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Research Article

Quantification of Radiation Exposure of the Lungs and Liver in Computed Tomography (CT): A Dose Level Analysis

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Abstract:

This study investigated the radiation dose that a patient's liver and lungs received while undergoing computed tomography (CT) procedures. Radiation exposure was simulated and measured using TLD-100 thermoluminescent dosimeter and Alderson Rando Phantom (ART). Each organ was scanned in a single session, and the radiation dose to which the organs were exposed was estimated by taking the arithmetic average for each section. By providing insights into optimizing radiation exposure for patient safety during computed tomography imaging, the study improves medical practices and procedures.

1. Introduction

Radiation, which is energy released as waves or particles, originates from both natural and artificial sources. Ionizing radiation and non-ionizing radiation are the two basic types into which it is separated. Due to its high energy, ionizing radiation can damage cells by ionizing atoms through electron removal. In medicine, this kind of radiation is frequently employed for both diagnosis and treatment. In contrast, non-ionizing radiation is generally less harmful as it lacks the energy required to ionize atoms. This type of radiation is found in everyday applications such as microwaves, radio waves, and visible light [1].Radiation has a major role in computed tomography's (CT) operation. The human body may be harmed by radiation. These damages may include radiation burns, cancer, shortened life expectancy, and genetic illnesses [2]. Medical applications are the primary source of artificial radiation exposure, with an average of 0.3 mSv per person [3]. Different parts of the human body have varying levels of sensitivity to radiation. Active tissues are more affected by radiation [4,5]. It has been observed that radiation increases the risk of cancer in vital tissues such as the lungs and liver [6,7]. CT shooting rooms must be lined with lead to reduce the radiation risk posed by scattered photons to the environment [8].Computed Tomography (CT) imaging is a revolutionary technique for sectional imaging that has completely changed radiology. CT imaging stands out as the most widely used device among ionizing radiation-utilizing devices [9]. This X-ray-based equipment uses X-rays to create a three-dimensional image of the inside of the body. Depending on the region of interest, X-rays with energy between 80 and 140 keV are transmitted. The patient is exposed to radiation because CT imaging uses X-rays. Numerous factors, such as the person's age, gender, the area being scanned, and the type of CT scanner, might affect the radiation dose that the body receives. The ionizing radiation type of X-rays utilized in CT scans can harm cells and tissues, resulting in radiation exposure. Radiation has both deterministic and stochastic impacts on the organism. The probability of radiation damage to the body is increased by stochastic effects, which are unpredictable and statistically occurring consequences. Usually, these effects appear when low radiation doses are administered. For example, radiation exposure may raise a person's risk of developing cancer. The radiation dose determines how severe these consequences are, but as there is no set threshold dose, any radiation dose has the potential to be hazardous. Radiation that produces noticeable and unique effects over a threshold level is known as a deterministic effect. Usually, these symptoms happen after high radiation exposures. Several studies have shown that exposure to low levels of ionizing radiation in diagnostic radiological examinations may cause various types of cancer, such as leukemia, thyroid, lungs, and breast cancer [10-13].

The increased use of CT devices raises the risk of various cancers, as mentioned above [14]. The lowest dose (as low as reasonably achievable, or ALARA) should be used to reduce these hazards [15]. This project is to investigate in detail the radiation dose levels that are administered to the liver and lungs, two essential organs, during Computed Tomography (CT) imaging. The study has multiple main goals. Initially, it concentrates on precisely determining the radiation dose levels that the liver and lungs receive during CT scans. In order to detect possible hazards and improve knowledge of the effects of radiation exposure, the second step involves evaluating the dose levels that were collected. This analysis will aid in the creation of safer and more effective procedures for medical imaging. Third, in order to keep radiation doses as low as practically possible, the project intends to develop techniques to avoid needless scans. The project hopes to accomplish these goals in order to enhance patient safety, optimize imaging procedures, and promote the general development of medical diagnostic methods.

2. Material and Methods

Alderson Rando Phantom (Fig.1), which resembles an adult female weighing 55 kg, was used for the study. The surrounding acrylic has the same density as human tissue, and also the phantom is made of human bones [16]. That is why the study was able to show the achievement of realistic outcomes. The Cerrahpasa Medical Faculty at Istanbul University-Cerrahpasa provided the facilities from which this phantom was used for the investigation. Phantom meets ICRU-44 standards [16] and represents a 55 kg, 155 cm tall female. Its composition material has a density of 0.985 gcm-1 [17]. It is divided into 32 sections, each measuring 2.5 cm in thickness. The TLD dosimeters, which are used to measure the absorbed dose, are attached to the sections using pins found within [16].

***Figure 1**. Alderson Rando Female Phantom (ART)*

Radiation doses are computed in the medical field using TLD-100 dosimeters (Fig. 2) [17]. For this study, ten dosimeters were used. The TLDs have dimensions of 0.89 mm in thickness, 3.2 mm in height. LiF, Mg, and Ti are the compounds in these dosimeters [17]. Also a Computed Tomography (CT) device was used for this study to get the results of the radiation dose of the lungs and the liver. Computed Tomography imaging was performed at the Radiology Unit of Cerrahpasa Medical Faculty. Radiation dose measurements were read using WinREMS software in the same lab using a Harshaw 4500 model reader that was connected to a PC. The reader was calibrated using the Yxlon International MGC 41 model X-ray system with the Cs-137 source. Radiation dose rate measurements were performed using a reference standard dosimeter [18].

Figure 2. *TLD-100 Dosimeters*

TLD dosimeters were annealed in the oven for two hours at 100 °C after an hour at 400 °C for calibration. These dosimeters' relative standard deviation ought to be less than 3% [17]. The TENMAK Cekmece Nuclear Research Center's secondary standard dosimetry laboratory (SSDL) was used for the calibration, imaging, and reading of the imaging processes.Following calibration, the TLD-100 dosimeters were placed in the lung and liver regions of the phantom, which represent vital organs. Sections 13–14 and 19–20 represent the lungs and liver regions, respectively, in the phantom. Two dosimeters per section, or four dosimeters total, were positioned in sections 19 and 20. Two dosimeters per section, four dosimeters total, were positioned in sections 13 and 14 (Fig.3). To determine the background (environment) in which the measurement is being made and the radiation exposure level of the operator, two TLD-100 dosimeters were utilized. These dosimeters stayed out of sight during the radiation treatments. Afterwards, these regions were imaged using computerized tomography. Computerized tomography scans are done in a single session. For the lungs and liver regions, the ambient dose was subtracted from the dose exposed to these vital organs (lungs and liver) and the net radiation dose value to which the organs are exposed were found.

Figure 3. *The Phantom sections and TLDs cassette.*

After the imaging was completed, readings of the radiation values to which the TLDs are exposed were made at the Çekmece Nuclear Research Center (TENMAK). Standard deviation and mean calculations were planned to be made using simple statistical methods. Thus, the dose of radiation to which some vital organs (lungs and liver) are exposed during computed tomography imaging were calculated.

3. Results and Discussions

In the experiment, the radiation doses received by the liver and lungs during automatic imaging, as well as the background radiation exposure level in the environment where the measurements were taken, were assessed. For background radiation, the TLD-100 dosimeter recorded a dose of 0.14 mSv. To measure the radiation dose impacting the liver, a total of four TLDs were utilized—two placed in section 19 (right side) and two in section 20 (left side). The radiation doses recorded by the TLDs were 37.64 mSv and 39.1 mSv for section 19 (right side), and 47.61 mSv and 42.41 mSv for section 20 (left side). Since each of these values was obtained after three automatic exposures, the results were divided by three. The mean values of the mean TLDs were determined as 12.55±1.03 mSv, 13.03 mSv, 15.87±1.96 mSv and 14.14±1.47 mSv, respectively. The average radiation dose to the right liver was measured as 12.79±1.03 mSv, while the left liver was exposed to an average dose of 15.01±1.13 mSv.

The measured radiation dose for the liver revealed that the right section (section 19) received a lower dose compared to the left section (section 20). This indicates that the right side of the liver is exposed to less radiation.Similarly, to determine the radiation dose affecting the lungs, four TLDs were utilized—two placed in section 13 (right side) and two in section 14 (left side). The radiation doses recorded by the TLDs were 40.64 mSv and 41.46 mSv in section 13 (right side), and 53.79 mSv and 58.43 mSv in section 14 (left side). As with the liver, since these values were obtained following three automatic exposures, they were divided by three. The mean values of the mean TLDs were determined as 13.55±1.68 mSv, 13.82±1.53 mSv, 17. ±1.38 mSv and 19.48±1.97 mSv, respectively. The average radiation dose to the right lung was measured as 13.69±1.24 mSv, while the left lung was exposed to an average dose of 18.71±1.36 mSv.A similar pattern is observed for the lungs, where the radiation dose measured in the right section (section 13) is lower than that in the left section (section 14). This indicates that the right side of the lungs is exposed to less radiation. The radiation dose values for the liver are presented in Table 1. The average radiation dose for the liver in the right section (section 19) is 12.79 mSv, while the average dose in the left section (section 20) is 15.00 mSv.

Table 1. *Radiation Dose for Liver (mSv)*

Section	1st TLD (mSv)	2nd TLD (mSv)	Average
Right (19)	12.55	13.03	12.79
Left (20)	15.87	14.14	15.00

Table 2. *Radiation Dose for Lungs (mSv)*

Section	1st TLD (mSv)	2nd TLD (mSv)	Average (mSv)
Right (13)	13.55	13.82	13.69
Left (14)	17.93	19.48	18.71

For the lungs, the average radiation dose measured in the right section (section 13) was 13.69 mSv, while in the left section (section 14), the average dose was 18.71 mSv (Table 2). Based on these results, the minimum radiation dose for the liver was 12.79 mSv in the right section, and the maximum was 15.00 mSv in the left section. For the lungs, the minimum radiation dose was 13.69 mSv in the right section, and the maximum was 18.71 mSv in the left section.

The radiation doses received by the lungs and liver are illustrated in figure 4. It is evident that the lungs receive higher radiation in both sections, suggesting that the lungs are more sensitive to radiation than the liver.

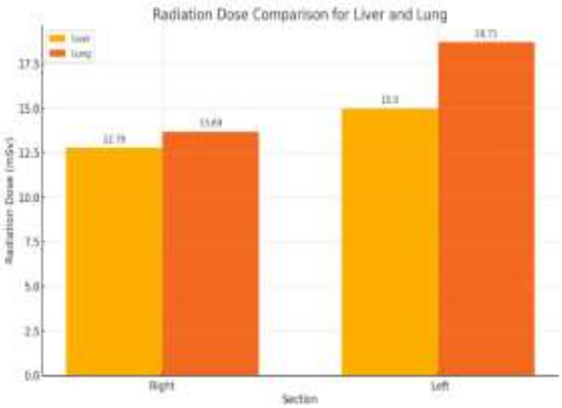

Figure 4. *Radiation Dose Comparison for Liver and Lungs*

The average radiation dose measured in the right part of the liver (section 19) was 12.79 mSv, while in the left part (section 20), it was 15.00 mSv. This results in a difference of 2.21 mSv between the two sections, indicating that the right part of the liver is exposed to less radiation. This suggests that the right side of the liver may be positioned more protectively or that the left side is closer to the radiation source.A similar pattern was observed in the lungs, with an average radiation dose difference of 5.02 mSv between the right (13.69 mSv) and left (18.71 mSv) parts. This shows that the right lung receives less radiation than the left lung, likely due to the left lung's closer proximity to the radiation source. The difference in radiation dose between the right and left lungs is more pronounced than in the liver, possibly due to anatomical differences and positioning of the lungs.Several factors may contribute to this dose disparity. Firstly, anatomical positioning plays a significant role. The left sections of the liver and lungs may be positioned closer to the radiation source, making them more exposed to the primary beam. For example, the right side of the liver is partially shielded by other organs, such as the gallbladder, which may contribute to lower radiation exposure. Similarly, the left lung is smaller but positioned in a way that may receive more direct radiation. Additionally, the configuration of the X-ray or CT beam can contribute to dose variation. If the imaging system is set up to direct more radiation toward the left side due to patient positioning or equipment design, this could explain the discrepancy. Scatter radiation is another contributing factor, as interactions with surrounding tissues or bones may cause secondary radiation to concentrate in certain areas, increasing the dose. Lastly, differences in tissue composition between the right and left sections may also play a role. If one side contains dense tissue, it may absorb more radiation, affecting the overall dose distribution.The study compares the measured radiation doses to typical diagnostic CT scan dose ranges (10-20 mSv) [19], with recorded doses for the liver (12.79 mSv and 15.00 mSv) and lungs (13.69 mSv and 18.71 mSv) falling within this range. However, beyond this comparison, it is crucial to evaluate these values in the context of established radiation safety guidelines, such as those provided by the International Commission on Radiological Protection (ICRP). The ICRP sets dose limits by considering the risks of long-term exposure, emphasizing the cumulative effects of repeated radiation exposure. The annual effective dose limit for the general public is set at 1 mSv, and for occupational exposure, it is set at an average of 20 mSv per year (but no year should exceed 50 mSv) [20]. Although the recorded doses in this study are within the safety limits for a single diagnostic CT scan, repeated examinations or higher radiation exposure over time may lead to greater risks and require further evaluation.In a study, it was determined that the effective doses measured for thoracic (chest) CT ranged from 10–20 mSv, which is consistent with the data from our study [8]. The findings of this study highlight significant concerns and offer potential solutions. One key takeaway is the variation in radiation dose depending on the organ and its location, underscoring the need for personalized rather than standard dose distribution. This is particularly crucial in scenarios like radiotherapy, where precise dosage is vital.Moreover, considering the sensitivity of the TLD-100 dosimeters, future studies should employ more advanced dosimeter technologies to improve measurement accuracy and reliability. Larger clinical studies, along with detailed computer simulations, should be conducted to better understand radiation effects on different organ regions. These studies will help refine dose distribution models and enhance the generalizability of the results.

4. Conclusions

The study highlights differences in radiation dose between the right and left parts of the liver and lungs, highlighting the importance of organ positioning and proximity to the radiation source in dose distribution. Specifically, the right sections of both organs received lower radiation doses than the left sections, indicating that anatomical positioning and organ proximity to the radiation source affect dose distribution. The observed doses are within the safety limits for diagnostic CT scans (10–20 mSv) [16].The study's limitations include using TLD-100 dosimeters, which, while effective, may not offer the highest sensitivity and accuracy compared to more advanced dosimeter technologies. Additionally, the sample size and the scope of the study were limited, potentially affecting the generalizability of the findings. The study did not account for variations in tissue density and composition, which could further influence dose distribution.Future research should aim to enhance the accuracy of dose measurements by incorporating more advanced dosimetry technologies. Detailed computer simulations should be conducted to model radiation distribution more comprehensively, taking into account the variations in tissue density and anatomical differences. Additionally, developing and implementing lower-dose imaging techniques can significantly reduce patient radiation exposure during both diagnostic and therapeutic procedures.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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