ORIGINAL ARTICLE

Estimation of Lifetime Attributable Risk (LAR) of Cancer Associated with Chest Computed Tomography Procedures in Children

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Abstract

Purpose: The danger of radiation at low doses continues linearly, and without a threshold, investigations concluded that although the risk of cancer from Computed Tomography (CT) scans is low, it is not zero.

This study aims to determine the patient's radiation dose and estimate the Lifetime Attributable Risk (LAR) of cancer incidence for a single chest CT scan in children.

Materials and Methods: We divided 1,105 children into four age groups: 0 years, 5 years, 10 years, and 15 years. Dosimetric data of chest CT scan were plugged in VirtualDoseCT software, and organ dose and effective dose were calculated. The cancer risk based on organ dose is estimated according to the BEIR VII report.

Results: The highest dose in boys was related to lung (5.13 - 6.8 mSv) and heart (5.27-5.97 mSv), and in girls, lung (4.98 - 5.91 mSv), breast (4.24 - 5.21 mSv), and heart (4.9 - 5.71 mSv) had the highest dose. The highest LAR (per 100,000) was obtained for the breast in the age group of 0 years (61.01), followed by the breast for the age group of 5 years (46.16) and lung in the age group of 0 years (43.32) in girls.

Conclusion: This study shows a better concept of radiation dose in the chest CT scan in children and how much effective dose and organ dose values increase the cancer risk.

Keywords: Lifetime Attributable Risk; Chest Computed Tomography Scan; Radiation Dose; Cancer Risk; Children; Biologic Effects of Ionizing Radiation VII.

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1. Introduction

Computed Tomography (CT) imaging in children and adolescents accounts for 3 to 11% of the total CT scan. In this age group, the range of organ doses from tens of mGy for one organ in the scan field to hundreds of µGy for one organ adjacent to the scan field [1, 2]. The organ dose received by the patient during a CT scan is powerful enough to alter the structure of the body's molecules, including DNA. These alterations may be complicated and irreversible; consequently, they can result in cancer or hereditary disorders [3]. There are worries regarding the usage of CT scans, which are expanding daily, and patients should be checked frequently. Epidemiological studies conducted in recent years have shown that ionizing radiation increases the risk of brain tumors, leukemia, breast cancer, and thyroid cancer in children [4, 5]. Because there is evidence for radiation hazards of less than 100 mGy [6], the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) in the seventh report (BEIR VII) proposes a linear no-threshold model to evaluate the effects of doses less than 100 mSv. The danger of radiation at low doses continues linearly and without a threshold, according to this model presented in Figure 1. Even the tiniest radiation dose may increase human risk [5]. For a given dose, such as a patient's dose on a CT scan, the Lifetime Attributable Risk (LAR) indicates the radiation risk and the likelihood of developing cancer over a patient's lifespan of up to 120 years. This quantity is a risk expression model resulting from epidemiological literature and is a risk indicator in radiation protection [7]. Several studies have used BEIR VII report risk models to estimate the LAR of primary tumors caused by radiation on CT images in children. These investigations concluded that although the risk of cancer from CT scans is low, it is not zero [8-10]. Based on this background, in this study, we calculate the radiation dose on a chest CT scan in children and estimate the LAR of cancer for a single chest CT scan based on the risk assessment tables in the BEIR VII report.

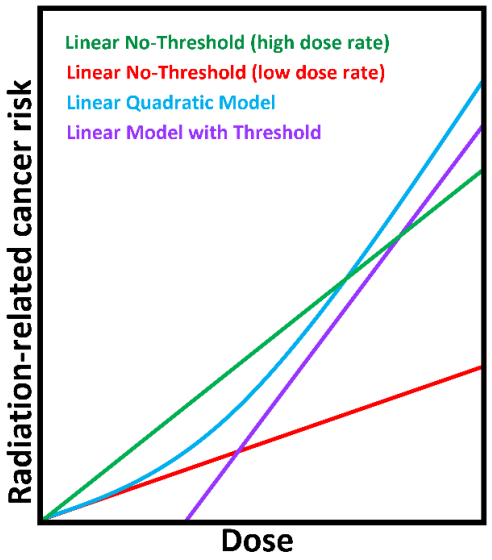

Figure 1. The linear no-threshold model considers the cancer risk in low dose values as possible and does not consider any threshold

2. Materials and Methods

2.1. Data Collection and Dose Estimation

From December 2020 to September 2021, we collected 1,105 chest CT scans performed on children. Ethical approval was obtained for this study (IR.AJUMS.REC.1400.209), and informed consent forms were obtained before data acquisition. All examinations were performed with a GE LightSpeed 16-slice CT scanner. All CT scans were done without injection of contrast agent. The parameters related to the patient, i.e., age and sex, and the parameters related to the radiation conditions of the CT scan machine were considered. We plugged these parameters into VirtualDose™CT software and calculated each patient's organ and effective doses. VirtualDoseCT is a web-based dose calculator software with 25 phantoms to calculate patients' doses online. VirtualDoseCT is sophisticated radiation dose simulation software for patient dosimetry in CT scans [11]. This software enables users to assess organ dose and effective dose, in addition to CTDIVOL and DLP data provided by the CT scanner. It is ready for use with the latest CT scanners and recent ICRP-60 and ICRP-103 recommendations on the effective dose [12, 13].

2.2. Cancer Risk Estimation

Because the BEIR VII model assumes linear no-threshold at low doses, we chose this model. This model also considers cancer in doses less than 100 mGy and a dose and dose-rate reduction factor of 1.5 for solid cancers. The cancer risk based on organ dose is estimated according to the BEIR VII report. This value is based on a dose of 100 mGy per 100,000

individuals. The dose received by each organ may be entered into the following Equation, and the cancer risk can be computed using Table 12D-1, according to this report [5, 14].

$$LAR\ in\ this\ study = \frac{Organ\ Dose\ (mGy)}{100} \times LAR_{100} \qquad (1)$$

LAR_{100} is the BEIR VII risk estimate for a single-dose (100 mGy) per 100,000 people. In the BEIR VII report, Table 12D-1 shows lifetime risk estimates for cancer incidence resulting from a single dose of 100 mGy at several specific ages. This table provides age and sex-specific risk estimates for several organs (stomach, colon, liver, lung, bladder, red bone marrow, thyroid, breast, uterus, ovary, and prostate).

2.3. Statistical Analysis

All dosimetric data collected were analyzed using SPSS Statistics 21 (SPSS Inc, Chicago, IL). Comparisons between boys and girls were performed with independent-sample t-tests. A value of P-Value <0.05 was considered statistically significant.

3. Results

3.1. Data Collected and Radiation Dose

Among 1,105 examined patients, 584 (52.8%) were boys, and 521 (47.2%) were girls. The mean age was 14.1 ± 1.3 years for boys (age range from two months to 16.9 years) and 15.2 ± 1.1 years for girls (age range from eight months to 17.2 years). We categorized patients according to four age groups based on the BEIR VII report. Age group of 0 years (newborn up to 2.5 years), age group of 5 years (2.5 to 7.5 years), age group of 10 years (7.5 to 12.5 years), and age group of 15 years (12.5 to 17.5 years). Table 1 shows demographic data for the total population and each patient's age group.

Table 1. Characteristics of 1,105 patients in this study

	Age group at exposure				
Gender	0	5	10	15	Total
Boys	58	82	181	263	584
Girls	61	94	130	236	521
Total	119	176	311	499	1105

The parameters of chest CT protocols for all age groups are shown in Table 2. We selected the mean value as the scan parameters for each age group. Table 3 reported the mean effective dose and equivalent organ dose for each organ, such as stomach, colon, liver, lung, bladder, red bone marrow, thyroid, breast, uterus, ovary, and prostate. In a CT scan, the dose received by the organ is directly related to the type of scan, so the organ inside the scan field receives a higher dose than the organ, not in the scan field. Table 3 shows that the organs in the scan field receive the highest dose directly from the primary radiation.

Table 2. Patient data scanning parameters according to age groups

	Age group at exposure			
Scan parameter	0	5	10	15
Tube current (mA)	120	120	150	150
Pitch	0.7	0.7	0.938	0.938
Tube voltage (kVp)	120			
Rotation time (s)	0.5			
Detector Collimation (mm)	16 × 1.5			
Slice Thickness (mm)	5			
AEC / AutomA 3D	ON			
Scan field of view	From the thoracic inlet to the costophrenic angle			
Scan mode	Spiral			

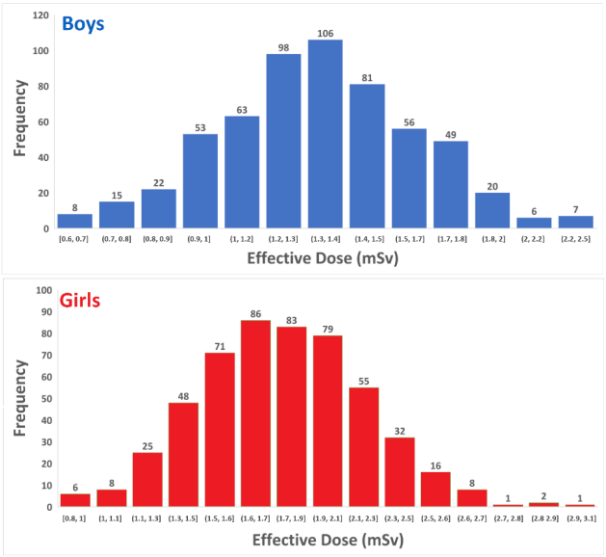

Figure 2. The distribution of effective doses in boys and girls

Table 3. The mean value of effective dose (mSv) and equivalent organ dose (mGy) according to age groups for boys and girls

Organ	Boys				Girls			
	Age group at exposure				Age group at exposure			
	0	5	10	15	0	5	10	15
Stomach	1.23	0.90	1.02	0.76	1.56	1.06	1.02	0.67
Colon	0.27	0.08	0.06	0.03	0.19	0.09	0.06	0.03
Liver	2.85	1.24	1.56	1.25	1.94	1.45	1.56	1.1
Lung	6.18	5.60	5.59	5.13	5.91	5.71	5.61	4.98
Bladder	0.08	0.01	0.01	0.01	0.06	0.01	0.01	0.02
Red Bone Marrow	0.38	0.30	0.34	0.36	0.35	0.31	0.35	0.3
Thyroid	3.06	2.04	1.1	0.84	3.05	2.59	1.76	1.37
Breast	-	-	-	-	5.21	5.05	4.90	4.24
Uterus	-	-	-	-	0.12	0.04	0.02	0.01
Ovary	-	-	-	-	0.12	0.03	0.02	0.01
Prostate	0.05	0.02	0.01	0.01	-	-	-	-
Esophagus	5.26	4.24	4.23	3.53	4.82	4.43	4.31	3.45
Heart	5.97	5.86	5.67	5.27	5.71	5.68	5.67	4.9
Thymus	5.71	5.92	6.04	5.01	5.65	5.34	5.04	5.83
Effective Dose	1.92	1.36	1.35	1.18	2.29	2.05	1.98	1.66

Consequently, the most significant doses are given to the breast, lung, esophagus, heart, and thymus.

Figure 2 shows the effective dose distribution for boys and girls. In boys, the highest frequency of effective dose is in the range of 0.9 to 1.8 mSv with a mean of 1.33 mSv; for girls, the highest frequency is 1.3 to 2.5 mSv with a mean value of 1.88 mSv.

3.2. Cancer Risk Estimation

Organ-specific LAR for organs in chest CT scan for children was determined using Equation 1. Figure 3 shows LAR values for boys and girls in the stomach, colon, liver, bladder, leukemia, uterus, ovary, and prostate. According to Figure 3, in lower-dose organs (relative to the lungs, thyroid, and breast), we observed a significant risk (or LAR) for liver and stomach cancers in boys. In contrast, for girls, stomach cancer risks were significant.

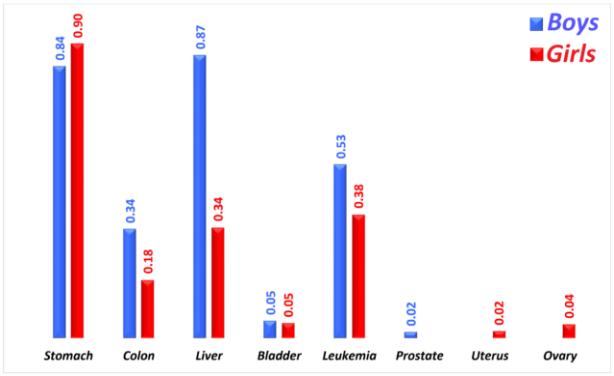

Figure 3. Lifetime Attributable Risk of cancer incidence in chest CT scan for children per 100,000 patients

Despite receiving high doses of heart, thymus, and esophagus, LAR for these organs has not been reported in the BEIR VII report. Based on BEIR VII, the lung, thyroid, and breast had the highest LAR of cancer incidence compared to other organs. Furthermore, according to Table 3 of this study, the lung, thyroid, and breast received high dose. As a result, the LAR of cancer incidence for these three organs in this study was much higher than the other organs, so we showed the LAR of cancer incidence for the lung, thyroid, and breast separately for each of the four age groups in Figure 4.

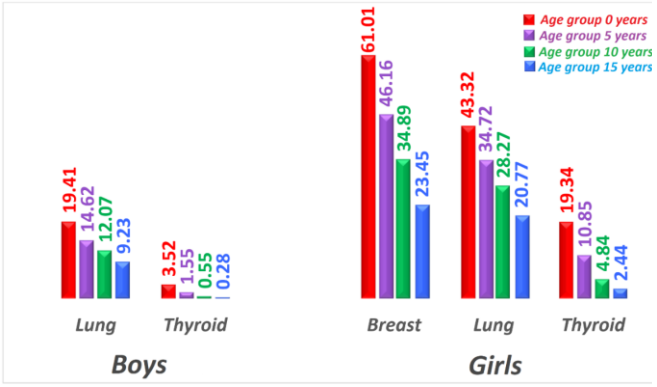

Figure 4. Lifetime Attributable Risk of lung, thyroid, and breast cancer in chest CT scan for all age categories children per 100,000 patients

4. Discussion

The radiation dose received by children in four age groups was evaluated. Based on the radiation dose of each age group, we examined the LAR of cancer in irradiated organs. The highest dose in boys was related to lung (5.13 - 6.8 mSv) and heart (5.27 - 5.97 mSv), and in girls, lung (4.98 - 5.91 mSv), breast (4.24 - 5.21 mSv), and heart (4.9 - 5.71 mSv) had the highest dose. In almost all age groups in this study, the dose received by the organs was less by increasing age due to the sensitivity of young children to older ages, and tissue weight coefficients are different at different ages. This is also included in phantom dose calculation software. As shown in Table 3, the effective dose for girls in all age groups is higher than for boys. The effective doses of girls in the age groups of 0 years, 5 years, 10 years, and 15 years were 19% (2.29 vs. 1.92 mSv), 50% (2.05 vs. 1.36 mSv), 44% (1.98 vs. 1.35), and 40%, (1.66 vs. 1.18 mSv) higher than boys, respectively. The effective dose for girls in age groups of 5, 10, and 15 years was significantly higher than the same age group in boys ($P < 0.0001$). For the age group of 0 years, there was no significant difference between the effective dose of girls and boys ($P = 0.17$). In particular, >65% of girls present an effective dose upper than 1.6 mSv, while in boys, >60% present an effective dose below 1.6 mSv.

This can depend on various factors, but one of the most important reasons can be related to breast tissue in girls because according to the equation: $E = \sum_T W_T \times H_T$, the effective dose is equal to the sum of the weighting tissue factor (W_T) multiplied by the equivalent organ dose (H_T) and when the breast dose in girls is high, it can increase the effective dose. The dose received by patients in this study was lower than in other studies. For example, the dose of red bone marrow in this study for all age groups is about 0.3 mGy, while in the studies, Journy *et al.* [9], Pearce *et al.* [15], and Miglioretti *et al.* [8] were 1, 3.9, and 3 mGy, respectively.

In Figure 3 and Figure 4, we plotted the LAR value for the organs. Figure 3 shows the organs that received lower doses and had lower incidence rates in the BEIR VII report. The LAR of cancer incidence (per 100,000) for organs that were not in the scan field, but in these organs, the incidence for stomach in girls (0.9) and liver in boys (0.87) was higher significantly than in other organs ($P < 0.001$). After that, the incidence of the stomach in boys (0.84) and leukemia is the highest (0.53 in boys and 0.38 in girls), which is due to the amount of dose received by the red bone marrow. Figure 4 shows the LAR of cancer incidence for the thyroid, lung, and breast, which received higher doses and higher incidence rates in the BEIR VII report by age group. This figure clearly shows that the risk of cancer decreases with age. However, the breast and lung have high LAR of incidence. The highest LAR was obtained for the breast in the age group of 0 years (61.01), followed by the breast for the age group of 5 years (46.16) and the lung in the age group of 0 years (43.32) in girls. For girls, the LAR value was significantly higher for the breasts and lungs than for other organs ($P < 0.001$). In boys, the LAR value for the lung was significantly higher than for other organs ($P = 0.0377$). This result was precisely in line with a study by Niemann *et al.* [16]. He reported the highest LAR for the breast, lung, and thyroid, respectively. Hence, the results of Niemann *et al.*'s study were lower than this study, so the estimated LAR of cancer incidence in children, and he obtained 47.58 for the breast of 0-year-old girls, 31.24 for the breast of 5-year-old girls, and 19.9 for the lung of 0-year-old girls. For a better explanation, LAR values for these organs are per 100,000 persons, which means that if a 5-year-old girl has a chest CT scan, the breast dose will be 5.05 mGy (according to Table 3), and the risk of breast incidence will be 46.16 per 100,000, i.e., approximately 46.16 / 100,000 = 0.0004616 or 0.04%. The highest LAR value was related to the breast, lung, and thyroid, consistent with the results of Ozasa *et al.* [17] and Hall and Giaccia [18], and well explained the risk of radiation exposure in children for these three organs. In a study, Tahmasebzadeh *et al.* also estimated LAR values in CT scans for children; in chest CT scans, the highest value was related to the breast, which is entirely consistent with the results of this study [19].

People who were thoroughly studied to determine the health effects of ionizing radiation are survivors of the Hiroshima and Nagasaki atomic bombs. 65% of these survivors received doses less than 100 mSv, approximately 40 times the average yearly background radiation exposure (2.4mSv). Surveys of Hiroshima and Nagasaki survivors showed that the incidence of solid cancers increased with increasing doses [7, 20]. Estimates of the risks are uncertain due to limitations. Uncertainty can depend on the radiation dose, quality, age, and sex. Therefore, if two people of the same age and gender are exposed to the same amount of radiation, according to the BEIR VII report, there is an equal risk

of developing cancer. However, other influential factors mentioned above can increase this risk. In other words, the BEIR VII report's risk assessment models calculate the risk of radiation-induced cancer for that specific exposure. However, the person may be re-dosed and receive radiation from imaging modalities at subsequent visits, or genetic, nutritional, and other factors may increase the risk of cancer. A patient may be exposed to radiation often during treatment, and each of these exposures must be documented in the patient's medical record. This study calculates the patient's radiation dose on chest CT scans in children and estimates the risk of cancer for a single chest CT scan based on the BEIR VII report. The linear no-threshold is still debatable because it is difficult to estimate the risks at low doses, but epidemiological and experimental studies still confirm this model [21, 22]. Therefore, it is better to reduce the patient's dose to prevent the same low risk. Studies were performed to estimate cancer risk due to patients being exposed to CT scans, which show that even a single CT scan may be associated with an increased risk of cancer. Especially for patients under 20 years of age, cancer risk is increased by 24% with a single CT scan [23].

In this study, except for the pitch factor, the other scanning parameters were the same for different age groups. In contrast, in the study of Tahmasebzadeh *et al.* [24], a significant difference was considered for the scanning parameters of different age groups (P-value < 0.05). This variation in scanning parameters may affect the patient's radiation dose. The risk of cancer for children due to radiation exposure is 2-3 times higher than the risk for adults; therefore, minimizing the radiation dose associated with pediatric CT examinations is particularly important [5]. There are various ways to reduce the dose in children; the first step is to check whether the benefits of a CT scan outweigh the risks.

In many cases, it is possible to achieve the desired diagnosis with other less dangerous modalities such as ultrasound or Magnetic Resonance Imaging (MRI) [25]. The CT scan protocol in children should be explicitly defined for this age group, and its parameters should be appropriate to the children's physical conditions. One of these factors is Automatic Exposure Control (AEC). The use of AEC can essentially prevent children from being exposed to radiation. This technique depends on the amount of radiation attenuation in the initial topogram and can reduce the mAs in children by 4-5 times compared to adults [26]. The use of low tube voltage (kVp) in children effectively reduces the dose. Because the attenuation of the beam is less in children, it is possible to obtain images with a suitable contrast with a lower kVp without increasing the noise of the image [27]. It is suggested to increase the Pitch factor to check the cases that do not need very high-resolution images to reduce children's exposure to radiation.

Below are the strategies to reduce the patient radiation dose in CT scans:

- increase tube filtration;

- use maximal slice thickness appropriate for specific diagnosis;

- reduce mAs;

- decrease kVp for thin objects;

- use the shortest rotation time available;

-use a spiral scan with pitch >1 (e.g., 1.5) to reduce the dose length product.

Finally, due to the dangers of exposing the patient to CT scans, As Low As Reasonably Achievable (ALARA) principle should be followed as much as possible [28]. Therefore, patient protection should be prioritized as much as possible, and methods and techniques that reduce the patient's dose should be used [29]. These techniques include automated tube current modulation, low kVp protocols in thin and non-obese patients, reducing the scan range, and iterative reconstruction techniques. Besides, the correct patient position can reduce the patient's dose [30, 31].

5. Conclusion

This research aimed to estimate the LAR of cancer incidence in children based on a single chest CT scan. This study showed that in pediatric chest CT scans, the organs that have the highest risk of cancer are the breast and lungs. This study reminds the importance of adhering to the principles of ionizing radiation protection. It shows a better concept of the radiation dose in CT scans and how much the organ dose values increase the cancer risk. In this study, we expressed the risk caused by radiation in children's CT scan numerically and comprehensibly. Therefore, this article clearly and numerically shows how hazardous cancer can be in children, considering the years ahead. Our article expresses all the concepts and risks in radiation

protection with numbers. It can lead physicians, radiologists, and CT scan Operators to understand the risks of radiation exposure in children more accurately.

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References

1- Bat Conservation International. (2008, December 15, 2011). Bat Conservation International. [Online]. Available: http://www.batcon.org.

2- Choonsik Lee, Kwang Pyo Kim, Wesley E Bolch, Brian E Moroz, and Les Folio, "NCICT: a computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans." *Journal of radiological protection*, Vol. 35 (No. 4), p. 891, (2015).

3- Eike I Piechowiak, Jan-Friedrich W Peter, Beate Kleb, Klaus J Klose, and Johannes T Heverhagen, "Intravenous iodinated contrast agents amplify DNA radiation damage at CT." *Radiology*, Vol. 275 (No. 3), pp. 692-97, (2015).

4- Richard Wakeford, Mark P Little, and Gerald M Kendall, "Risk of childhood leukemia after low-level exposure to ionizing radiation." *Expert review of hematology*, Vol. 3 (No. 3), pp. 251-54, (2010).

5- National Research Council, "Health risks from exposure to low levels of ionizing radiation: BEIR VII phase 2." (2006).

6- Joseph P Neglia *et al.*, "New primary neoplasms of the central nervous system in survivors of childhood cancer: a report from the Childhood Cancer Survivor Study." *Journal of the National Cancer Institute*, Vol. 98 (No. 21), pp. 1528-37, (2006).

7- Christopher Rääf, Nikola Markovic, Martin Tondel, Robert Wålinder, and Mats Isaksson, "Introduction of a method to calculate cumulative age-and gender-specific lifetime attributable risk (LAR) of cancer in populations after a large-scale nuclear power plant accident." *Plos one*, Vol. 15 (No. 2), p. e0228549, (2020).

8- Diana L Miglioretti *et al.*, "The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk." *JAMA pediatrics*, Vol. 167 (No. 8), pp. 700-07, (2013).

9- Neige Journy *et al.*, "Predicted cancer risks induced by computed tomography examinations during childhood, by a quantitative risk assessment approach." *Radiation and environmental biophysics*, Vol. 53 (No. 1), pp. 39-54, (2014).

10- Neige MY Journy, Choonsik Lee, Richard W Harbron, Kieran McHugh, Mark S Pearce, and Amy Berrington de González, "Projected cancer risks potentially related to past, current, and future practices in paediatric CT in the United Kingdom, 1990–2020." *British journal of cancer*, Vol. 116 (No. 1), pp. 109-16, (2017).

11- (2022). Virtual phantoms inc. Retrieved from virtualphantoms. [Online]. Available: https://www.virtualphantoms.com/.

12- Dale L Preston, Yukiko Shimizu, Donald A Pierce, Akihiko Suyama, and Kiyohiko Mabuchi, "Studies of mortality of atomic bomb survivors. Report 13: solid cancer and noncancer disease mortality: 1950–1997." *Radiation research*, Vol. 178 (No. 2), pp. AV146-AV72, (2012).

13- DL Preston *et al.*, "Solid cancer incidence in atomic bomb survivors: 1958–1998." *Radiation research*, Vol. 168 (No. 1), pp. 1-64, (2007).

14- C Ghetti, O Ortenzia, M Maddalo, L Altabella, and N Sverzellati, "Dosimetric and radiation cancer risk evaluation of high resolution thorax CT during COVID-19 outbreak." *Physica Medica*, Vol. 80pp. 119-24, (2020).

15- Mark S Pearce *et al.*, "Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study." *The Lancet*, Vol. 380 (No. 9840), pp. 499-505, (2012).

16- Tilo Niemann *et al.*, "Estimated risk of radiation-induced cancer from paediatric chest CT: two-year cohort study." *Pediatric radiology*, Vol. 45 (No. 3), pp. 329-36, (2015).

17- Kotaro Ozasa *et al.*, "Studies of the mortality of atomic bomb survivors, Report 14, 1950–2003: an overview of cancer and noncancer diseases." *Radiation research*, Vol. 177 (No. 3), pp. 229-43, (2012).

18- Eric J Hall and Amato J Giaccia, Radiobiology for the Radiologist. *Philadelphia*, (2006).

19- Atefeh Tahmasebzadeh, Reza Paydar, Mojtaba Soltani-Kermanshahi, Asghar Maziar, and Reza Reiazi, "Lifetime attributable cancer risk related to prevalent CT scan procedures in pediatric medical imaging centers." *International Journal of Radiation Biology*, Vol. 97 (No. 9), pp. 1282-88, (2021).

20- Charles E Land *et al.*, "Incidence of female breast cancer among atomic bomb survivors, Hiroshima and Nagasaki, 1950–1990." *Radiation research*, Vol. 160 (No. 6), pp. 707-17, (2003).

21- US Environmental Protection Agency. EPA radiogenic cancer risk models and projections for the US population. . [Online]. Available: https://www.epa.gov/radiation/blue-book-epa-radiogenic-cancer-risk-models-and-projections-us-population.

22- United Nations Scientific Committee on the Effects of Atomic Radiation. Volume I: report to the general assembly. Scientific Annexes A and B. 2008. [Online]. Available: https://www.unscear.org/docs/publications/2008/UNSCEAR_2008_Report_Vol.I-CORR.pdf.

23- John D Mathews *et al.*, "Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians." *Bmj*, Vol. 346(2013).

24- Atefeh Tahmasebzadeh, Reza Paydar, Mojtaba Soltani kermanshahi, Asghar Maziar, Mehdi Rezaei, and Reza Reiazi, "Pediatric regional Drl assessment in common Ct examinations for medical exposure optimization in Tehran, Iran." *Radiation protection dosimetry*, Vol. 192 (No. 3), pp. 341-49, (2020).

25- Daniel M Lindberg *et al.*, "Feasibility and accuracy of fast MRI versus CT for traumatic brain injury in young children." *Pediatrics*, Vol. 144 (No. 4), (2019).

26- Michael Esser *et al.*, "Radiation dose optimization in pediatric chest CT: major indicators of dose exposure in 1695 CT scans over seven years." in *RöFo-Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren*, (2018), Vol. 190 (No. 12): © *Georg Thieme Verlag KG*, pp. 1131-40.

27- Marilyn J Siegel, Demetrios Raptis, Sanjeev Bhalla, and Juan Carlos Ramirez-Giraldo, "Comparison of 100-Kilovoltage Tin Filtration With Advanced Modeled Iterative Reconstruction Protocol to an Automated Kilovoltage Selection With Filtered Back Projection Protocol on Radiation Dose and Image Quality in Pediatric Noncontrast-Enhanced Chest Computed Tomography." *Journal of computer assisted tomography*, Vol. 46 (No. 1), pp. 64-70, (2022).

28- Paul A Oakley and Deed E Harrison, "Death of the ALARA radiation protection principle as used in the medical sector." *Dose-Response*, Vol. 18 (No. 2), p. 1559325820921641, (2020).

29- MH Jamshidi, A Keshavarz, A Karami, Y Salimi, and GA Valizadeh, "Patient radiation dose and lifetime attributable risk of cancer due to ionizing radiation in cardiovascular interventional radiological procedures." *Radioprotection*, Vol. 57 (No. 2), pp. 113-21, (2022).

30- Xiao-ying Zhao *et al.*, "Effects of Adaptive Statistical Iterative Reconstruction-V Technology on the Image Quality and Radiation Dose of Unenhanced and Enhanced CT Scans of the Piglet Abdomen." *Radiation research*, (2021).

31- Touko Kaasalainen, Kirsi Palmu, Anniina Lampinen, and Mika Kortesniemi, "Effect of vertical positioning on organ dose, image noise and contrast in pediatric chest CT—phantom study." *Pediatric radiology*, Vol. 43 (No. 6), pp. 673-84, (2013).