ORIGINAL ARTICLE

Evaluating Organ Doses and Cancer Risk Estimation in Pediatric Chest and Abdominal CT Imaging: A Multicenter Study in Iraq

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Abstract

Purpose: Computed Tomography (CT) is an essential diagnostic imaging modality in pediatric medicine; however, exposure to ionizing radiation poses a potential risk of radiation-induced malignancy. This multicenter study evaluated organ-specific radiation doses and estimated lifetime cancer risks in pediatric patients undergoing chest and abdominal CT imaging across multiple Iraqi healthcare centers.

Materials and Methods: Data from 200 pediatric patients (100 chest CT, 100 abdominal CT) were collected from three hospitals in Dohuk, Mosul, Anbar, and Baghdad, Iraq. CT acquisition parameters (kilo-Voltage (kVp), pitch, slice thickness, scan length) and dose metrics ($CTDI_{vol}$, DLP, effective dose) were recorded. Organ doses to lungs, thyroid, breast, and heart were estimated using imPACT software based on scanner-reported parameters. Lifetime Attributable Risk (LAR) of cancer incidence was calculated using BEIR VII risk models with linear interpolation for pediatric age groups (1–5, 6–10, 11–15 years).

Results: Radiation dose metrics increased significantly with age. Mean $CTDI_{vol}$ increased from 8.1 ± 1.1 mGy in the 1–5-year group to 20.8 ± 1.2 mGy in the 11–15-year old group, with effective doses of 3.2 ± 0.3 to 6.7 ± 0.5 mSv. Organ doses demonstrated parallel trends: lung doses 4.8–8.9 mSv, thyroid doses 4.3–8.0 mSv. Cancer risk was highest in younger children (LAR: 0.16 ± 0.02 cancers/10,000 person-years/mSv), decreasing with age but remaining clinically significant.

Conclusion: This study demonstrates that as children age and body size increases, CT dose and cancer risk increase; therefore, dose optimization and the use of appropriate protocols are essential.

Keywords: Pediatric Computed Tomography Imaging; Organ Dose; Lifetime Attributable Risk; Cancer Risk Estimation; Dose Optimization; Iraq.

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1. Introduction

Since its introduction in the 1970s, Computed Tomography (CT) imaging has revolutionized diagnostic approaches in medicine and is now considered a valuable tool for producing high-resolution, three-dimensional images of internal body structures [1]. This method plays a vital role, especially in emergencies and pediatric diseases such as traumatic injuries, complex infections, congenital anomalies, and tumors. However, despite its undeniable clinical benefits, CT contributes very high cumulative medical radiation doses and can account for up to 43% of the total dose received by patients, while it accounts for only 6% of all imaging procedures [2].

The use of ionizing radiation in CT poses a serious public health concern because this type of radiation, through direct and indirect damage to DNA, has the potential to induce genetic mutations and stimulate carcinogenic pathways that can lead to malignancy years or even decades after exposure [3-5]. This is especially important in children due to their rapid growth, active cell division, and longer lifespan after exposure. Sensitive tissues such as the breast [6], lungs, thyroid, and bone marrow of children are much more vulnerable to radiation, and repeated exposure, for example, in chronic diseases such as cystic fibrosis or recurrent pneumonia, increases this risk [7].

Internationally recognized evidence emphasizes the existence of a dose-response relationship between radiation exposure from CT in childhood and an increased incidence of cancers such as leukemia, brain tumors, and thyroid cancer; in such a way that the probability of some cancers multiplies with increasing cumulative dose [8]. In some countries, including Iraq, health authorities report that childhood cancer rates are on the rise, underscoring the need for epidemiological and preventive assessments [9]. Despite technological advances and projects to improve radiation safety, in many regions, especially in the Middle East and developing countries such as Iraq, there is still a lack of sufficient and accurate data on organ dose, long-term cancer risk estimates, and the effectiveness of optimization protocols [10]. Most of the existing studies have either only assessed overall cancer risk or have not paid sufficient attention to doses to specific organs in the abdominal and thoracic regions. These limitations have prevented the development of evidence-based policies to protect children [11]. Other difficulties in assessing the risk of childhood CT-related cancers include the long time lag between tumor onset (especially for solid malignancies), the presence of confounding factors (predisposing genes, environmental factors), and the difficulty of long-term follow-up [12].

CT, as one of the advanced medical imaging tools, is of great importance in the diagnosis and management of pediatric clinical conditions and plays a pivotal role in discovering diseases that are undetectable by simpler methods [13]. However, the widespread use of ionizing radiation in this method, especially in the pediatric population, has raised serious concerns among experts about the increased risk of secondary cancers and late complications [14]. Children's bodies are more susceptible to genetic damage and tumorigenesis due to active growth and rapid cell division, long life after radiation exposure, and the sensitivity of organs such as the lung, thyroid, bone marrow, and breast. Global studies have shown that repeated exposure or high doses of medical radiation can increase the risk of diseases such as leukemia, thyroid cancer, and solid tumors several times over years or decades [15].

In Iraq, despite the high prevalence and necessity of CT imaging in pediatric medical centers, there is still no adequate and local database of vital organ doses and a clear estimate of cancer risk in children [16]. The lack of accurate information on the doses administered and their consequences has led to the failure to implement dose optimization standards, establish Diagnostic Reference Ranges (DRLs), and develop scientific guidelines to reduce potential radiation harm to children [17]. This is that even though developed countries have implemented extensive programs to improve radiation safety in children for many years with accurate data recording [18]. On the other hand, the complexities of radiation protection management, the lack of uniform regional protocols, and heterogeneous operator behaviors have reduced the possibility of achieving optimal protection and exposed patients to unnecessary and dangerous exposure [19]. Although major studies have confirmed a direct and dose-response relationship between radiation exposure and increased cancer risk in children; however, the indigenous characteristics of

the Iraqi pediatric population and differences in scanning protocols require specific, community-based studies to develop country-specific practical, regulatory, and clinical strategies [20]. For this reason, conducting extensive, multicenter studies to quantify doses to sensitive organs and accurately estimate the risk of cancers from medical radiation in Iraqi children is a research, medical, and social necessity [16].

Given the high importance of CT imaging in the diagnosis of acute and chronic diseases in children, and based on the growing evidence showing an association between exposure to ionizing radiation during childhood and an increased risk of secondary cancers, the need to accurately assess radiation doses to sensitive organs and estimate the long-term risk of cancer in pediatric patients is highly felt. Currently, many imaging centers in developing countries, including Iraq, do not operate in accordance with the strict international standards of dose optimization for the pediatric population, and data on regional dosimetric parameters are limited. This multicenter study aims to fill the scientific gap in the Middle East data by comprehensively reporting dosimetric parameters related to children in different hospitals in Iraq (Baghdad, Dohuk, Mosul, and Anbar), comprehensively evaluating CT acquisition parameters, estimating organ doses for sensitive organs (lung, thyroid, breast, heart), and calculating lifetime attributable risk (LAR) for each age group, and provide regional evidence to improve pediatric imaging protocols and reduce unnecessary radiation exposure.

2. Materials and Methods

2.1. Study Design and Feasibility Setting

This was a retrospective study of 200 pediatric patients who underwent chest and lung or abdomen and pelvis CT scans between 2000 and 2024. Data were collected from four imaging centers in Iraq: AMAL Hospital in Baghdad (for chest studies) and three hospitals in Dohuk, Mosul, and Anbar (for abdomen and pelvis studies). All CT scans were performed using standard vendor-supplied devices, and technical parameters and dose reports were retrospectively extracted from hospital records.

2.2. Study Population and Sample Size

The study included 200 pediatric patients who were divided into two groups: (a) 100 children aged 1 to 15 years who underwent chest or lung CT imaging at AMAL Hospital, Baghdad, and (b) another 100 children aged 1 to 15 years who underwent abdominal and pelvic CT imaging at three different hospitals in Duhok, Mosul, and Anbar. The study population included children who had a single imaging scan as well as children who had multiple scans under treatment. Inclusion criteria included: (1) age between 1 and 15 years, (2) CT scan performed during the study period, and (3) complete dose information in the scanner reports. Exclusion criteria included: (1) incomplete or missing dose information, and (2) studies that did not follow standard technical parameters.

2.3. Data Collection and Imaging Parameters

The CT imaging parameters collected for each patient included: (1) peak kilovoltage (kVp), (2) tube current-exposure time product (mAs), (3) slice thickness, (4) pitch factor, and (5) other protocol parameters. The CT volumetric dose index ($CTDI_{vol}$) and dose-length product (DLP) were extracted from the CT scanner reports for each examination. All scan settings were recorded from the scanner computer. Different pediatric standard parameters were used for the studies according to the patient's age and body size.

2.4. Radiation Dose Calculations and Cancer Risk Estimation

2.4.1. Dose Calculations

Scan parameters were extracted directly from the scanner computer system and dose report sheets. These parameters were entered into imPA CT software, version 1.0.4, 27/05/2011, a validated dosimetry tool, which calculated the organ absorbed doses (in mGy) and effective dose (in mSv) for each patient. Effective dose (E) was calculated according to the studies.

For the chest study in Baghdad, organ-specific doses were estimated using validated Monte Carlo simulation software that accurately models the

geometry of the LightSpeed VCT CT system (GE Healthcare) and includes the 3D structure of the bow tie filters and the motion of the X-ray tube during axial and helical scans. The accuracy of the simulation was confirmed using cylindrical and anthropomorphic phantoms, with dose agreement of about 1–11% on average and a maximum deviation of 5–17% from the actual measured values.

For each patient, the total scan length was calculated by adding the actual image coverage to the over ranging distance, which accounts for the additional imaging for data interpolation during helical reconstruction. For the abdomen and pelvis study in the three cities, simpler methods were used that involved direct calculations of the scanner parameters.

2.4.2. Cancer Risk Estimation

The LAR for cancer incidence was calculated using linear interpolation based on the BEIR VII report. Specifically, LAR values were generated by scaling the risk estimates for a single dose of 0.1 Gy (100 mSv) presented in Table 12D-1 of the BEIR VII report to the patient-specific effective doses from imPACT. This method allows for the quantification of the increased lifetime cancer risk attributable to radiation exposure from CT scans in children, taking into account age and organ sensitivity. Risk ratios (rT) for each tissue/organ and each age group were extracted from the BEIR VII tables.

2.5. CT Machines and Protocols

For the Baghdad Chest Study, CT examinations were performed using a 64-slice MDCT machine system (LightSpeed VCTVCT, GE Healthcare). The device was evaluated for estimating radiation dose and associated cancer risk using eight predefined pediatric chest imaging protocols. These protocols were selected to assess the impact of patient size, patient age, and various scan parameters on dose and risk estimates. The first four protocols were adapted from the pediatric chest imaging protocols based on the size used at the study institution. For the abdominal and pelvic studies in Duhok, Mosul, and Anbar, various MDCT devices were used with local standard pediatric protocols. All devices and protocols were selected based on patient age and body size.

3. Results

3.1. Patient Demographic Characteristics

This retrospective cohort study was conducted on 200 pediatric patients who underwent chest and lung CT imaging (100 patients in Baghdad) or abdominal and pelvic CT imaging (100 patients in Dohuk, Mosul, and Anbar) to evaluate the risk of secondary malignancies resulting from CT radiation exposure. Table 1 presents the demographic characteristics of the included pediatric patients.

Patient ages ranged from 1 to 15 years, with a mean (± standard deviation) of 8.3 (± 4.41) years. Sex distribution comprised 51% males and 49% females. Weight ranged from 4 to 42 kg with a mean of 25.15 (± 11.04) kg, and height ranged from 82.5 to 178 cm with a mean of 134.83 (± 32.03) cm. Body mass index (BMI) ranged from 5.9 to 17 kg/m² with a mean of 13.15 (± 3.22) kg/m².

Table 1. Demographic characteristics of pediatric patients (n=200)

Parameters	Chest Study (Baghdad)	Abdominal/Pelvic Study (3 Cities)	Total
Number	100	100	200
Age (years)	8.4 ± 4.48 (1–15)	8.2 ± 4.35 (1–15)	8.3 ± 4.41 (1–15)
Sex (Male/Female)	52/48%	50/50%	51/49%
Weight (kg)	25.5 ± 11.15 (4–40)	24.8 ± 10.92 (5–42)	25.15 ± 11.04 (4–42)
Height (cm)	134.45 ± 31.92 (82.5–176)	135.20 ± 32.15 (85–178)	134.83 ± 32.03 (82.5–178)
BMI (kg/m²)	13.2 ± 3.26 (5.9–17)	13.1 ± 3.18 (6.0–16.8)	13.15 ± 3.22 (5.9–17)

3.2. CT Scan Acquisition Parameters by Age Group

CT imaging technical parameters for pediatric patients were analyzed according to age group, reflecting protocol adjustments for optimal image quality and radiation safety. Table 2 summarizes the mean, standard deviation, and range for slice thickness, pitch, tube voltage (kVp), and tube current (mAs) in each age category.

Analysis reveals a clear trend of increasing slice thickness, tube voltage (kVp), and tube current (mAs) with patient age, while pitch values decrease. For children aged 1–5 years, mean slice thickness was 1.75 mm (SD: 0.32), mean pitch was 1.33 (SD: 0.10), and mean kVp was 83.2 (SD: 7.2). In the 6–10-year group, mean slice thickness increased to 2.38 mm (SD: 0.40), pitch decreased to 1.12 (SD: 0.08), and kVp rose to 102.0 (SD: 4.7). In the oldest group (11–15 years), mean slice thickness reached 2.70 mm (SD: 0.21), pitch declined further to 1.07 (SD: 0.06), and kVp averaged 115.9 (SD: 5.8). These adjustments are consistent with best practices for balancing image quality and radiation dose in pediatric CT imaging.

3.3. Comparative Analysis of Radiation Dose and Exposure Parameters

Radiation dose parameters from pediatric CT scans in this study were analyzed and compared across three age groups (1–5, 6–10, and 11–15 years). Results are summarized in Table 3, showing mean values, standard deviations (SD), and ranges for scan length, $CTDI_{vol}$, DLP, and effective dose.

Data demonstrate a clear increase in scan length, $CTDI_{vol}$, DLP, and effective dose with patient age, reflecting the need for higher radiation doses in larger children to maintain diagnostic image quality. This aligns with established pediatric CT dose optimization principles, which recommend adjusting scan parameters based on patient size and clinical indication. Also, Mean scan length increased from 16.5 cm in the youngest group to 23.1 cm in the oldest, consistent with anatomical growth and larger scan coverage.

Mean $CTDI_{vol}$ more than doubled from 8.1 mGy (1–5 years) to 20.8 mGy (11–15 years), and mean DLP nearly quadrupled from 132.6 mGy·cm to 496.2 mGy·cm. These values are within the range reported for pediatric CT dose reference levels internationally and reflect appropriate

Table 2. CT scan acquisition parameters by age group (mean ± SD, range)

Age Group (years)	N	Slice Thickness (mm)	Pitch	kVp	mAs
1–5	25	1.75 ± 0.32 (1.30–2.40)	1.33 ± 0.10 (1.20–1.49)	83.2 ± 7.2 (80–100)	27.0 ± 5.2 (25–45)
6–10	37	2.38 ± 0.40 (1.26–2.96)	1.12 ± 0.08 (1.00–1.29)	102.0 ± 4.7 (100–115)	50.1 ± 8.7 (44–83)
11–15	38	2.70 ± 0.21 (2.06–3.00)	1.07 ± 0.06 (1.01–1.18)	115.9 ± 5.8 (107–120)	92.1 ± 7.7 (53–120)

Table 3. Mean ± standard deviation (SD) and range for scan length, CTDIvol, DLP, and effective dose in pediatric CT Scans, by age group

Age Group (years)	N	Scan Length (cm)	CTDIvol (mGy)	DLP (mGy·cm)	Effective Dose (mSv)
1–5	25	16.5 ± 0.8 (15–19)	8.1 ± 1.1 (6.5–11.9)	132.6 ± 22.1 (104.2–189.6)	3.2 ± 0.3 (2.7–3.7)
6–10	37	18.8 ± 1.7 (17–25)	15.1 ± 2.0 (12.6–19.7)	289.3 ± 47.8 (240.2–370.5)	4.6 ± 0.5 (3.9–5.4)
11–15	38	23.1 ± 1.2 (22–25)	20.8 ± 1.2 (18.0–23.5)	496.2 ± 36.3 (426.6–582.5)	6.7 ± 0.5 (5.6–7.9)

adjustments to maintain image quality while adhering to the ALARA principle. Also, the effective dose increased from 3.2 mSv in the youngest group to 6.7 mSv in the oldest. These doses are comparable to published pediatric CT dose data and highlight the importance of dose optimization strategies, including tailored protocols and advanced technologies such as Automatic Exposure Control (AEC) and iterative reconstruction.

Findings demonstrate that CT protocols used in the studied hospitals appropriately scale radiation dose parameters according to patient age and size, consistent with international guidelines for pediatric imaging safety.

3.4. Cancer Risk Estimates by Age Group

Cancer risk parameters associated with pediatric CT radiation exposure were analyzed according to the same age categories used throughout this study: 1–5 years, 6–10 years, and 11–15 years. Table 4 summarizes the mean and range of the Risk Factor, LAR, and Risk values for each age group.

Table 4 presents cancer risk estimates associated with pediatric CT radiation exposure by age group. Risk Factor represents the baseline probability of developing cancer per unit radiation dose and reflects the population's general sensitivity to ionizing radiation. LAR estimates the cumulative probability that an individual exposed to a given radiation dose will develop cancer over their lifetime. Both metrics are derived from BEIR VII models.

Risk Factor values were highest in the youngest age group (1–5 years), averaging 0.043 cancers per 10,000 person-years per mSv, reflecting the increased radiosensitivity of younger children. This value decreased with age, reaching 0.027 in the 11–15-year old group. Similarly, LAR was highest in the youngest group (mean 0.16), slightly lower in the 6–10-year group (mean 0.14), and comparable in the oldest group (mean 0.15). The Risk parameter remained very low and consistent across all age groups. Risk Factor is highest in the youngest age group (1–5 years), reflecting greater inherent radio-sensitivity of younger children. It decreases progressively with age, consistent with reduced tissue sensitivity and shorter remaining lifespan in older children. LAR values also peak in the youngest group but remain relatively stable between the 6–10 and 11–15-year-old groups. This reflects cumulative lifetime risk, which accounts for both age at exposure and biological factors influencing cancer development over time. Notably, LAR values are approximately 3 to 5 times higher than Risk Factor values across all age groups. This difference arises because LAR integrates additional risk modifiers and latency effects, providing a more comprehensive estimate of lifetime cancer risk attributable to radiation exposure. Small variation in LAR between older age groups suggests that while radio-sensitivity decreases with age, longer latency periods and other factors balance risk in older children.

3.5. Organ-Specific Radiation Dose Analysis by Age Group

Organ doses to the lung, thyroid, breast, and heart were analyzed according to pediatric age groups used throughout this study: 1–5 years, 6–10 years, and 11–15 years. Table 5 presents the mean, standard deviation (SD), minimum, and maximum doses for each organ within these age categories.

The lung received the highest average radiation dose among analyzed organs, with a mean dose of 6.86 mSv (SD: 2.02), ranging from 3.12 to 11.17 mSv. This is expected given the lung's frequent inclusion in chest and upper abdominal CT scans. Thyroid dose was slightly lower on average, with a mean of 5.79 mSv (SD: 2.02), but with a similar range (2.46–11.17 mSv), reflecting its radiosensitivity and proximity to scanned regions in head and neck imaging. Breast dose averaged 4.43 mSv (SD: 1.68), ranging from 0.94 to 11.29 mSv.

Table 4. Comparison of Risk Factor and Lifetime Attributable Risk (LAR) for Cancer Incidence Associated with Pediatric CT Radiation Exposure, by Age Group (Unit: Cancers per 10,000 Person-Years per mSv)

Age Group (years)	N	Risk Factor	LAR	Risk
1–5	25	0.043 ± 0.005 (0.035–0.050)	0.16 ± 0.02 (0.12–0.21)	0.001 ± <0.001 (0–0.001)
6–10	37	0.033 ± 0.004 (0.027–0.039)	0.14 ± 0.02 (0.11–0.18)	0.001 ± <0.001 (0–0.001)
11–15	38	0.027 ± 0.003 (0.023–0.031)	0.15 ± 0.02 (0.13–0.19)	0.001 ± <0.001 (0–0.001)

Table 5. Organ-specific radiation doses (mean ± SD, range) for Lung, Thyroid, Breast, and Heart, stratified by pediatric age groups (unit: mS)

Age Group (years)	N	Lung Dose	Thyroid Dose	Breast Dose	Heart Dose
1–5	25	4.8 ± 1.2 (3.1–7.4)	4.3 ± 1.1 (2.5–6.5)	2.8 ± 1.0 (0.9–5.6)	3.3 ± 0.7 (2.3–4.6)
6–10	37	6.9 ± 1.5 (4.5–9.9)	5.9 ± 1.4 (3.1–9.1)	4.2 ± 1.2 (1.3–7.5)	4.8 ± 1.0 (3.1–6.6)
11–15	38	8.9 ± 1.4 (6.4–11.2)	8.0 ± 1.7 (5.2–11.3)	6.3 ± 1.5 (3.7–11.3)	6.1 ± 1.1 (4.4–7.0)

The wide range reflects variability in scan protocols and patient anatomy, particularly in female patients. Finally, the heart received the lowest average dose among these organs, with a mean of 4.78 mSv (SD: 1.32) and a narrower range (2.34–6.91 mSv), consistent with its anatomical location and scan coverage.

Mean lung dose increased significantly with age, from 4.8 mSv in the 1–5-year group to 8.9 mSv in the 11–15-year group. This reflects larger scan volumes and higher exposure parameters in older children. Similarly, thyroid doses rose from an average of 4.3 mSv in the youngest group to 8.0 mSv in the oldest, consistent with increased scan coverage and patient size. Breast radiation exposure showed a marked increase with age, from 2.8 mSv in the youngest group to 6.3 mSv in the oldest, highlighting the importance of dose reduction strategies in female patients, especially during adolescence. Heart doses also increased with age, from 3.3 mSv to 6.1 mSv, reflecting anatomical growth and scan protocol adjustments.

Progressive increase in organ doses with age aligns with international findings that larger body size and extended scan lengths in older children require higher radiation doses to maintain image quality. These results underscore the critical need for age- and size-adapted CT protocols to minimize radiation exposure to radiosensitive organs, particularly the thyroid and breast, which are associated with elevated lifetime cancer risks in pediatric populations. Findings are consistent with published pediatric dose reference levels and emphasize the importance of continuous monitoring and optimization of CT protocols in children to adhere to the ALARA principle.

4. Discussion

This multicenter study represents the first comprehensive assessment of pediatric CT radiation doses and associated cancer risks in Iraq, addressing a critical gap in Middle Eastern radiation dosimetry literature. Our findings reveal striking age-dependent patterns: effective doses increased 2.1-fold with age (3.2–6.7 mSv), while paradoxically, the youngest children (1–5 years) exhibited the highest lifetime cancer risk (LAR: 0.16 per 10,000 person-years/mSv), reflecting extreme radiosensitivity and prolonged post-exposure lifespan. Organ doses to lungs, thyroid, and particularly breast demonstrated substantial age-related escalation. These findings align with international evidence yet provide critical regional data supporting implementation of stringent age-specific dose optimization protocols, advanced dose-reduction technologies, and enhanced clinical justification strategies for pediatric CT imaging in resource-limited Middle Eastern healthcare settings.

Despite extensive clinical evidence of the superiority of CT in diagnosing pediatric diseases, the exponential growth in requests for scans has been accompanied by growing concerns about the effects of ionizing radiation on children's health. Children are much more vulnerable to radiation than adults: first, their growing organs and tissues have a higher rate of cell division and a greater potential for genetic mutations due to DNA damage; second, they have a longer window of opportunity for radiation-induced cancers to develop due to their longer lifespan after exposure. Epidemiological studies have estimated that the lifetime risk of cancer for the same radiation dose is two to three times higher in children than in adults. For example, a CT scan of the abdomen in a five-year-old child can increase the chance of developing cancer by 0.1% (1 in 1000) over a lifetime, but the same scan in a 50-year-old person is associated with a much lower risk [21]. Another important point is that the radiation dose in CT is much higher than in conventional imaging such as plain radiography; a CT scan typically delivers an effective dose of 5 to 10 mSv (equivalent to 2 to 3 years of natural environmental radiation). Also, patients who are frequently exposed

to CT scans (such as those with chronic lung diseases or childhood cancer) may receive more than 20 scans over a few years, leading to dose accumulation and a significant increase in risk [22].

The rapid development of CT technology, such as multi-detector devices and spiral/helical imaging modes, has enabled high-resolution volumetric images and short scan times, but at the same time increases the potential for increased unwanted radiation exposure, especially for children. Therefore, the most important clinical concern is to strike a balance between "vital diagnostic benefit" and "cumulative risk of cancer and delayed radiation effects [23]."

In this regard, medical and health physics practitioners continue to emphasize the need to optimize scanning protocols based on patient weight and age, train professionals, use new dose-reducing technologies (such as AEC, iterative reconstruction, collimation calibration, and pitch adjustments), and accurately refer patients. The ALARA (As Low As Reasonably Achievable) principle should always be observed in pediatric imaging, and the development of diagnostic reference levels and continuous recording and monitoring of patient doses should be at the heart of national policy recommendations [24].

The present study, by examining 100 pediatric patients (1–15 years of age), provides a well-representative sample of patients presenting for CT scans in Iraq. The demographic characteristics of these patients (age, weight, height, BMI, and sex ratio) were recorded in accordance with the standards of large global studies [25]. The mean age of the patients in this study was 8.4 years, the mean weight was approximately 25 kg, the mean height was 134 cm, the mean BMI was 13.2, and the sex ratio was approximately equal. These indicators are clearly consistent with the data of Almohammed and Ploussi (2023 and 2020) as well as the populations studied in the comprehensive studies of Niemann, Little, Jamshidi, and others [26].

For example, Almohammed recorded a mean weight of 41.87±16.56 kg and a mean height of 143±20 cm for the same age group, and Ploussi reported a mean weight of 11.5 kg and a height of 90 cm for children under five years of age, and a weight of 45.4 kg and a height of 150 cm for the five to fifteen-year-old group, which represents a favorable statistical alignment with the present study. From a technical perspective, the characteristics of the imaging parameters (slice thickness, tube voltage and current, pitch, and scan length) in the samples examined in the present study are within the framework of global data: slice thicknesses are mainly between 1.26 and 3 mm, tube voltages between 80 and 120 kV, and mAs between 25 and 120 [26]. Other studies have reported a similar range of these parameters: Ploussi (2020) recorded a slice thickness of 2.5 mm, kV equivalent to 100, and mAs range of 24 to 109 for younger age groups, and a thickness of 5 mm, kV equivalent to 120, and mAs up to 269 for older age groups. This emphasizes the accuracy and precision of device settings and compliance with international standards in the Iraqi centers studied [27].

Globally, according to the IAEA report and the Asia-Europe-Africa comprehensive studies, the overall ratio of pediatric scans to total CT scans is up to 12% in Asia and about 4% in Europe; however, the rate of chest and abdominal scans in children varies depending on the level of infrastructure development and control policies of different countries. The present study, like the summary of data from France, Germany, and the United Kingdom, shows that the highest frequency of pediatric CT scans is often in the age groups of 6 to 10 and 11 to 15 years. The sex ratio between girls and boys is also—although it differs in some cases—but the trend of age changes and dose increases in higher groups is almost similar to all regional and international studies [28].

Also, one of the important strengths of this study is the complete correspondence between the sample demographic data and global and regional statistics; so that its results, in terms of risk stratification, quality indicators, and dose measures, can be easily compared and interpreted in the global epidemiological context. Finally, this demographic and technical alignment ensures the validity of the current study results, both for the design of national health policies and for the use of researchers at international levels and future databases [29].

A quantitative study of CT scan radiation dose parameters in pediatric patients in this study showed that radiation indices ($CTDI_{vol}$ and DLP) and effective dose (Effective Dose) increase in proportion to the age and body size of the child. This finding is fully

consistent with the physiology of body growth; as with increasing age, body dimensions, scan volume and the need for technical adjustment of higher parameters (tube voltage, current, pitch, and slice thickness) increase. Also, increasing scan length and area covered in older patients increases the dose received by the whole body and organs [30].

The current study findings, in terms of both the range and the mean of $CTDI_{vol}$ and DLP, are fully consistent with data published from leading Asian and European centers. For example, the mean $CTDI_{vol}$ in the 1–5-year age group was 8.1 mGy and in the 11–15 year age group it was 20.8 mGy, while the DLP increased from 132.6 to 496.2 mGy cm, respectively. These values are consistent with the European DRL reference tables, Kang, Brady, and Nor Muhammad data, and no unusual or higher than recommended exposures were recorded. The results confirm the same increasing trend with age in the large Gao study, which enrolled more than 14,000 children in the United States [31].

In the analysis of the Effective Dose, it was observed that the value varied from 3.2 mSv in the youngest children to 6.7 mSv in adolescents; studies such as Tahmasebzadeh, Miglioretti, Jamshidi, and Shubayr reported the same amount and gradient—and this indicates an optimal level of protocol development in the centers studied and adherence to dose standardization [32].

Your English and left-handed tables allow for a direct comparison of the numbers with the work of Keshtkar (Iran), Alenazi (Riyadh), and Shubayr (Saudi Arabia), both in terms of organ dose and effective dose. At the organ dose level, the increasing trend of lung, breast, thyroid, and heart doses with increasing age is also quite clear. Lung doses ranged from 4.8 mSv to 8.9 mSv, thyroid doses from 4.3 to 8.0 mSv, and breast doses from 2.8 to 6.3 mSv; Results that are not only in agreement with Jamshidi (Iran), but also with Saudi and Multinational references [33]. The distribution of organ dose and the simultaneous increase in LAR with age show that despite the increase in effective dose with age, the lifetime risk of cancer for the under-5 age group remains higher, and this is a very crucial concept for protocol optimization [34].

Another noteworthy point is the intelligent dose management compared to the minimized centers: in some centers such as the Niemann study (Germany) with emphasis on low-dose protocol, the $CTDI_{vol}$ range was reported up to 1.47 mGy, but the dose reduction came at the cost of image quality loss, and in parallel studies of such centers, the rate of additional (re)scanning and higher cumulative radiation were reported. While in the current research model, a better balance between imaging quality and dose has been observed, which creates the basis for modeling protocol improvement for the entire region [35].

A detailed analysis of the baseline risk (Risk Factor) and lifetime cumulative risk (LAR) in children undergoing CT scans revealed that children in the younger age group (1–5 years) receive the highest relative and absolute cancer risk, and these values gradually decrease with age. This pattern is biologically inevitable due to the rapid cell growth, more active division, small distances between organs, and longer residual life of young children; this is why all risk standards and models such as BEIR VII and famous studies such as Brenner and Miglioretti confirm this age gradient. Major population studies suggest that even a single CT scan with an average dose of 8 mSv can increase the relative risk of leukemia or brain tumor in children by 10–16%, and repeated exposures (such as two or three CT scans before the age of 15) increase this risk by up to threefold. On average, for every 10,000 children with a standard scan, 1–2 cases of associated cancer are expected to develop within 12–15 years of the scan [36].

In the present study, the LAR in the 1–5-year age group reached 0.16 (mSv/10,000 person-years) and decreased with age but remained constant. Another key factor is the difference in risk and LAR by gender: certain tissues, such as the breast and thyroid in girls, have higher radiobiological sensitivity, which manifests itself particularly in adolescence and early adulthood as an increased lifetime risk of cancer. This figure is consistent with the studies of Tahmasebzadeh, Alenazi, and Keshtkar and is also consistent with reviews from South Korea, Australia, EPI-CT, and Western European hospitals. At the population level, comparative studies have shown that the excess risk from CT scans is directly related to the number of scans and the cumulative dose; In

particular, children who undergo frequent scans or are overweight or are imaged in centers with suboptimal protocols may experience a higher LAR gradient and cumulative risk than other children [37].

A key finding of this review is the need to adopt dose-reducing protocols, modify parameters based on the child's age/sex/body mass index, and strictly adhere to the ALARA principle; these measures are not only part of international recommendations but also part of good radiological policy worldwide [38]. Finally, this age and sex risk and LAR classification, in addition to helping to improve radiation protection strategies, also provides the basis for standardizing screening algorithms, quality monitoring, and health data collection in the regional and global pediatric health system [39]. The findings of this study are comparable in all technical, dosimetric, and cancer risk layers with the data and results of the most prominent multinational and regional studies, including Brady (Europe), Keshtkar (Iran), Kang (China), Alenazi (Saudi Arabia), and reports of global organizations. For example, the range of mean $CTDI_{vol}$, DLP and Effective Dose in this project was practically within the range of standards published by IAEA, ICRP, American Society of Radiology and Asia-Europe data banks, and none of the findings were outside the confidence limits of global reports [40].

One of the main challenges in reconciling the findings is the impact of "technology diversity", device brand, type of image reconstruction algorithm, and the use of dose reduction technologies. For example, the dose dispersion reported in the Niemann and Miglioretti's studies resulted from the targeted use of low-dose protocols and parameter minimization, which reduced the average dose, but sometimes at the expense of image quality and increased the likelihood of repeat scans. In contrast, the joint Iranian and Saudi studies were usually performed with more classic devices or without Iterative Reconstruction technologies, which increased the average dose [41].

Regarding the assessment and estimation of lifetime cancer risk, although there are differences between computational models, the dominant approach of all studies is based on the BEIR VII model or its derivatives—but the type of software, the extent to which age and sex factors are taken into account, and the way the data is regressed affect the output of LAR and Risk. For example, some protocols only consider the total dose, while some also record the dose to high-risk organs, which increases the ability to individualize the risk. These points lead to slight differences in the reported numbers, but the overall gradient of "increasing dose and risk with age and size" and "sex-specific risk differences" remains constant [42]. Finally, these comparative studies show that the findings of the Iraqi centers are quite outstanding in terms of validity, global and regional referencing, and clinical generalizability to similar countries and even future management of children's health. The need to define national and regional DRLs, continuously referencing multinational data banks, and improving software adaptability are key messages of this section to promote the systemic health of pediatric patients [43].

Considering our study's novelties and strong points, it should be acknowledged that it has several limitations. First, cross-sectional design prevents temporal trend assessment; prospective studies would strengthen causal inference. Second, cancer risk estimates are model-based (BEIR VII) projections rather than observed outcomes, with inherent uncertainties at low doses (3–7 mSv). Third, clinical indications for each CT were not systematically documented, limiting appropriateness analysis. Fourth, the lack of long-term follow-up precludes empirical validation of risk predictions. Fifth, geographic specificity to Iraq may limit generalizability to other regions with different technologies and healthcare systems. Sixth, heterogeneous equipment across centers introduces measurement variability (±10–15%), though normalization by $CTDI_{vol}$/DLP mitigates this. Despite these limitations, the multicenter design, large sample size (n=200), validated dosimetry methods, and first-ever regional pediatric CT dosimetry data provide robust evidence for radiation safety optimization in Middle Eastern settings.

5. Conclusion

This multicenter study of pediatric CT imaging in Iraq, comprising 200 pediatric patients (100 chest CT in Baghdad; 100 abdominal/pelvic CT in Dohuk, Mosul, and Anbar), provides comprehensive evidence that radiation doses and estimated lifetime cancer risks demonstrate clear age-dependent patterns, with

younger children exhibiting disproportionately elevated cancer risks despite lower absolute radiation doses. Specifically, the study found that: (1) effective dose increased nearly 2.1-fold from 3.2 ± 0.3 mSv in children aged 1–5 years to 6.7 ± 0.5 mSv in children aged 11–15 years; (2) LAR peaked in the youngest age group at 0.16 ± 0.02 cancers per 10,000 person-years per mSv, representing approximately 1.6 times higher risk than the oldest group (0.15 ± 0.02); (3) organ doses demonstrated progressive increases with age, with lung doses escalating from 4.8 ± 1.2 mSv to 8.9 ± 1.4 mSv (1.85-fold increase), thyroid doses rising from 4.3 ± 1.1 mSv to 8.0 ± 1.7 mSv (1.86-fold), and breast doses increasing markedly from 2.8 ± 1.0 mSv to 6.3 ± 1.5 mSv (2.25-fold increase); and (4) $CTDI_{vol}$ and DLP approximately doubled and quadrupled respectively across age groups. The findings underscore the critical importance of age- and size-adapted CT protocols, targeted dose reduction strategies for radiosensitive organs (particularly the thyroid and breast, which demonstrated the highest lifetime cancer risks), implementation of modern dose-reduction technologies capable of reducing doses by 20–50%, and rigorous clinical justification for each CT examination.

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