0)	2,235 (7.5) 15,890 (53.1) 1,350 (4.5) 9,154 (30.6) 34 (0.1) 1,237 (4.1)
Total Radiation Dose from Most Frequent Study Type mSv (%) Plain Chest Radiography CT Abdomen/Pelvis Plain Abdominal Radiography CT Chest CT Head	350 (2.4) 9,370 (63.3) 855 (5.8) 4,034 (27.3) 910 (6.2)	448 (3.0) 9,170 (60.7) 663 (4.4) 2,576 (17.1) 1,159 (7.7)	798 (2.7) 18,540 (62.0) 1,518 (5.1) 6,610 (22.1) 2,069 (6.9)
Total Radiation Dose from Studies Contributing Most Radiation mSv (%) CT Abdomen/Pelvis Nuclear Medicine (Cardiac) CT Chest Fluoroscopy Plain Abdominal Radiography CT Head Nuclear Medicine (Bone) Nuclear PET Scan Plain L-S Spine GI Studies	6,180 (41.8) 1,955 (13.2) 2,195 (14.8) 1,044 (7.1) 551 (3.7) 291 (2.0) 465 (3.1) 301 (2.0) 94 (0.6) 145 (1.0) 146 (1.0)	4,750 (31.4) 5,555 (36.7) 1,019 (6.7) 301 (2.0) 373 (2.5) 278 (1.8) 80 (0.5) 161 (1.0) 259 (1.7) 170 (1.1) 150 (1.0)	10,930 (36.6) 7,510 (25.1) 3,214 (10.7) 1,345 (4.5) 923 (3.1) 569 (1.9) 545 (1.8) 462 (1.5) 353 (1.2) 315 (1.1) 296 (1.0)

Plain Chest Radiography			

Table 5: Description of 150 Patients with over 100 mSv of Effective Cumulative Radiation over the 5-year Study Period

There were 150 patients (12%) who received a five year effective dose of over 100 mSv of ionizing radiation, 13.7% at ORMC and 10.8% at WHS. Of these 33% were exposed to over 200 mSv of effective radiation, 13% were exposed to over 300 mSv and 6% were exposed to over 400 mSv of effective radiation.

Of those patients receiving a five year effective dose of over 100 mSv of ionizing radiation, 53% of the effective radiation dose came from CT Scans and 31% from nuclear medicine studies. One difference between the two groups was the contribution of CT scanning and nuclear medicine to the total estimated effective dose. At ORMC 65% of the exposure resulted from CT scans while 20% resulted from nuclear studies and at WHC 41% of the total exposure resulted from CT while 41% resulted from nuclear medicine studies. It appears that the WHC study cohort received a greater radiation dose from nuclear medicine diagnostic studies compared to the ORMC group, primarily because of a difference in type and dosage of the radiopharmaceuticals used for cardiac stress tests. At WHC, an average dose of 63 mSv was used for a cardiac nuclear study compared to an ORMC average dose of 30 mSv. The distribution of effective radiation dose by imaging modality and by age when patients are stratified into greater or less than 100 mSv of cumulative radiation exposure is shown in (Figure 2).

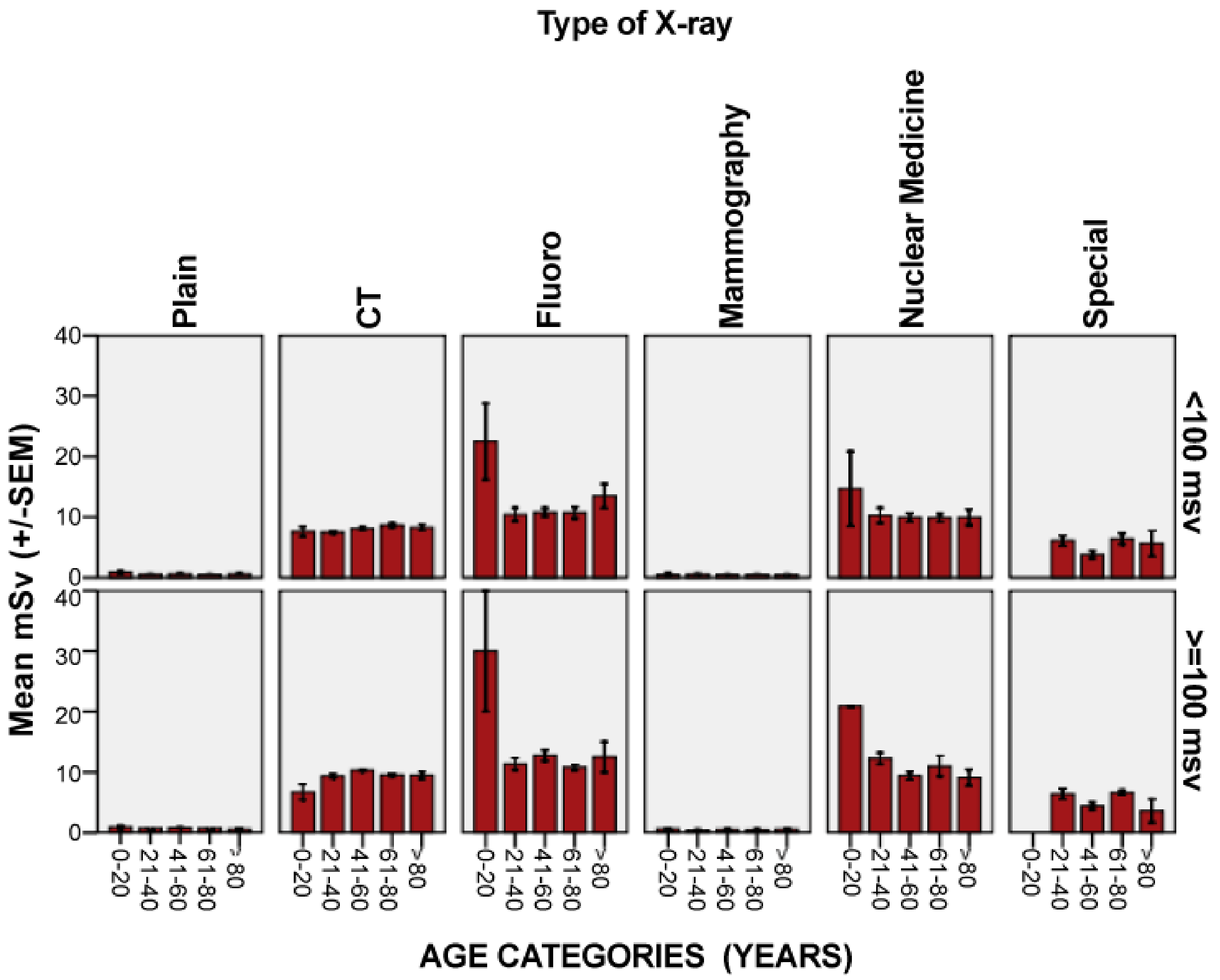

Figure 2: Mean effective radiation dose by type of imaging modality and by age group in those above and below 100 mSv of cumulative radiation exposure

The diagnostic tests contributing to the highest cumulative radiation in the subgroup of patients with over 100 mSv of radiation was the same as in those less than 100 mSv of cumulative radiation: CT scan of the abdomen/pelvis; nuclear cardiac testing; and CT scan of the chest.

Limitations

There are a number of limitations to this study. Firstly, data collection was retrospective and actual radiation doses were not obtained in real-time but calculated so that estimated effective doses and not actual effective doses were used in the calculation. Estimated effective dose is based solely on the type of diagnostic test and not on the actual dose delivered, the size of the patient, or the specifics of the individual imaging device. Secondly, for fluoroscopic studies, the time of the study also had to be estimated in order to calculate the estimated effective dose. Thirdly, there were a small number of interventional procedures to which an estimated effective dose could not be assigned because the exact type of study could not be ascertained from the medical record; 154 diagnostic studies were excluded from the study for this reason. This exclusion could result in a slight underestimate of the effective radiation dose received by the study population. Fourthly, cardiac catheterization procedures were also excluded from the data set resulting in further underestimation of the estimated doses. Despite these limitations, the results of this study are likely under-estimating the effective radiation dose received in this population; particularly since we only obtained five years-worth of radiologic studies and did not include studies that may have been obtained by visits to other facilities.

Discussion

The results of this study demonstrate how ubiquitous this issue and supports the ongoing concerns over the amount of ionizing radiation that patients are being exposed to over time. Since the data only represents a five year period and only captures diagnostic imaging obtained at two single institutions, the figures represented are likely under-estimating the cumulative radiation exposure from diagnostic imaging in this population. Any radiation exposure the patient received from other sources was not counted. One hundred and fifty of our patients exceeded the BEIR VII definition of low dose radiation. Given that the average age of patients who received more than 100 millisieverts over five years was 55, it is likely that the cumulative lifetime radiation exposure for those patients was considerably higher. The tests that contributed most significantly to the total exposure in our sample were CT and nuclear medicine testing. While the mean age of patients receiving 100 or more millisieverts was 55 years; 42% were age fifty or younger. A number of these patients received diagnostic tests for conditions such as renal colic and chronic or recurrent pain that could potentially be imaged by other modalities.

Brenner, Semelka and others have raised concerns about the potential harmful effects of ionizing radiation that patients are currently being exposed to through diagnostic imaging [7,13,42,43,45,49,50]. CT scanning technology exposes patients to substantially more radiation than traditional plain radiography [1]. It has been estimated that a single abdominal CT scan delivers the equivalent effective radiation dose of at least 100 chest x-rays [7,13,14,42-48]. This equivalent radiation is increased four-fold when the lowest estimated plain radiograph dose is compared with the highest estimated CT scan dose. Doses from a typical CT scan range from 6 to 35 times the dose from a typical plain radiograph [51]. As the given dose depends on many different factors including beam energy, filtration, collimation, grids, and patient size, more research must be done to standardize the lowest effective dose for imaging when necessary [51].

Much has been learned about the risks of exposure to ionizing radiation in the last several years. A major portion of that knowledge has come from following survivors of the Hiroshima and Nagasaki atomic bomb blasts [52]. A number of the survivors were determined to have received an effective radiation dose of between 10 and 100 millisieverts and a small but statistically significant percentage of them developed cancer at a higher rate than a normal population. The study of nuclear radiation workers has also provided a link between ionizing radiation and cancer. One study of 400,000 nuclear radiation workers showed a dose related increase in all cancer mortality from radiation [51]. A linear no-threshold model has been developed to explain the risk of cancer from low dose ionizing radiation based on the atomic bomb experience and other data from medical studies as well as studies on nuclear worker exposure. The BEIR VII Committee (Biologic Effects of Ionizing Radiation) which is comprised of experts in the field of radiation has endorsed this model [33].

According to the linear no-threshold model there is no safe threshold for ionizing radiation exposure. The Committee defines a low dose of radiation to be less than 100 mSv. In the model, cancer risk rises linearly with dosage and is cumulative. The risk is higher in children and decreases with age. The risk for females is higher than males. The findings of the Scoliosis Cohort Study, which looked at breast cancer rates in scoliosis patients exposed to low level ionizing radiation from radiographic studies, is an example of a recent large study supporting the no-threshold linear model [53]. Additionally, a data-linkage study of 11 million Australians, 680,000 of which were exposed to radiation from CT scans, provides further evidence to support this link between cancer and ionizing radiation as well as the linear no-threshold model. In this study, the overall cancer incidence was 24% greater for those individuals who were exposed to ionizing radiation from CT scans, than those individuals who were not exposed [54]. Additionally, it was found that the incidence rate ratio (IRR), defined as the incidence rate of disease occurrence in the exposed divided by the incidence rate of disease in the unexposed group, increased by 0.16 for each additional CT scan. The IRR was greater after exposure at younger ages. The study concluded that the increased incidence in cancer after CT scan exposure in this cohort could be contributed primarily to irradiation [54].

A single abdominal CT scan delivers an estimated effective dose of 10 millisieverts [33]. Based upon the linear no-threshold model endorsed by BEIR VII that dose would result in an incremental chance of developing cancer above the natural rate for cancer in the population at 1 in 550 for a child and 1 in 1000 in an adult. At 100 mSv the adult rate jumps to 1 in 100. Using this general risk estimate, if distributed equally among the study patients, the 56,857 mSv delivered to our study population from medical diagnostic studies would result in approximately six cancers above the natural cancer incidence. The higher the dose received by an individual, the higher his or her risk of developing cancer. In the 150 patients who received more than 100 mSv of estimated cumulative effective radiation dose, at least 1.5 patients would be expected to get an iatrogenic cancer from the cumulative radiation. Of note is the disproportionate contribution of CT scans and nuclear medicine diagnostic studies to cumulative lifetime radiation dose.

Our study raises a number of questions and concerns. Most importantly, the study demonstrates that cumulative radiation exposure from medical imaging has no geographic boundaries and a global approach is needed. In 2010, the FDA revealed an initiative to reduce unnecessary radiation exposure from medical imaging. Their initiative focused on reducing ionizing radiation exposure from CT scans, nuclear medicine, and fluoroscopy [55]. Further initiatives, such as this one, must be implemented in order to raise awareness and protect patients from the harmful effects of ionizing radiation. Based on our data, a much larger longitudinal multi-institutional study with direct radiation dose measurements is needed to better define the actual risks patients are incurring from radiation exposure associated with current diagnostic imaging.

Conclusion

This study is a unique addition to the literature because it demonstrates how unaware physicians are of the amount of cumulating radiation patients have received, especially when patients are being evaluated in the emergency department or other outpatient setting. The study demonstrates that it is important for physicians to know how much cumulative radiation exposure from medical imaging their patients have received. Furthermore, because these were two distinct hospital systems that located far away, it shows that this problem has no geographic boundaries and a global approach is needed. There is a need to forge ahead with technology that results in less radiation exposure and models of care that promote more continuity of care with the need for fewer diagnostic tests. This is one more example of the urgent need for medical record portability and information sharing. Development of tools that allow rapid recognition of cumulative effective radiation dose for any given patient would go far in helping physicians recognize potential harm. Finally, physicians must exercise careful judgment in the application of diagnostic imaging technologies, especially CT and nuclear medicine studies.

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