ORIGINAL ARTICLE

Assessing Radiation Exposure and Its Implications for Cancer Risk in Chest CT Scans: An Experimental Study

Saleh Salehi Zahabi [1], Saeed Bagherzadeh [2], Karim Khoshgard [1], Ali MohammadSharifi [3], Afsane Mir Derikvand [1*]

[1] Department of Medical Physics, Faculty of Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran

[2] Department of Medical Physics, Faculty of Medicine, Urmia University of Medical Sciences, Urmia, Iran

[3] Clinical Research Development Center, Shahid Modarres Educational Hospital, Shahid Beheshti University of Medical Science, Tehran, Iran

*Corresponding Author: Afsane Mir Derikvand

Email: mirderikvand.afsaneh@gmail.com

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Abstract

Purpose: The rise in coronavirus cases has led to an increased reliance on CT scans, which are known for delivering higher radiation exposure. This study aims to estimate organ doses (ODs) and effective doses (EDs) to evaluate the lifetime attributable risks (LARs) of cancer occurrence and mortality among patients. A total of 600 patients, either confirmed or suspected to have COVID-19, were included in this investigation.

Materials and Methods: To assess patient doses and associated cancer risks, dosimetric parameters such as DLP, volumetric CTDI, and scan length were utilized. The ImPACT CT dosimetry software was employed to calculate ODs and EDs.

Results: For female patients, the mean ED was recorded as 2.36 ± 0.48 mSv based on ICRP Report 103 and 1.2 ± 0.28 mSv based on ICRP Report 60. In male patients, these values were 2.31 ± 0.53 mSv and 1.21 ± 0.45 mSv, respectively. The mean LAR for all cancer rates in males was found to be 14.79 ± 4.85 per 100,000 individuals, while for cancer mortality, it was 8.59 ± 2.42 per 100,000 individuals. For females, the LARs were higher, at 23.37 ± 9.59 for incidence and 12.61 ± 3.89 for mortality per 100,000 individuals.

Conclusion: The findings indicate that chest CT scans are associated with significant radiation exposure and potential cancer risks. Therefore, it is essential to optimize CT protocols according to the ALARA principle to minimize radiation-induced risks while maintaining diagnostic effectiveness during the ongoing pandemic.

Keywords: Radiation Dose; Dosimetry; Computed Tomography Scan; Cancer Risk; Lung.

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1. Introduction

The COVID-19 pandemic, first identified in Hubei, China, in 2019, has posed significant global challenges through 2023. Although the RT-PCR test is the standard for diagnosing COVID-19, chest computed tomography (CT) scans have become increasingly common due to clinician preferences, initial shortages of RT-PCR tests, and the occurrence of false negatives. Chest CT has proven to be more sensitive in detecting pneumonia in patients suspected of having COVID-19 but who test negative on RT-PCR. This reliance on CT imaging emphasizes its critical role in diagnosing and managing COVID-19 effectively, particularly when timely identification of pulmonary complications is essential for patient care [1]. Many of these cases were examined using CT scans, and some even required multiple CT scans ranging from two to eight scans [2]. Following that, various communities proposed low-dose procedures for chest CT examinations in these doubted patients [3, 4]. CT scan is responsible for approximately 24 % of entire radiation exposure and 49% of the medical imaging methods. CT scans are a significant source of radiation for patients [5]. Ionizing radiation, such as the X-ray produced by CT, is categorized as a hazard because it has the potential to damage DNA and lead to cancer [6]. Radiation-induced cancer is a random and dose-dependent linear process in which the possibility of occurrence surges as the dose is increased [7]. Today, the risk of cancer from CT scan is a controversial issue. Although the risk of malignancy is generally significant at doses above 100 millisieverts, there are discussions about the risk caused by lower doses [8, 9]. The most reliable data regarding the cancer risk associated with low-dose radiation comes from studies of atomic bomb survivors. The large cohort has undergone long-term and detailed follow-up. Research indicated that exposure to radiation doses between 5 and 100 mSv is linked to an increased risk of developing malignancies [10, 11]. Radiation exposure significantly contributes to overall cancer risk, influenced by several factors, including the type of CT scan, frequency of use, radiation dose, and individual health characteristics [12]. In line with two other studies, a 2019 epidemiological study confirms a statistically substantial growth in the risk of malignancy among children and adolescents who undergo CT scan examinations [8, 13, 14]. It is estimated that the lifetime mortality rate from cancers caused by diagnostic radiation is between 0.6 and 3% higher than the normal baseline [15, 16]. CT radiation exposure may cause up to 29,000 new cancer ones annually in the US [12]. The DLP and the CTDI are two prevalent dose descriptors used to calculate the radiation dose in a detailed CT practice. The DLP is a crucial metric in assessing radiation exposure during CT scans, but it has limitations. DLP is calculated based on the scan length and the volume CTDI, which reflects the radiation output of the CT scanner [17-19]. The ICRP defines effective dose (ED) as a key metric that accounts for the radiosensitivity of various organs. Utilizing the (ED) has allowed for the comparison of the risks associated with various imaging modalities [17]. Effective CT dose is dependent on CT technique, patient size, and radiosensitivity of organs within the field of view [20].

A chest CT scan exposes multiple radiation-sensitive tissues including the breast, lungs, and thyroid gland. The risk of cancer ratio in tissues such as the breast in <33 mSv doses, ages < 20 years, and in women receiving ≥2 exposures has been increased [21]. Due to the high number of patients with COVID-19 infection who utilize CT scan imaging, it is necessary to appraise the radiation dose and the associated lifetime attributable risk (LAR) of cancer occurrence from chest CT checks. This study's outcome helps to know the amount of received dose and cancer risk of patients considering age, gender, and body mass index, and to take specific actions to reduce patient dose by the ALARA principle of radiation protection.

2. Materials and Methods

2.1. Study Design and Population

All CT scans in this study were performed without the administration of contrast media. The scanning parameters and demographic data for 600 patients were meticulously recorded. Notably, individuals younger than 18 years or older than 80 years were excluded from participation in this research. This approach allowed for a focused analysis of the imaging results while minimizing potential confounding factors related to age.

2.2. Scan Protocol

In the present study, all chest CT scans were conducted using a 16-slice CT scanner (Philips Brilliance 16-slice). The scanning parameters included a tube voltage of 120 kVp, an effective mAs of 50, a tube rotation time of 0.5 seconds, a pitch factor of 0.813, and a slice thickness of 3 mm. To minimize radiation exposure for patients, an automatic exposure control (AEC) system was employed during the scans. This system modulates the radiation dose based on the patient's size and the attenuation characteristics of their anatomy, ensuring that the radiation exposure is kept as low as reasonably achievable while maintaining image quality.

2.3. Monte Carlo (MC) Estimation

To estimate radiation doses for each patient in this study, dosimetric parameters such as CTDI, DLP, pitch factor, mAs, kVp, and scan length were recorded. The ImPACT software (version 1.0.4) was utilized to assess organ doses (ODs). The ImPACT software needs several input parameters to compute organ absorbed doses and total EDs for an anthropomorphic phantom weighing 70 kg. These parameters include the scanner type, kVp, pitch factor, rotation time, mA, collimation size, scan length, and scan region. By inputting these values, the software provides a detailed assessment of the radiation exposure associated with each CT examination, allowing for a more accurate estimation of potential health risks related to radiation exposure.

2.4. Organ Doses (ODs)

ODs in a patient with a certain weight were calculated using the certain Equation [22].

The correction factor for a constant exposure parameter such as DLP and CTDI with increasing the weight of patient decrease and contrariwise as shown in Figure 1.

2.5. Effective Dose (ED)

Here, the ED was calculated by two approaches. 1) ED was intended from the scanner-derived DLP using Equation 1 [23]:

$$E_c = k.\ DLP \quad (1)$$

Where, k is 0.017 $mSv.mGy^{-1}cm^{-1}$.

2) The ImPACT software was employed to compute the ED by following formula [22].

$$ED\ (E_i) = DLP \times c\text{-}factor \times R(W) \quad (2)$$

In which, DLP was documented from the scanner console. The c-factor is the conversion factor and is calculated by dividing the whole ED by the DLP that both of them have been learnt from software. R(w) is the correction factor.

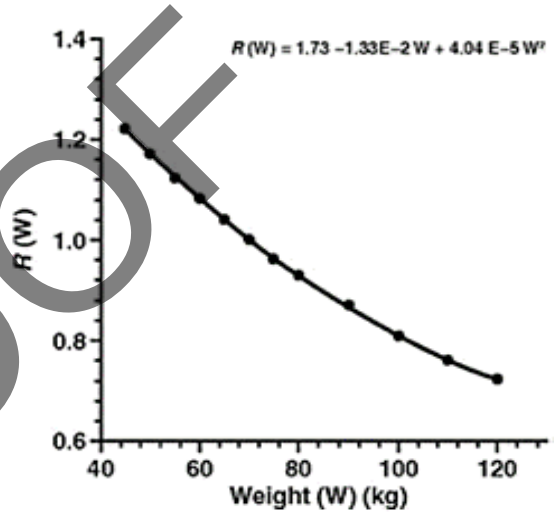

Figure 1. Weighting correction factor [R(w)] showing the function of patients' weights[22]

2.6. Radiation Risk Assessment

LAR refers to the probability of developing cancer induced by radiation in a population of 100,000 individuals exposed to a dose of 100 mGy. This metric is essential for evaluating the long-term health effects of radiation exposure [24]. The equations used to calculate LAR are based on data from the BEIR VII report, which provides detailed estimates of cancer risk associated with low-level ionizing radiation exposure. According to the findings in BEIR VII, the risk of developing cancer increases in direct proportion to the amount of radiation received, supporting the linear-no-threshold (LNT) model. This model suggests that even minimal doses of radiation can contribute to an elevated cancer risk[24]. As shown in previous studies [25, 26] the BEIR VII report

was used in order to assess the risk of LAR of cancer incidence (CI) and mortality per 100000 population who exposed to 0.1 Gy (100 millisievert) radiation. The following formula was used to calculate LAR for each specific organ [24]:

$$LAR_{organ} = LAR_{org}(100\ mGy) \times (\text{organ dose(w)} /100\ mGy) \quad (3)$$

$LAR_{org}(100\ mGy)$ is the LAR of organ according to table 12D-1 and organ dose (W) is the organ dose (mGy). The LARs of all cancer occurrence and mortality were considered using the subsequent equation:

$$LAR = \frac{E_i(mSv)}{D} \times \frac{(\text{LAR of cancer incidence or mortality})_{\text{at the age}}}{100000} \quad (4)$$

Where, D represents the dose, which is equivalent to 0.1 Gy. Additionally, E_i denotes the ED obtained through the utilization of software and the application of correction factors. LAR of CI or mortality at specific ages is derived from the BEIR VII report [24].

3. Results

3.1. Demographic and Dosimetric Factors

In this study, demographic and dosimetric data of 600 patients (243 males and 357 females) were collected. The mean and SD of age, weight, and BMI were 41.84± 14.08 years, 83.21 ± 14.97 kg, and 26.43 ± 3.99 kg/m^2for males, respectively. These values for females were 38.95 ± 13.72 years, 70.58 ± 13.41 kg, and 26.2 ± 4.68 kg/m^2, respectively. The values of CTDIv, DLP, and scan length values for males were 3.69 ± 0.77 mGy, 127.5 ± 26.38 mGy.cm, 34.64±2.89 cm, in turn. The corresponding values for females were 3.75 ± 0.73 mGy, 118.96 ± 22.93 mGy.cm, and 31.74±2.57 cm, respectively (Table 1).

The CTDIv and DLP versus BMI graphs illustrate that CTDIv and DLP in chest CT examinations were independent of patient size (Figure 2).

3.2. Organ and ED Assessments

For males, the esophagus was the organ receiving the maximum absorbed dose with 5.74±1.37 mGy and then the lung with 5.48±1.27 mGy. For females, these organs were the esophagus with a mean of 6.33±1.30 mGy and the lung with 5.95±1.16 mGy (Table 2, Figure 3).

Table 1. Demographic and dosimetric characteristics of the patients

Gender	Age groups	N	CTDIv (mGy)	Scan length(cm)	DLP (mGy.cm)	Weight (kg)	BMI (kg/m^2)
Females	18-35	158	3.68±0.44	32.04±2.51	118.19±15.69	66.51±12.01	24.55±4.17
	36-55	149	3.8±0.73	31.59±2.61	120.19±25.79	73.96±14.04	27.46±4.59
	>55	49	3.8±1.3	31.2±2.63	117.83±32.16	73.55±12.42	27.78±4.89
	overall	357	3.75 ± 0.73	31.74±2.57	118.96 ± 22.93	70.58±13.41	26.2±4.68
Males	18-35	93	3.6±0.28	34.8±3.21	124.59±10.16	84.6±15.41	26.32±4.42
	36-55	112	3.77±1.05	34.45±2.5	130.09±35.57	84.43±14.19	27.11±3.48
	>55	38	3.64±0.53	34.81±3.16	127.02±21.38	76.21±14.54	24.71±3.81
	overall	243	3.69 ± 0.77	34.64±2.89	127.5 ± 26.38	83.21±14.97	26.43±3.99

Table 2. Radiation dose for different organs from chest CT scan

Organs	Males			Females		
	Mean±SD			Mean±SD		
	Organ dose (mGy)	Effective dose (mSv) (ICRP 103)	Effective dose (mSv) (ICRP 60)	Organ dose (mGy)	Effective dose (mSv) (ICRP 103)	Effective dose (mSv) (ICRP 60)
Lung	5.48±1.27	0.65±0.15	0.65±0.15	5.95±1.16	0.71±0.14	0.71±0.14
Stomach	2.77±0.97	0.33±0.11	0.33±0.11	2.11±0.94	0.25±0.11	0.25±0.11
Breast	-	-	-	4.89±0.98	0.57±0.13	0.24±0.04
Liver	3.35±0.95	0.13±0.03	0.16±0.04	2.79±0.99	0.11±0.06	0.13±0.04
Esophagus	5.74±1.37	0.22±0.05	0.28±0.06	6.33±1.30	0.25±0.07	0.31±0.06
Thyroid	0.84±0.23	0.03±0.009	0.04±0.01	0.93±0.24	0.03±0.009	0.04±0.01
Heart	5.06±1.29	0.04±0.01	-	5.48 ±1.29	0.05±0.06	-

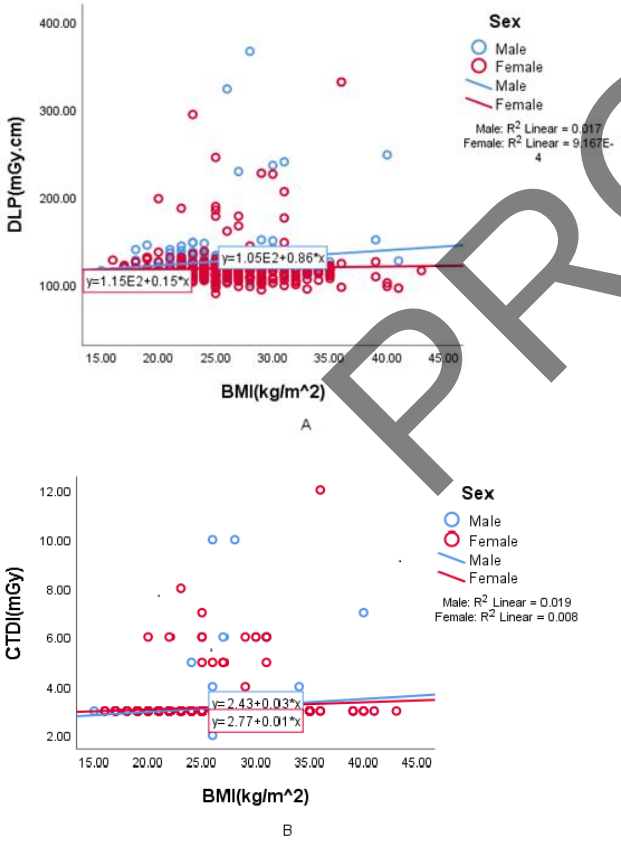

Figure 2. The relationship between the DLP and CTDIv with patient's BMI (A and B)

For males, the mean of the total ED was 2.31 ± 0.53 mSv, 1.89 ± 0.41 mSv, and 2.16±0.44 mSv according to ICRP 103, ICRP 60, and Ec, respectively. For females, this parameter was 2.36 ± 0.48 mSv, 1.95 ± 0.36 mSv, and 2.02±0.38 mSv according to ICRP 103, ICRP 60, and Ec, respectively.

3.3. Lifetime Attributable Risks (LARs) Estimations

The LAR of lung CI was 4.85 ±0.72 cases for males and 12.53 ± 2.17 cases for females, per 100,000 persons. The LAR of breast CI was 7.34 ± 4.73 cases per 100,000 persons. The LAR of lung cancer mortality was 4.31±0.72 cases for males and 11.27±1.86 cases for females, per 100,000 persons. The LAR of breast cancer death was 2.03±1.36 cases per 100,000 persons (Figure 4 A and B). The risk of LAR of all CI and mortality were 14.79 ± 4.85 and 8.59 ± 2.42 cases per 100,000 persons for males, correspondingly. These values were 23.37 ± 9.59 and 12.61± 3.49 cases per 100,000 persons for females, in turn.

As shown in Figures 5 and 6, LARs of lung and breast cancer occurrence and mortality diminished with increasing age.

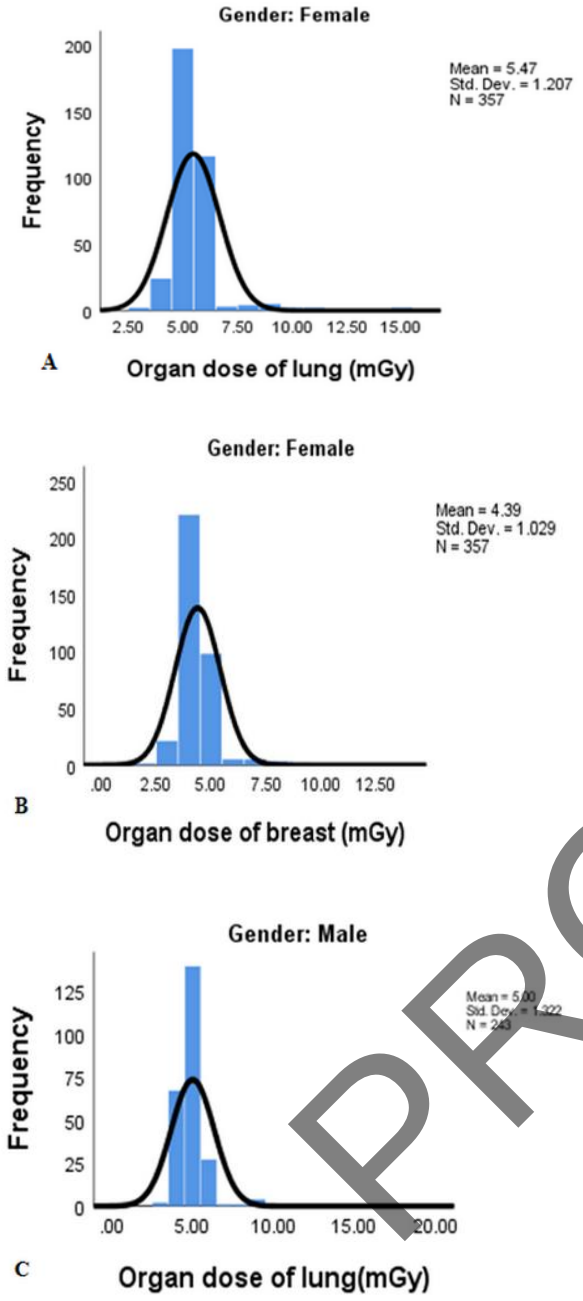

Figure 3. Distribution of organ doses to the lung and breast from chest CT examinations (A,B, and C)

Also, the LARs of cancer risk decline with age (Figure 7.). In the female population, the median LARs for both cancer frequency and cancer mortality were found to be 1.58 and 2.29, respectively. These amounts were comparable to the LARs of 1.58 and 2.29 observed in males. The LARs for all cancer occurrence and death were meaningfully dissimilar among males and females($p<0.05$).

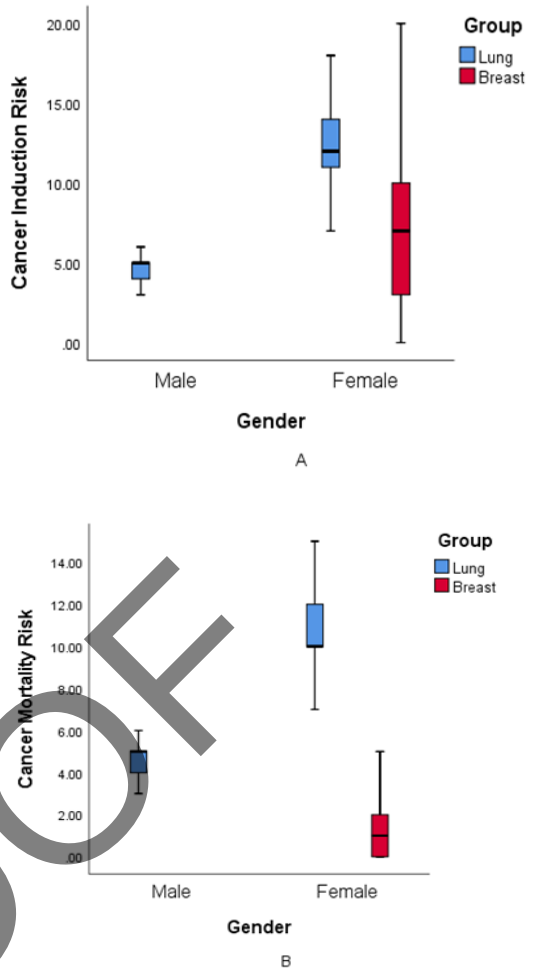

Figure 4. LAR of lung and breast cancer incidence and mortality for female and male patients (A and B)

4. Discussion

This study assessed patients' organ doses, as well as the probability of CI and mortality from CT scans during the COVID-19 outbreak period. Similar to the findings of relevant study [22], the outcomes of the present study demonstrated an independent association between CTDIv and BMI.[25] and [26] discovered a direct correlation between CTDIv and BMI. It may be a result of the different regions scanned, as [25] and [26] evaluated abdominal CT scans, whereas our study and Huda et al. evaluated chest CT scans.

In our investigation, the mean CTDIv and DLP were 3.72 mGy and 122.42 mGy.cm, respectively. These values were lower than those found by [27] in their 16-slice scanner investigation (CTDIv = 6.8

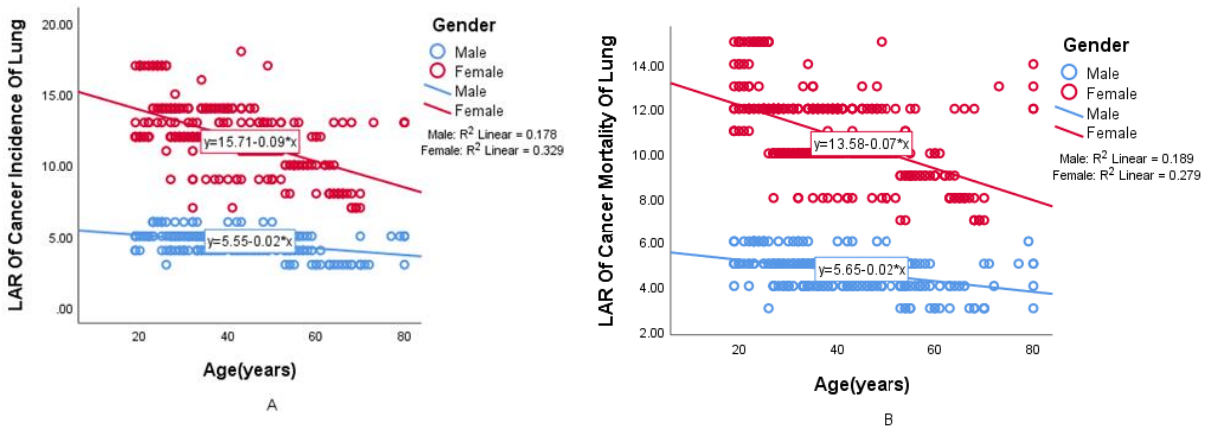

Figure 5. LAR of lung cancer incidence and mortality as a function of age for female and male patients

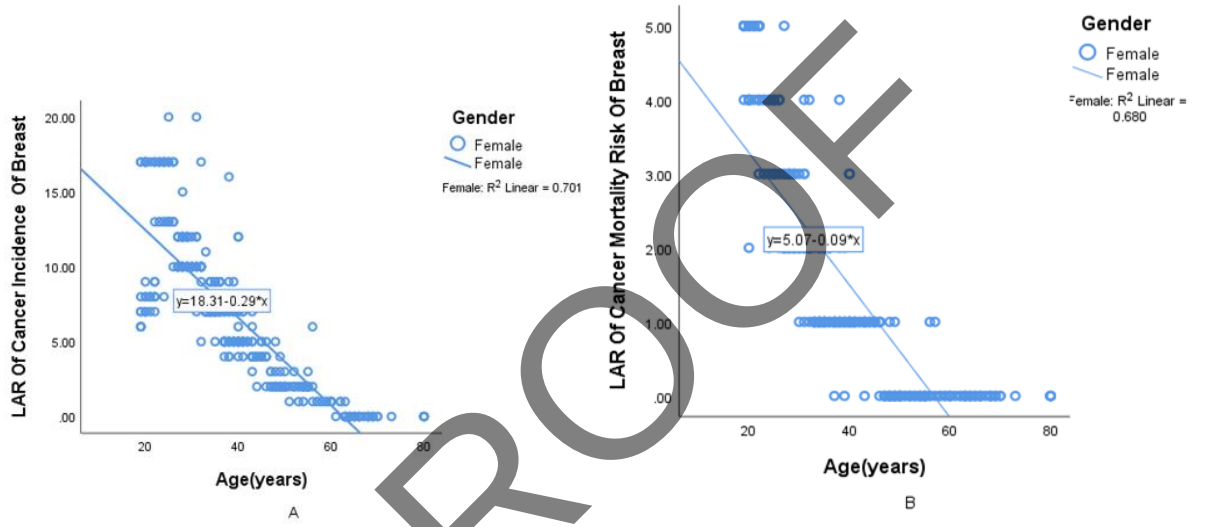

Figure 6. LAR of breast cancer incidence and mortality as a function of age for female

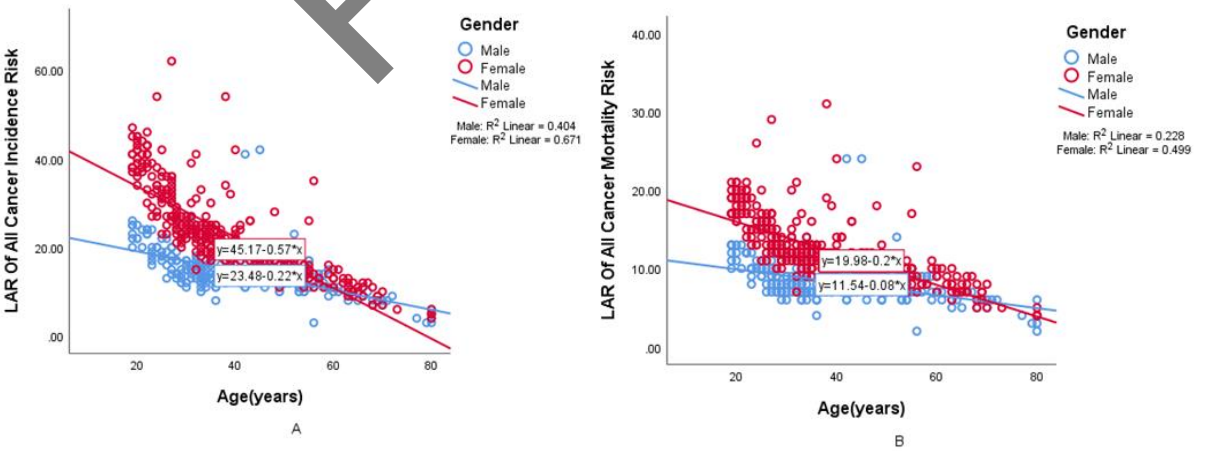

Figure 7. LAR of all cancer incidence and mortality as a function of age for female and male patients

mGy, DLP = 239 mGy.cm). These disparities may be attributable to the different CT scan parameters utilized in the two investigations. The effective mAs in our trial was 50, but in Ghetti's study it was 110. Reducing tube current is the most effective strategy for lowering CT radiation exposure. With a 50% decline in mA, the radiation dose is cut in half without appreciably compromising image quality [28-30]. The

CTDIv and DLP exhibited a range of values spanning from 0.39 to 3.5 mGy and 14.2 to 112 mGy.cm, respectively, as reported in multiple investigations pertaining to low-dose CT scans [2]. In our investigation, the length of the chest CT scan was 32 cm. Atli et al. reported a scan length of 40 cm, while Kanal et al. reported 35 cmAccording to Badawy et al., the ED for a typical procedure increased by 15% when the length of the chest CT scan was raised by 10 cm [31], higher than the Masjedi et al. report for chest CT (3.30 mSv) and HRCT examinations (3mSv) [32].

The dose to the breast ranges between 2.99 and 13.11 mGy, with an mean dose of 4.89 mGy. The dose to the lung varies from 3.64 to 17.17 mGy, with 5.76 mGy. Various investigations have reported varying lung and breast organ dose values.Also, Lahham et al., reported breast dose from thoracic CT scans from 6.5 to 28 mGy, with a mean of 15 mGy. In a separate study, Ghetti et al. described an equivalent dose of 9.7 and 9.6 mSv for the breast and lung, respectively [27].

The average ED here was around 2.32 mSv according to ICRP 103 which was in line with Ghetti et al. (3.9 mSv) and Matkevich et al. (3.1 mSv) findings [27, 33]. In an experimental investigation by Mpumelelo, patients' ED was 2.5±0.21mSv [34]. Also, Svahn et al. reported ED of 0.24-2.9 mSv which was estimated by utilization of TLD [35]. These experimental outcomes were in conformity with our study. The observed discrepancy may be attributed to the marginally higher CTDIv in females (3.75 mSv) compared to males (3.69). ED is dependent on patient size and radiosensitivity of organs within the field of view [20]. Due to the radiosensitivity of the breast, the ED was faintly higher in females than in males, despite the fact that their BMI and scan length were slightly less than those of males.

The average ED was 1.2 mSv based on ICRP 60, 2.34 mSv based on ICRP 103, and 2.07 mSv based on the DLP to ED conversion factor. These discrepancies may be attributable to the fact that the DLP to ED conversion factor is the same for all patients and ignoring patient characteristics, scan parameters, and scanner type. In addition, the mean ED based on ICRP 60 was lower than per ICRP 103. In ICRP publication 103, the weighting factor of a large number of organs was altered [36, 37]. Current research demonstrates the enhanced radiosensitivity of breast and the breast cancer consists around a quarter of all female health risks [38]. According to ICRP publication 60 and ICRP publication 103, the breast weighing factor has been enlarged from 0.05 to 0.12.

The LAR values of lung CI from chest CT (10.05 and 9.19 cases per 100,000 people, respectively) indicated that women were at a more risk than males. The LAR values of CI and mortality for the breast were 8.25 cases and 2.02 cases per 100,000 persons, in turn (Fig. 2.A and B). Ghetti et al. also stated similar findings, aligning with our results. However, organ doses to the lungs were found to be nearly equivalent between the two genders [27]. According to BEIR VII, which is derived from the impacts of low-dose radiation on Nagasaki survivors, the risk of lung CI in women is higher than men. Here, the breast LAR values observed in females were found to be comparatively lower than the values described by Ghetti et al [27].

The OD and age at exposure are two of the most effective modifiable factors of ionizing radiation-induced cancer risk. The relative risk of lung CI and mortality declined with increasing age at exposure. This decline was more pronounced for females than for males. The LAR of breast CI and mortality decreased as age at exposure increased. It has been observed that the dose of 0.01Gy to a woman younger than 35 years can surge her breast cancer risk by 13.6% during her lifetime [39]." " In this investigation, the LAR of all CI and mortality for women was over 1.5 times that of men due to the augmented risk of breast cancer and the higher risk factors for lung cancer. This gap diminishes as age increases. For females aged 20, 40, and 60, LAR of all cancers was 45, 25, and 10 per 100,000, respectively. This value was 22, 15, and 10 per 100000 men aged 20, 40, and 60 years old, respectively. The results obtained from this study enhance the knowledge of healthcare personnel regarding the consequences of radiation exposure resulting from medical interventions, with the ultimate goal of minimizing the amount of radiation received by patients.

Our research on dose measurement and cancer risk assessment is not devoid of drawbacks. Firstly, the risk of cancer varies across individuals based on factors such as tobacco use, lifestyle, hereditary factors, and diet, which were not considered in this study. Secondly, our research has not investigated the clinical indications for CT scans. This study did not assess the

image quality. Fourth, it is implausible that the measurable risk estimates produced from this investigation were the most precise estimations. Owing to our study's organ doses, the chest doses did not surpass 100 mGy, but the BEIR VII reports gave 100 mGy-normalized risk estimates.

5. Conclusion

This study used a low-dose protocol, wherein the administered dose to the patient is lower than that of the regular procedure, resulting in a correspondingly reduced risk of cancer. Hence, this approach can be employed for doing a low-dose chest CT scan.

It is crucial to emphasize that the LAR of cancer induced by CT scans should not be dismissed or overlooked. Furthermore, the LAR of cancer was somewhat greater for females compared to males. Optimizing radiation exposure and minimizing the utilization of needless scans is of utmost importance in patient care, particularly in the case of younger women who possess an elevated susceptibility to cancer.

Acknowledgments

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This retrospective cross-sectional study had been granted approval by the ethical committee of Kermanshah University of Medical Sciences (approval number: IR.KUMS.REC.1400.181).

Written informed consent was obtained from all the participants who voluntarily agreed to participate in the study.

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