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Technical note

Estimates of the number of patients with high cumulative doses through recurrent CT exams in 35 OECD countries

Madan M. Rehani[a,*], Michael Hauptmann[b]

[a] Massachusetts General Hospital, Boston, MA 02114, USA
[b] Institute of Biostatistics and Registry Research, Brandenburg Medical School, 16816 Neuruppin, Germany

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ABSTRACT

Purpose: To estimate the number of patients in OECD (Organization for Economic Co-operation and Development) countries who receive a cumulative effective dose (CED) ≥ 100 mSv from recurrent computed tomography (CT) exams.

Methods: Taking into account recently published data on the number of CTs per patient and the fraction of patients with CED ≥ 100 mSv as well as country-specific data for the number of CT exams/1,000 population from OECD publication, this paper makes estimations for 35 OECD countries.

Results: The estimated total number of patients with CED ≥ 100 mSv for all 35 OECD countries combined in a 5-year period is around 2.5 million (2,493,685) in a population of 1.2 billion (1,176,641,900), i.e., 0.21% of the population. Expressed per 1,000 population, the range is from 0.51 for Finland to 2.94 for the US, a nearly six-fold difference. Countries with more than 2 patients with CED ≥ 100 mSv in a 5-yr period per 1,000 population are: Belgium, France, Iceland, Japan, Korea, Luxembourg, Portugal, Turkey, and US.

Conclusions: The first estimates of the number of patients likely receiving CED ≥ 100 mSv through recurrent CT exams in 35 OECD countries indicate that 2.5 million patients reach this level in a 5-year period. There is an urgent need for various stakeholders including medical physicists, referring physicians, health policy makers, manufacturers of CT equipment and epidemiologists to attend to the issue in the interest of patient radiation safety.

1. Introduction

While acknowledging the immensely useful role computed tomography (CT) plays in diagnosis and management of patients, attention has frequently been drawn to radiation exposure of patients. This has resulted in lowering the patient radiation doses in large parts of the world both at the per exam level and the collective dose [1–4]. A recent study reported that low-dose CT had no effect on human DNA whereas in the same setting, DNA double-strand breaks and chromosome aberrations were shown to increase after standard-dose CT [5]. A number of studies have documented increased cancer risk after CT scan related radiation exposures and more studies are ongoing [6–8].

Thus, radiation dose optimization should remain a continuous pursuit, especially when there is scope for further improvement [3,4,9]. However, despite tremendous improvements in radiation doses in the last decade, Rehani et al. 2020a [10] demonstrated that patients undergoing recurrent CT exams during a short span of 1 to 5 years are not uncommon. The authors used a yardstick of cumulative effective dose (CED) of ≥100 mSv, not that radiation effects start at 100 mSv but at this level of dose some organs may receive doses of a few tens of mGy or even exceed 100 mGy, a range at which a statistically significant excess of certain cancers like of bone marrow, thyroid, bladder, breast, colon and lung has been demonstrated in a number of studies and there is a reasonable degree of agreement among official international organizations like ICRP, UNSCEAR, and national organizations like NCRP on potential stochastic radiation effects [11–13]. A recent review shows that there is now convincing evidence of excess cancer risk at organ doses below 100 mGy [14].

Assessments of the number of patients who may be receiving high doses in different countries are therefore of high priority. This paper reports such estimates for countries included in the Organization for Economic Co-operation and Development (OECD) as required data on CT frequency is not available collectively from a credible source for others.

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* Corresponding author at: Radiology Department, Massachusetts General Hospital, 175 Cambridge Str., Suite 244, Boston, MA 02114, USA.
E-mail addresses: mrehani@mgh.harvard.edu, madan.rehani@gmail.com (M.M. Rehani), michael.hauptmann@mhb-fontane.de (M. Hauptmann).

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2. Materials and methods

OECD is an intergovernmental economic organisation with 36 member countries as of 2019. We used the population information for OECD countries available from the internet [15].

2.1. Assessment of the number of patients undergoing CT exam in each country

We used data on the number of CT exams per 1,000 population per year provided by OECD for 2017 or nearest [16] to estimate the number of CTs in each country as:

$$\begin{aligned}&\textit{No. of CT exams in a country}\\&=\textit{No. of CT exams}/1000\,\textit{population}\times\textit{population of the country}\end{aligned}$$

Since the number of patients undergoing CT exams in different countries is not available, we used data from Rehani et al. 2020a [10] who estimated an average number of CT exams per patient of 1.92 from the data of 4,819,661 CT exams performed in 2,504,585 patients in 324 hospitals in the US and a country in Europe during periods of one to five years. This number differed across different institutions (range 1.84–2.23). The annual number of patients undergoing CT exams in each country was thus obtained by dividing the annual number of CT exams in each country by 1.92.

$$\begin{aligned}&\textit{No. of patients undergoing CT exams in a country/yr}\\&\approx\textit{No. of CT exams in a country per yr}/1.92\,\textit{CTs per patient}\end{aligned}$$

2.2. Assessment of the number of patients with CED ≥ 100 mSv

The data provided by Rehani et al. [10] indicates that 33,407 of the 2,504,585 patients (1.33%) received a CED ≥ 100 mSv. The total person-time from data in [10], (sum over number of patients *years) of observation in 4 institutes for these patients was approximated as $267{,}013 * 5 + 807{,}526 * 5 + 430{,}049 * 31/12 + 999{,}997 * 13/12 = 7{,}566{,}985$ patient-years. This corresponds to an incidence of 33,407 patients/7,566,985 * 5 years or 0.02207418 for 5 years among patients undergoing a CT exam.

Because of missing data in OECD for some countries, we used numbers for Ireland from the UK, for New Zealand from Australia, and for Norway and Sweden from Denmark. We excluded Mexico from all calculations in view of lack of data. We also excluded new OECD countries that got added after the release of the 2019 publication [16].

3. Results

Table 1 shows the population size of OECD countries and the annual frequency of CT exams from public OECD data [15,16]. Using the estimated incidence of receiving a CED ≥ 100 mSv per 5 years of 0.02207418, as derived above, the estimated numbers of patients receiving a CED ≥ 100 mSv per 5 years for each of the 35 countries are presented in Table 1. The total estimated number of patients with CED ≥ 100 mSv for all 35 countries combined in a 5-year period is around 2.5 million against a population of 1.2 billion (0.21%).

The number of patients with CED ≥ 100 mSv per 5 years ranges from 867 for Iceland to 961,799 for the USA. Expressed per 1,000 population (last column in Table 1), the range is from 0.51 for Finland to 2.94 for the USA, a nearly six-fold difference. Fig. 1 presents the number of patients with CED ≥ 100 mSv per 1,000 population in ascending order.

Table 2 stratifies countries by number of patients with CED ≥ 100 mSv in 5-yr period per 1,000 population (Low: 0 to < 1, Medium: 1 to < 2 and High: ≥2). There are 2 countries in Low group, 24 in medium and 9 in high number group.

4. Discussion

The driving force for this paper was to obtain an approximation of the number of patients likely receiving CED ≥ 100 mSv in a defined time frame. We translate the results presented in recent papers [10,17] to a large group of countries in which CT scanning is a standard diagnostic procedure and radiation protection efforts are presumably widely implemented. If true, the numbers presented here are alarming as they indicate that a large group of patients is exposed to doses for which there is now convincing epidemiological evidence of a causal link with cancer [11,14].

There is no direct correlation of the number of patients with CED ≥ 100 mSv with population size. For example, the UK and France are similar in terms of population but the number of patients with CED ≥ 100 mSv in France is nearly double as the frequency of CT use per unit population is nearly double. Germany and Canada have a similar frequency of CT use per unit population and therefore the number of patients with high cumulative dose is proportional to population. Within the European Union, there is a vast difference in CT use frequency from around 44 CTs/1,000 population in Finland to nearly 210 for Luxembourg and Iceland, a 5-fold difference. However, the number of patients with CED ≥ 100 mSv per 1,000 population differs by up to a factor of 2.94. Countries with more than 2 patients per 1,000 population in the relatively high dose range ≥100 mSv are: Belgium, France, Iceland, Japan, Korea, Luxembourg, Portugal, Turkey, United States (Table 2).

Our study has some limitations. The number of patients with CED ≥ 100 mSv in a given period and country is a function of the number of patients who receive CT scans, the number of CT scans received by those patients and the doses to which their organs were exposed during the CT scans. These parameters likely differ substantially between countries but also between hospitals and other providers within a country [18]. Our calculations are partly based on country-specific information (CT frequency) and partly on assumptions derived from a large number of CTs performed in several institutions in two countries (number of CTs per patient and effective dose estimated based on actual exposure parameters used in those two countries). Another limitation is the lack of data on the indication for the CT scans. Many of these repeated CTs may be for conditions with a limited life expectancy (e.g., non-curable cancer) so that radiation-related cancer risk 10–15 years after the procedures is of limited concern for the patient. However, Rehani et al. [19] show that 10% of patients with CED ≥ 100 mSv in one of the hospitals included in their survey had non-malignant conditions and 20% were ≤50 years of age. This will imply potentially a quarter of a million patients with non-malignant conditions in the 35 countries. On the other side, we did not include radiation doses from other exams such as nuclear medicine studies and interventional procedures, both of which involve significant radiation doses. We also assumed that all patients in the study by Rehani et al. [10] were followed for the entire interval collected in each institution. These reasons are expected to result in an underestimate of the number of patients with CED ≥ 100 mSv in a five-year period.

Despite these limitations, our results are the first assessment of the number of patients with relatively high doses that should lead to a strategic agenda by various stakeholders for patient radiation safety. These should include manufacturers of CT equipment because there is substantial scope for further improvement in radiation doses [4,20]. Physicians need to develop and implement imaging appropriateness criteria, otherwise a fairly large number of patients may receive unnecessary exposure, especially with the background of the lack of knowledge among physicians [19,21]. Further extrapolation of OECD data to global population requires availability of CT usage data of countries outside of OECD and can be done by others if they have data of their country on CT use, using the above approach. The estimations can be easily extended to countries that have been added recently to OECD or are being added, such as: Croatia, Columbia, Argentina, Brazil,

Table 1
Country-specific data as per OECD on population, number of CT exams/1000 population/yr and estimated number of patients with cumulative effective dose (CED) ≥ 100 mSv.

No.	Country	Population *	CTs/1,000 population/year**	Estimated No. of Patients with CED ≥ 100 mSv in 5-yr period	Estimated No. of Patients with CED ≥ 100 mSv in 5-yr period per 1,000 population
1.	Australia	24,992,860	126.0	36,205	1.45
2.	Austria	8,837,707	149.6	15,200	1.72
3.	Belgium	11,403,740	200.5	26,287	2.31
4.	Canada	37,058,856	152.9	65,145	1.76
5.	Chile	18,751,405	99.9	21,537	1.15
6.	Czech Republic	10,626,430	103.5	12,645	1.19
7.	Denmark	5,789,957	172.8	11,503	1.99
8.	Estonia	1,321,977	168.7	2,564	1.94
9.	Finland	5,515,525	44.3	2,809	0.51
10.	France	66,941,698	189.7	145,998	2.18
11.	Germany	82,914,191	148.5	141,559	1.71
12.	Greece	10,725,886	150.3	18,534	1.73
13.	Hungary	9,767,600	122.5	13,756	1.41
14.	Iceland	352,722	213.7	867	2.46
15.	Ireland	4,857,015	92.3	5,154	1.06
16.	Israel	8,872,943	145.2	14,812	1.67
17.	Italy	60,421,797	89.9	62,451	1.03
18.	Japan	126,443,180	230.8	335,517	2.65
19.	Korea	51,635,256	204.6	121,461	2.35
20.	Latvia	1,927,170	171.9	3,809	1.98
21.	Lithuania	2,801,541	101.8	3,279	1.17
22.	Luxembourg	607,950	211.1	1,476	2.43
23.	Netherlands	17,231,622	94.0	18,622	1.08
24.	New Zealand	4,885,500	126.0	7,077	1.45
25.	Norway	5,311,916	172.8	10,553	1.99
26.	Poland	38,413,139	97.0	42,839	1.12
27.	Portugal	10,283,822	188.9	22,334	2.17
28.	Slovakia	5,446,771	153.9	9,637	1.77
29.	Slovenia	2,070,050	70.9	1,687	0.82
30.	Spain	46,733,038	114.9	61,734	1.32
31.	Sweden	10,175,214	172.8	20,215	1.99
32.	Switzerland	8,513,227	109.9	10,757	1.26
33.	Turkey	81,407,211	206.6	193,364	2.38
34.	United Kingdom	66,435,550	92.3	70,499	1.06
35.	United States	327,167,434	255.7	961,799	2.94
	Total	1,176,641,900		2,493,685	

*Population size in 2018 for the 36 member countries of the Organisation for Economic Co-operation and Development (OECD) except Mexico from [12].
**Number of CTs per 1,000 population in 2017 or nearest year from OECD Health at a glance 2019 [13]. We used numbers from the UK for Ireland, from Australia for New Zealand, and from Denmark for Norway and Sweden.

Bulgaria, Peru, Romania; when their data of CT frequency becomes publicly available.

The age and sex distribution of patients for all OECD countries is not available and thus it is not possible to include this information in the calculations. However, Rehani et al. [10] do provide this information for their large study with representative data. The RP180 [2] provides the age and sex distribution for the Top 20 X-ray examinations for 3 OECD countries of Europe. It might be possible to incorporate the

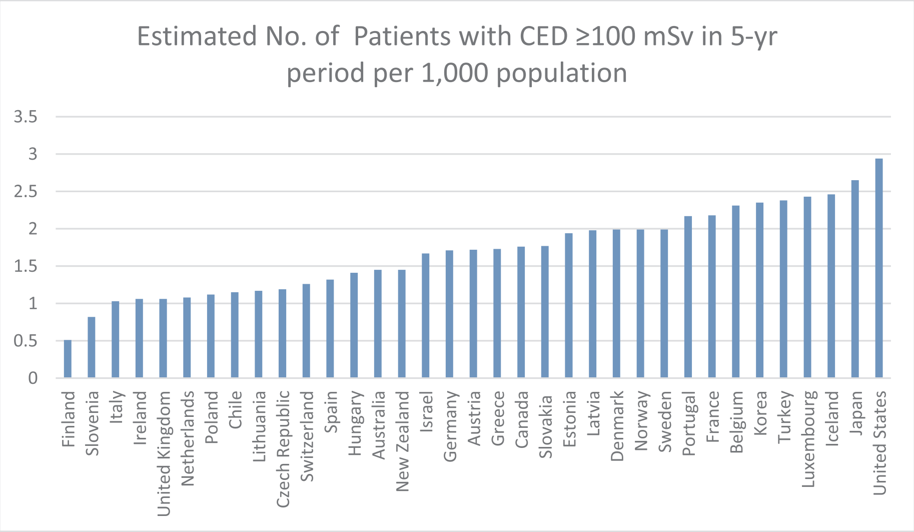

Fig. 1. Estimated number of patients with CED ≥ 100 mSv in 5-yr period per 1,000 population in 35 OECD countries in increasing order.

Table 2
Stratification of countries based on estimated number of patients with CED ≥ 100 mSv.

Category	Number of patients with CED ≥ 100 mSv in 5-yr period/1000 population	Number of countries	Names of countries
Low	0 to < 1	2	Finland, Slovenia
Medium	1 to < 2	24	Australia, Austria, Canada, Chile, Czech Republic, Denmark, Estonia, Germany, Greece, Hungary, Ireland, Israel, Italy, Latvia, Lithuania, Netherlands, New Zealand, Norway, Poland, Slovakia, Spain, Sweden, Switzerland, United Kingdom
High	≥2	9	Belgium, France, Iceland, Japan, Korea, Luxembourg, Portugal, Turkey, United States

information into the calculations. Similarly, information on what disease or clinical conditions are contributing to recurrent imaging is outside the scope of the current paper as such information is not available at international and even at national level. This subject is best handled at the local level better at hospital or group of hospitals under the same service provider as done in recent paper by Rehani et al. [19]. With wide availability of dose monitoring and tracking systems in many countries it should be possible to gather data from many countries in the near future to verify or complement our findings [22].

The current radiation risk management policies for patients need to be re-evaluated as they have not been as effective as other areas like flying, travel by car or even occupational safety. National and international organizations need to realize that their current policies are not able to stop this situation of high cumulated doses from happening and need to review policies.

With actions on the above, it should be possible to conduct justified CT exams that minimize radiation dose and maximize clinical benefit.

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