



# Organ doses and cancer risk assessment in patients exposed to high doses from recurrent CT exams

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## ARTICLE INFO

### Keywords:

Computed tomography doses  
Organ doses CT  
Cumulative doses  
Radiation risk CT  
Cancer risk CT

## ABSTRACT

**Purpose:** To estimate cumulative organ doses and age- and gender-stratified cancer mortality risks in patients undergoing recurrent computed tomography (CT) exams.

**Methods:** Cohorts of patients who received cumulative effective dose  $\geq 100$  mSv were stratified into age and gender groups. Organ doses of 27 organs using Monte Carlo methods were available, and the relative risk model from the Biological Effects of Ionizing Radiation VII (BEIR VII) was used to estimate lifetime attributable cancer mortality risks (LACMR).

**Results:** Out of the 8956 patients, 6.7% were 16–44 years of age, with median organ doses higher than 200 mGy for stomach and liver, whereas organ doses for nine organs, which included lungs, breasts, colon, red bone marrow, urinary bladder, esophagus, testicles, ovaries, and skin were between 100 and 200 mGy. Thyroid and salivary glands had smaller doses in the range of 45–69 mGy, but the mean dose for each organ was over 100 mGy. The age- and gender-specific median LACMR for the 16–44-years cohort was 0.6 to 0.7 deaths per 100 individuals for males, and 0.8 for females. The mortality estimated figures were highest for patients 16–54 years with slightly lower values for older age groups. Except for the highest age bracket of 75–84 years, the LACMR values for 55–74 years are not lower by orders of magnitude, and thus one cannot ignore risks in this age group.

**Conclusions:** Organ doses over 100 mGy for most organs and for some organs  $\geq 200$  mGy with unignorable associated lifetime attributable cancer mortality rates were found.

## 1. Introduction

Computed tomography (CT) is an indispensable imaging modality in modern medicine with its immense applications in diagnosis, follow-up of disease, and CT-guided interventions. While the usefulness of CT imaging is undisputed, there have been regular reports of potential radiation risks for the past two decades, so much so that CT has remained a hot topic all these years [1–3]. These reports led to substantial improvement in CT technology and optimization actions at the level of users such that every week there have been 3–5 publications on CT dose optimization for at least during the past five years [4]. With the impetus on dose optimization and a series of national and regional campaigns on safer imaging, a growing feeling had started to emerge that radiation risks in CT imaging can be put to rest [4,5]. However, this impression got disturbed when several papers on cumulative dose to patients emerged in the last two years [4,6–10]. Although there have been more than a

hundred papers in the last decade on cumulative doses to patients, the new aspect of recent papers was that they allowed extrapolation of numbers to estimate the national or global magnitude of patients with high doses taken as 100 mSv of cumulative effective dose (CED) [7,11]. Another new finding has been high doses with a single procedure or a single day [12,13]. Several papers in 2021 itself provided a comprehensive review of recurrent imaging with X-ray and nuclear medicine examinations and the cumulative doses involved [7,14]. It has been inferred in recent papers that at the level of CED  $\geq 100$  mSv, many organs may receive  $\geq 100$  mGy, a dose range where the dose–effect is less controversial. However, there is a paucity of large-scale studies reporting organ doses in patients who undergo multiple CT examinations and age- and sex-stratified cancer risk estimations. This study aims to estimate organ doses and lifetime attributable cancer mortality risks in cohorts of patients who underwent recurrent CT exams, leading to CED  $\geq 100$  mSv.

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<https://doi.org/10.1016/j.ejrad.2022.110224>

Received 11 September 2021; Received in revised form 24 January 2022; Accepted 16 February 2022

Available online 19 February 2022

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## 2. Methods

### 2.1. Data sources and collection process

This HIPAA-compliant retrospective study involving the analysis of patients receiving high radiation doses was approved by the Institutional Review Board (IRB) at the senior author’s institution. The current cohort included 8956 patients (ages 16–80 years old, 51.7% male, 48.3% female) who received a CED of  $\geq 100$  mSv through recurrent CT exams within five years (2013–2017). Further information about the cohort is available in an earlier report [4]. For the current study, because the recurrent CT studies were acquired in 5 years, patients were classified into age groups according to Biological Effects of Ionizing Radiation VII (BEIR VII) publication, Table 12D-2 [15]. For example, patients between age 25 and 34 were assigned to cohort group age 30, while patients between age 35 and 44 were assigned to cohort age 40 and so on.

### 2.2. Organ doses

A commercial software, Radimetrics™ Enterprise Platform (Bayer HealthCare, Whippany, NJ, USA, <https://www.radiologysolutions.bayer.com/dose-data>), provided several measures of radiation dose from CT, including organ dose and effective dose calculated from Monte Carlo simulations. The system provided cumulative organ doses for individual patients who have undergone multiple CT exams for 27 organs. Mean, median, and interquartile range (IQR) values were calculated for the 14 organs for which tissue weighting factors from International Commission on Radiological Protection 103 (ICRP 103) [16] are available. Furthermore, because the younger patients have higher radiosensitivity, we reported organ doses in more detail for the age group of 16–44 years.

### 2.3. Statistical analysis and cancer mortality estimation

To calculate LACMR values for each patient, the organ dose for the generic organ T ( $OD_T$ ) was multiplied for the gender-, age- and tissue-specific lifetime attributable cancer mortality risk-weighting factor  $r_T$  for the related organ given in Table 12D-2 in the BEIR VII report [15]. For organs not specified in Table 12D-2, dose data of all organs combined was averaged and LACMR was calculated using mortality risk indices reported as “Other” in BEIR VII report. LACMR values were then divided by 100 to account for the standardized 100 mGy used in Table 12D-2 of the BEIR VII report:

$$LACMR = \frac{1}{100} \sum_T r_T OD_T$$

Example: Two females, ages 28 and 33, received doses of 190.7 and 349.3 mGy to the colon, respectively. Table 12D-2 of the BEIR VII report provides estimates of lifetime attributable risk of cancer mortality from colon cancer for females of age-group 30 exposed to 0.1 Gy as 38 per 100,000. The mortality risk of each of the individuals in this example is calculated as  $(0.1907 \text{ Gy} * 38 / 100,000 \text{ individuals}) / 0.1 \text{ Gy}$ , and  $(0.3493 \text{ Gy} * 38 / 100,000 \text{ individuals}) / 0.1 \text{ Gy}$ . The mortality risks are 72.5 and 132.7 per 100,000 individuals respectively. Cumulative risk indices were calculated by adding lifetime attributable risk of cancer mortality from each organ of individuals as illustrated in this example. Calculated LACMR values are per 100,000 individuals, however, for clarity of presentation, these values are reported as percentages (per 100 patients).

Mean, median, 1st quartiles, and 3rd quartiles for LACMR were calculated for each age group.

## 3. Results

Table 1 provides the age distribution of our patient cohorts with CED  $\geq 100$  mSv, and data is visually represented in Fig. 1 for males and females separately. The largest fraction of patients (84.4%) fall under the higher age bracket of 55–84 years of age. Those in the age bracket of 16–54 constitute 15.6%, while those between the ages of 16–44 years constitute 6.7%. Table 1 indicates the overall CED mean of 174.5 mSv, median of 141.0 mSv, and maximum of 1184.7 mSv in this cohort.

Table 2 provides median and IQR values of organ doses for each age group for the 14 organs for which tissue weighting factors are reported in ICRP 103 [16]. With the exception of salivary gland, brain, and thyroid all other organs received median doses higher than 100 mGy. Moreover, some organs such as stomach, liver, and colon were exposed to doses over 200 mGy.

Table 3 presents mean, median, and IQR values of cumulative doses for the 16–44 years old group, and data is arranged in decreasing order of median values. Median organ doses over 200 mGy were observed for stomach and liver, whereas doses between 100 and 200 mGy were observed in lungs, breast, colon, red bone marrow, urinary bladder, esophagus, testicles, ovaries, and skin. Thyroid and salivary glands showed doses in the range of 45–69 mGy. Despite the varying median doses of individual organs, mean dose values for all organs were over 100 mGy.

The age- and gender-specific LACMR per 100 patients undergoing recurrent CT scanning is presented in Table 4. The median mortality risk value of 0.6 to 0.7 deaths per 100 patients for males and 0.8 deaths per 100 patients for females are for patients between the ages of 16–44 years with slightly lower mortality risk values for higher age groups of patients.

Fig. 2 shows estimates of LACMR in males (a) and females (b) in our cohorts of patients who were exposed to CED  $\geq 100$  mSv.

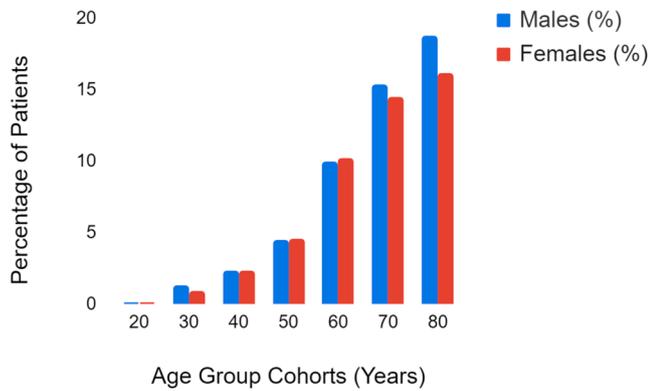
## 4. Discussion

The main findings from our study that pertains to cohort of patients with CED  $\geq 100$  mSv is that most organs were exposed to doses in excess of 100 mGy and some organs had doses  $> 200$  mGy. The age- and gender-specific lifetime attributable cancer mortality risks was highest for age groups 16–54 years with slightly lower values but not ignorable for the higher age group.

There has been consistent realization that organ doses are the best to assess radiation risks [17,18]. Radimetrics system used in this study has Monte Carlo simulator that includes the modeling of the X-ray source spectrum, the patient phantoms, and the interaction between X-ray photons with the patient. Although there is definite need for validation of estimations made by different vendors, there has been progress in using phantom that simulates patient’s anatomy. The parameters used to

**Table 1**  
Age classification and corresponding age distribution of our patient cohorts along with CED in mean, median and range values in mSv.

Age Classifiers (years)	Age Range (years)	Number of Patients (%)	Mean CED (mSv)	Median CED (mSv)	Range CED (mSv)
20	16–24	8 (0.1%)	167.0	120.0	108.9–340.1
30	25–34	188 (2.1%)	158.6	138.7	100.2–443.5
40	35–44	400 (4.5%)	178.3	149.3	100.3–889.7
50	45–54	797 (8.9%)	184.2	153.5	100.1–794.1
60	55–64	1788 (20.0%)	185.3	150.7	100.0–838.5
70	65–74	2660 (29.7%)	182.0	152.5	100.0–1050.6
80	75–84	3115 (34.8%)	166.3	141.0	100.0–1184.7
Total		8956 (100%)	174.5	141.0	100.0–1184.7



**Fig. 1.** Bar graph illustrates the percentage age cohort distribution of male and female patients with CED ≥ 100 mSv. Please refer to Table 1 for age group classification.

match a patient to a phantom include weight, effective diameter, or water-equivalent diameter (WED). Moreover, the system has capability to pool all CT imaging studies of an individual patient as same medical record number (MRN) is used at the facility. Thus, the system can provide cumulative organ doses automatically, obviating the need for manual work that could add errors.

A number of studies in the past have attempted utilizing organ doses. Brambilla et al. [19] studied patients undergoing endovascular aortic repair (EVAR) and reported the median cumulative organ doses of 191, 205, 230, 269 and 271 mGy for lung, bone marrow, liver, colon, and stomach, respectively. The average risk of exposure-induced death was 0.8 % (i.e., odds 1 in 130).

Jones et al. [20] reported median cumulative organ doses from 3 to 94 mGy in children who underwent multiple cardiac catheterization procedures during the investigation and management of congenital heart disease. There are other studies in different disease condition such

as in patients undergoing abdominal stent implantation [21], lung transplantation in patients with cystic fibrosis [22], lymphoma [23], pediatrics [24], and ischemic heart disease [25]. These studies are useful in getting a picture of organ doses in different disease conditions or in different imaging procedures. Our study is different as it includes all CT imaging exams individual patient had undergone over a period of time, not just for a defined disease. A recent paper analyzing the CT imaging studies indicated that more than half of CT exams of patient with high cumulative dose were unrelated to follow-up of a primary chronic disease [6]. Thus, it may be seen as moving from parts to sum of parts. Such an approach can provide unique data, enabling radiation risk assessment.

When it comes to cancer statistics, a lot of confusion prevails, particularly as it needs assuring fair comparison of those which can reasonably be compared. For example, the figure of about 40% is often cited as cancer risk in normal living. This figure comes from the statement that approximately 39.5% of men and women will be diagnosed with cancer at some point during their lifetimes [26]. To achieve rational comparison with radiation risk estimates, one needs to understand that if one is estimating mortality risk using radiation exposure, the comparison has to be with mortality rates. The cancer mortality rate in US population is 158.3 per 100,000 men and women per year (based on 2013–2017 deaths) which leads to a figure of 0.16% and thus the comparison cannot be with 39.5% and needs to be with 0.16%. Therefore, our estimated figure of nearly 1% (Table 4) imply nearly 6 times higher chance of cancer mortality. With current knowledge of radiation effects at organ doses reported in this paper, the level of evidence of radiation effects is higher [27].

Further, it must be noted that we did not make any extrapolation of doses this cohort may accrue over lifetime. Our estimates are based on doses received during the data collection period of 5-years. Many of these patients will continue to receive more doses possibly every year. Also, we have not accounted for radiation doses this cohort may have received from other exams that involve either X-rays (such as

**Table 2**  
Median and IQR organ doses in mGy for each age group for the 14 organs for which tissue weighting factors are reported in ICRP 103.

Sr. No	Organ	Age groups (years)						
		16–24	25–34	35–44	45–54	55–64	65–74	75–84
		Organ doses in mGy Median IQR (25th- 75th percentile)						
1.	Stomach	132.6 117.8–252.4	209.8 164.8–278.5	226.7 173.8–304.6	234.2 175.6–337.0	234.3 181.3–336.9	238.1 182.9–335.6	220.0 174.6–296.0
2.	Liver	125.5 101.3–243.2	202.4 163.8–271.2	129.6 171.6–301.4	225.5 171.2–322.8	229.0 176.6–327.8	230.8 179.0–323.8	213.5 170.6–288.9
3.	Lung	146.5 45.7–219.8	162.3 126.5–217.4	184.3 139.7–251.5	177.6 134.8–254.8	179.3 135.4–255.7	181.9 131.6–253.2	166.0 126.8–229.5
4.	Breast	90.6 3.5–90.6	143.7 104.7–191.4	153.7 95.3–215.8	155.5 108.1–233.0	158.5 107.6–117.6	158.7 105.5–237.6	141.6 90.7–204.9
5.	Colon	211.0 91.7–379.3	148.5 114.5–215.0	149.8 111.5–225.2	165.5 117.0–256.7	162.4 117.6–247.1	162.8 117.4–246.8	154.0 114.0–222.3
6.	Skin	125.7 93.5–196.9	118.9 96.6–162.2	130.9 106.2–173.7	136.8 103.8–185.0	132.8 103.2–185.2	133.3 101.8–182.5	121.4 97.9–160.9
7.	Esophagus	106.9 35.4–191.9	113.5 89.3–151.3	128.3 98.1–172.0	123.5 95.3–178.8	123.8 96.1–172.7	125.0 94.9–172.0	115.7 90.8–155.3
8.	Red bone marrow	118.6 100.1–202.9	117.4 97.3–149.2	123.8 97.1–165.2	126.9 96.7–173.3	122.5 96.7–169.8	121.3 96.3–166.4	113.8 93.7–149.8
9.	Urinary bladder	88.5 78.8–107.3	118.5 78.5–158.8	117.3 81.1–171.8	125.2 86.2–186.8	119.6 83.7–176.2	119.6 81.8–174.1	117.8 79.3–165.3
10.	Testicle	152.9 57.3–246.9	116.7 58.3–175.8	145.1 75.4–183.8	121.9 75.1–182.7	115.4 65.9–188.8	108.3 64.6–180.0	105.8 59.3–166.7
11.	Ovary	137.1 110.6–228.6	114.9 69.5–150.1	115.4 86.9–181.4	132.7 91.3–202.3	131.8 89.5–201.0	124.7 86.3–188.9	115.3 82.1–166.4
12.	Thyroid	70.9 15.2–390.2	66.3 18.8–145.4	69.5 28.6–145.4	59.2 18.4–130.4	57.7 21.7–124.1	48.7 17.4–116.9	40.6 14.2–105.5
13.	Salivary gland	107.8 0.7–194.0	48.3 1.6–129.7	42.4 2.1–146.2	19.6 1.2–92.2	20.4 1.3–99.1	17.2 1.0–92.2	11.2 0.8–84.2
14.	Brain	107.8 0.7–194.0	48.3 1.6–129.7	42.4 2.1–146.2	19.6 1.2–92.2	20.4 1.3–99.1	17.2 1.0–92.2	11.2 0.8–84.2

**Table 3**

Mean, median, and IQR for organ doses for 16–44 years old group for the 14 organs for which tissue weighting factors are reported in ICRP 103 arranged in decreasing order of median dose.

Sr. No.	Organ	Mean (mGy)	Median (mGy)	IQR (mGy)
1.	Stomach	257.9	220.8	168.4–293.6
2.	Liver	250.7	213.5	166.1–292.3
3.	Lungs	199.5	177.8	134.5–241.0
4.	Breasts (females)	166.8	150.1	98.6–202.3
5.	Colon	184.2	149.8	111.9–223.9
6.	Skin	147.9	128.2	103.7–170.2
7.	Esophagus	139.8	123.9	94.9–165.8
8.	Red Bone Marrow	139.7	121.7	97.3–159.8
9.	Urinary Bladder	134.4	117.1	80.9–167.2
10.	Testicles (males)	138.6	116.9	67.9–178.2
11.	Ovaries (females)	141.6	115.4	84.8–169.8
12.	Thyroid	112.8	68.8	24.2–145.5
13.	Salivary Glands	122.0	45.5	1.9–145.5
14.	Brain	122.0	45.5	1.9–145.5

**Table 4**

Age- and gender-stratified LACMR as minimum/ maximum, mean, median and interquartile range (IQR) per 100 patients.

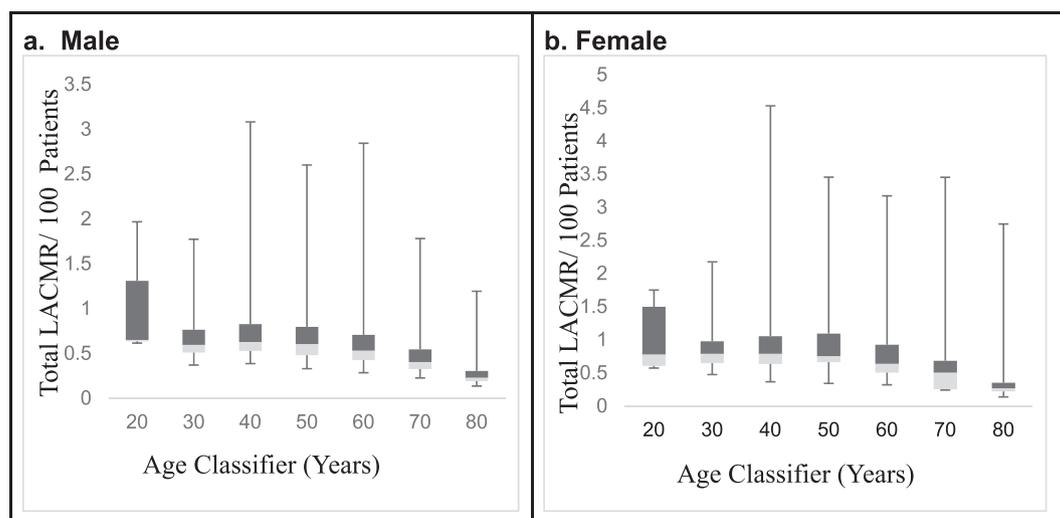
Age group (range)	LACMR (Number of estimated deaths per 100 patients)			
	Minimum/Maximum	Mean	Median	Interquartile Range (IQR)
<b>Male</b>				
20 (16–24)	0.6 / 2.0	1.1	0.7	0.6–1.3
30 (25–34)	0.4 / 1.8	0.7	0.6	0.5–0.8
40 (35–44)	0.4 / 3.1	0.7	0.6	0.5–0.8
50 (45–54)	0.3 / 2.6	0.7	0.6	0.5–0.8
60 (55–64)	0.3 / 2.8	0.6	0.5	0.4–0.7
70 (65–74)	0.3 / 1.8	0.5	0.4	0.3–0.6
80 (75–84)	0.1 / 1.2	0.3	0.3	0.2–0.3
<b>Female</b>				
20 (16–24)	0.6 / 1.8	1.0	0.8	0.6–1.5
30 (25–34)	0.5 / 2.2	0.9	0.8	0.7–1.0
40 (35–44)	0.4 / 4.5	0.9	0.8	0.6–1.1
50 (45–54)	0.3 / 3.5	0.9	0.8	0.7–1.1
60 (55–64)	0.3 / 3.2	0.8	0.6	0.5–0.9
70 (65–74)	0.2 / 3.5	0.6	0.5	0.3–0.7
80 (75–84)	0.1 / 2.8	0.3	0.3	0.2–0.4

fluoroscopic guided interventions) or radiopharmaceuticals (such as PET/CT).

Higher mortality estimates in younger age group is evident and understandable, being on the expected line. Significantly large spread in mortality estimate values for some age groups are noted, and that is typically associated with a single patient within that age group receiving high CED. Despite getting reflected on the plots in Fig. 2, these high CED values in some cohorts did not affect the median mortality estimate values to a notable degree.

The limitations of the study include that it is a single hospital study and similar studies in other healthcare settings will allow extrapolation to get estimates at regional, national, and global level. Further, our data pertains only to radiation exposure through recurrent CT exams and excludes other relatively high dose exams patients may have undergone such as interventional procedures, which have been shown to result in over 100 mSv in as much as 4% of the patients [7,28,29] and most dose in one year. Some nuclear imaging exams also contribute high doses and thus actual estimate of radiation risk requires cumulative doses from all exams which needs to be accounted for to get appropriate assessment of actual risk. Future studies can explore the assessment of cumulative dose and risks from all exams and procedures that involve ionizing radiation. At the moment, the only way to deal with organ doses received by patients at different times is to calculate the sum. In the future, when some correction factor to account for time gap between exposures becomes available, it may be possible to obtain more accurate time-weighted values of doses that would have better correlation with risk.

It must be borne in mind that the risk estimations are as average estimations applicable to the group and not for individual. There are several parameters where uncertainties exist, and there is scope for inaccuracy. For example, in our cohort, patients underwent multiple exams over the 5 years of the study (median 19 exams and maximum 109) [4], thus the age of those patients has to be at some point during that 5-year period. In addition, the division into the age slots further blurs the age and increases the variation. For example, patients between age 25 and 34 were assigned to cohort group age 30, while patients between age 35 and 44 were assigned to cohort age 40 and so on. This introduces an age interval of 9 years with potential for inaccuracy. Ideally, one should define a specific age and do interpolation of LAR coefficient provided by BEIR VII Table 12D-2 to get more accurate estimation. Further, there is a need to have more studies on the validation of effective doses estimated by vendors as current studies are limited [30,31].



**Fig. 2.** Box-and-whisker plots of LACMR in male (a) and female (b) patients per 100 persons. Box extremes indicate 1st and 3rd quartile, center between light and dark gray boxes indicate median, and top and bottom whiskers indicate maximum and minimum mortality risk values respectively.

## 5. Conclusions

In our cohort of patients who had received CED of  $\geq 100$  mSv through recurrent CT exams within five years, most organs had doses between 100 and 200 mGy and this includes lungs, breast, colon, red bone marrow, urinary bladder, esophagus, testicles, ovaries, and skin, whereas thyroid and salivary glands showed doses in the range of 45–69 mGy. Some organs had over 200 mGy. The age- and gender-specific lifetime attributable cancer mortality risks (LACMR) per 100 patients for those between 16 and 44 years of age were 0.6 to 0.7 for males and 0.8 for females. The mortality estimate figure was highest for age groups 16–54 years with slightly lower values for the higher age group. Except for the highest bracket of 75–84 years, the LACMR values for 55–74 years are not lower by an order of magnitude, and thus one cannot ignore the risks in this age groups.

### CRedit authorship contribution statement

**Nahom Zewde:** Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Francesco Ria:** Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Madan M. Rehani:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

### Acknowledgements

Thanks are due to AAPM DREAM Fellowship program 2021 under which the fellow Nahom Zewde had the chance to work under the mentorship of Prof. Madan M. Rehani.

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