ORIGINAL ARTICLE

Radiation-Induced Cancer Risk Assessment in Iranian Patients Undergoing Head and Neck Computed Tomography Scans

Abolhasan Divband [1*], Amir Ali Forghani [2], Mohammad Reza Deevband [3*], Somaye Rashedi [3], Fatemeh zahra Nosrati [3]

[1] *Department of Pediatrics, Faculty of Medicine, Hormozgan University of Medical Sciences, Bandar Abbas, Iran*

[2] *School of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

[3] *Department of Biomedical Engineering and Medical Physics, School of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

*Corresponding Authors: Abolhasan Divband, Mohammad Reza Deevband
Received: 04 February 2026 / Accepted: 24 April 2026
Email: drbahmandivband@gmail.com, mdeevband@sbmu.ac.ir

Abstract

Purpose: Head and neck CT examinations constitute more than 50% of all CT scans in Iran, and their utilization has dramatically increased in recent years, raising concerns about population radiation burden. Objectives: This study aimed to estimate organ doses, effective dose, and Lifetime Attributable Risk (LAR) of cancer in Iranian patients undergoing routine head and neck CT using Monte Carlo-based dosimetry.

Materials and Methods: In this retrospective cross-sectional study, 429 patients (215 females, 214 males; mean age 45.5 ± 17.2 years) from nine imaging centers (2020–2022) were evaluated. Organ and effective doses were calculated using NCICT software with Size-Specific Dose Estimate (SSDE) adjustment. LAR of cancer incidence and mortality was estimated using BEIR VII models, adjusted for Iranian life tables.

Results: Mean $CTDI_{vol}$ and DLP were 36.36 ± 17.17 mGy (95% CI 34.02–38.70) and 542.44 ± 292.56 mGy·cm (95% CI 503.12–581.76), respectively. The mean effective dose was 1.23 ± 0.67 mSv (95% CI 1.14–1.32). Proposed national diagnostic reference levels (75th percentile) were 48.31 mGy for $CTDI_{vol}$ and 752 mGy·cm for DLP. The highest organ doses were received by the brain (22.36 mGy,95% CI 20.85–23.87) and salivary glands (19.84 mGy, 95% CI 18.48–21.20). The total LAR of cancer incidence was 181.82 per 100,000 (95% CI 174.13–189.51); females showed a 15.5% higher risk than males ($p < 0.01$). The "other cancers" category (mainly brain and salivary glands) contributed 98% of the total risk.

Conclusion: Individual risk is low, but high CT frequency (>10 million/year) may cause thousands of radiation-induced cancers. Recommend ALARA adherence, protocol optimization, and national DRLs.

Keywords: Computed Tomography; Radiation Dosimetry; Lifetime Attributable Risk; Diagnostic Reference Levels; Biologic Effects of Ionizing Radiation VII.

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1. Introduction

Computed Tomography (CT) is the largest contributor to medical radiation exposure in most countries [1]. In Iran, the number of CT scanners increased from 546 in 2015 to 915 in 2019. Head and neck CT examinations account for more than 50% of all CT procedures, with head CT alone constituting approximately 57% of the total in some reports [2]. This rapid growth has raised serious concerns about population radiation burden and long-term cancer risk [3, 4].

These procedures expose several highly radiosensitive organs, including the brain, salivary glands, and thyroid [5]. The Lifetime Attributable Risk (LAR) of cancer from such exposures varies significantly with absorbed organ dose, patient age, and gender [6]. Previous Iranian studies have established local Diagnostic Reference Levels (DRLs) for common CT protocols and estimated cancer risks from chest and cardiac CT [7-9]. However, no comprehensive nationwide study has yet assessed cancer risk from the most frequently performed examination, head and neck CT, using patient-size-adjusted Monte Carlo dosimetry.

The present study addresses this critical gap by: (1) Using NCICT software (Monte Carlo-based) with SSDE correction, which is significantly more accurate than the conventional K × DLP method [10]; (2) Proposing the first Iranian DRLs for head and neck CT derived from a multicentre dataset; and (3) Providing age- and sex-specific LAR estimates using BEIR VII models adjusted for Iranian life-tables.

2. Materials and Methods

2.1. Study Design and Population

This multicenter retrospective study included 429 consecutive patients (≥15 years) who underwent routine head and neck CT examinations between 2020 and 2022 in nine imaging centers across Iran. Ethical approval was obtained from the institutional review board of Shahid Beheshti University of Medical Sciences. Consecutive patients were selected from the PACS of each center. Inclusion criteria were age ≥15 years and undergoing routine head and neck CT. No additional exclusion criteria were applied to reflect real-world clinical practice. Clinical indications (trauma, headache, sinusitis, stroke, tumor follow-up, etc.) were not collected because the study focused solely on dosimetry. Patients with repeat scans during the study period were not excluded to represent actual clinical workload.

2.2. Data Collection and Dosimetry

The nine imaging centers used multi-detector CT scanners from GE Healthcare, Siemens Healthineers, Philips, and Canon/Toshiba with detector rows ranging from 16 to 128. Iterative reconstruction was utilized in all scanners, and Automatic Exposure Control (AEC) was active in 100% of examinations. Routine head and neck CT protocol parameters were: tube voltage 120 kVp, tube current-time product 150–350 mAs (modulated by AEC), pitch 0.5–1.0, rotation time 0.5–1.0 s, and reconstructed slice thickness 5 mm. All dosimetric parameters ($CTDI_{vol}$, DLP, scan length) were extracted from DICOM headers. Organ and effective doses were calculated using NCICT v3.0 software [10] with patient-specific effective diameter and SSDE correction. Effective doses were derived using tissue weighting factors from International Commission on Radiological Protection (ICRP) Publication 103 [11]. Patient-specific phantoms in NCICT v3.0 were matched to the ICRP reference library by age, gender, and effective diameter. Effective diameter was calculated according to AAPM Report 220. SSDE conversion factors were applied according to AAPM Report 293. The scan range was standardized from the vertex of the skull to the superior border of the clavicle to ensure consistent organ coverage.

2.3. Cancer Risk Estimation

Lifetime Attributable Risk (LAR) of cancer incidence and mortality was calculated using BEIR VII Phase 2 preferred models [12]. The LAR was calculated as a weighted logarithmic average of the Excess Relative Risk (ERR; multiplicative model) and Excess Absolute Risk (EAR; additive model) models per BEIR VII Phase 2, with weights of 0.7 for ERR and 0.3 for EAR for most solid cancers, adjusted for leukemia (EAR only). Risks were transferred from the LSS cohort to the Iranian population using this hybrid approach. Latency periods were handled per BEIR VII

recommendations: 5 years for solid cancers and 2 years for leukemia. Attained age was projected up to 100 years, integrated over the patient's remaining lifespan using age-specific survival probabilities from Iranian life tables (2021). Organ doses from NCICT were mapped to BEIR VII cancer sites as follows: brain dose to brain cancer risk; salivary glands to salivary gland cancer risk; thyroid to thyroid cancer; red bone marrow to leukemia. The "other cancers" category aggregates risks for sites not explicitly modeled separately in BEIR VII, primarily brain, salivary glands, oral mucosa, and other head/neck tissues, based on equivalent doses to these regions. Risks were scaled to organ-equivalent doses from NCICT and adjusted for age and gender using Iranian life tables (2021). Uncertainty was quantified as previously described [12]. Uncertainty was quantified using the 95% confidence intervals provided in BEIR VII Phase 2, incorporating Monte Carlo simulation variance, dose conversion uncertainty from NCICT, and risk model uncertainty from the ERR/EAR transfer models.

2.4. Statistical Analysis

Data analysis was performed using IBM SPSS Statistics version 23. The normality of distribution for dosimetric and risk parameters was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. As the data were non-normal ($p < 0.05$), non-parametric tests (Mann-Whitney U for two-group comparisons, Kruskal-Wallis for multiple groups) were employed. For multiple comparisons (e.g., gender and age group differences), Bonferroni correction was applied to adjust the significance threshold ($p < 0.05$ / number of comparisons). Confidence intervals (95% CI) were calculated for all dose and risk metrics using non-parametric bootstrapping (1,000 iterations). Exponential regression ($LAR = a * e^{(-b * age)}$) was used to model the age-LAR relationship, with parameters estimated via non-linear least squares; goodness-of-fit was assessed by R^2. Statistical significance was defined as $p < 0.05$.

3. Results

3.1. Patient Characteristics and Dosimetry

The study population consisted of 429 patients with a balanced gender distribution (215 males, 214 females) and a mean age of 45 ± 17 years. The demographic distribution is detailed in Table 1.

The mean $CTDI_{vol}$ was 36.36 ± 17.17 mGy (95% CI 34.02–38.70), and the mean DLP was 542.44 ± 292.56 mGy·cm (95% CI 503.12–581.76). The 75th percentile values, proposed as national DRLs, were $CTDI_{vol}$ 48.31 mGy and DLP 752 mGy·cm (Table 2). These are comparable to European guidelines [13].

Table 1. Demographic Distribution of Study Population

Age Group (years)	Males (n)	Females (n)	Total (n)
15-25	38	32	70
25-35	38	38	76
35-45	27	25	52
45-55	23	31	54
55-65	33	35	68
65-75	33	25	58
75-85	23	28	51
Total	215	214	429

Table 2. Proposed Iranian Diagnostic Reference Levels (DRLs) for patients undergoing Head and Neck CT

Parameter	75th Percentile (Proposed DRL)	International Comparison (EU)
$CTDI_{vol}$ (mGy)	48.31	50–60 mGy
DLP (mGy·cm)	752	750–1000 mGy·cm

The mean effective dose calculated by NCICT was 1.23 ± 0.67 mSv (95% CI 1.14–1.32). A significant gender difference was observed, with females receiving a higher effective dose (1.32 ± 0.71 mSv, 95% CI 1.21–1.43) than males (1.14 ± 0.61 mSv, 95% CI 1.05–1.23; $p < 0.001$). In contrast, the conventional K × DLP method (K=0.0021) yielded an effective dose of 1.14 ± 0.61 mSv (95% CI 1.05–1.23), which was 7.3% lower than the NCICT estimate ($p < 0.001$), confirming the superiority of the patient-specific Monte Carlo approach. The large standard deviations in $CTDI_{vol}$ (17.17 mGy) and DLP (292.56 mGy·cm) reflect major protocol variability, attributable to differences in scanner models (16–128 detector rows), tube current modulation settings (150–350 mAs), and scan lengths across the nine centers, highlighting the need for standardized protocols. Inter-center variation was analyzed using Kruskal-Wallis tests. Significant differences were observed in $CTDI_{vol}$ ($p < 0.001$) and DLP ($p < 0.001$), with higher doses at centers using older scanners (e.g., 16-detector: mean $CTDI_{vol}$ 42.50 mGy, 95% CI 38.20–46.80) versus newer ones (128-

detector: 32.10 mGy, 95% CI 29.50–34.70). This variation underscores opportunities for optimization through national guidelines.

3.2. Organ Doses

Organ doses are presented in Figure 1. The highest doses were received by superficial and directly irradiated organs. The brain (22.36 mGy ± 10.45 mGy, 95% CI 20.85–23.87) and salivary glands (19.84 mGy ± 9.87 mGy, 95% CI 18.48–21.20). The lens received the highest mean equivalent dose of 25.90 ± 12.50 mGy (95% CI 23.90–27.90), highlighting the need for eye shielding or gantry tilt where possible. Thyroid doses showed a statistically significant gender difference ($p < 0.001$), with females receiving higher values, likely due to differences in neck anatomy and tissue distribution. Breast dose (0.89 ± 0.56 mGy overall; females only) was included per ICRP 103 weighting factors, though minimal due to scatter radiation; exclusion would reduce effective dose by <2%, not significantly altering comparisons. Scanner parameters (e.g., kVp, mAs) showed no systematic differences by sex ($p = 0.45$, Mann-Whitney U), as protocols were indication-based rather than sex-specific. Figure 3 Bar Chart of Mean Organ Doses (mGy) from Head and Neck CT Scans. Bars represent means for all patients (n=429), males (n=215), and females (n=214), with error bars indicating standard deviations. Organs include the brain, salivary glands, thyroid, red bone marrow, breast (females only), and lens. Significant difference noted for thyroid ($p < 0.001$) between males and females.

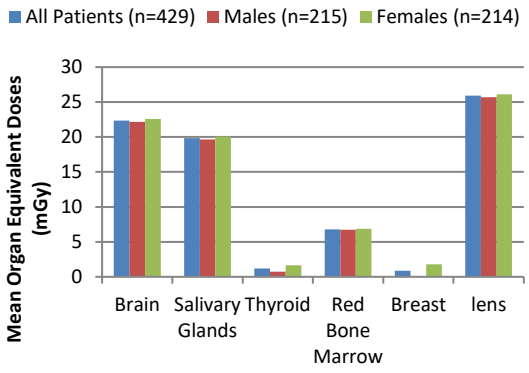

Figure 1. Mean organ doses (in mGy) from routine head and neck CT scans in 429 Iranian patients

3.3. Lifetime Attributable Risk (LAR)

The total LAR of cancer incidence was 181.82 per 100,000 exposed individuals (95% CI: 174.13–189.51). The LAR for cancer mortality was 94.57 per 100,000. As illustrated in Figure 2, the risk is overwhelmingly dominated by the "other cancers" category (mainly brain and salivary gland cancers), which contributed 178.13 per 100,000 (95% CI: 170.50–185.76) — approximately 98% of the total incidence risk. Thyroid cancer and leukemia each accounted for <1–2% of the total LAR, reflecting their lower organ doses and/or lower risk coefficients per unit dose in the BEIR VII framework. This distribution highlights that radiation protection efforts should primarily focus on minimizing doses to the brain and salivary glands.

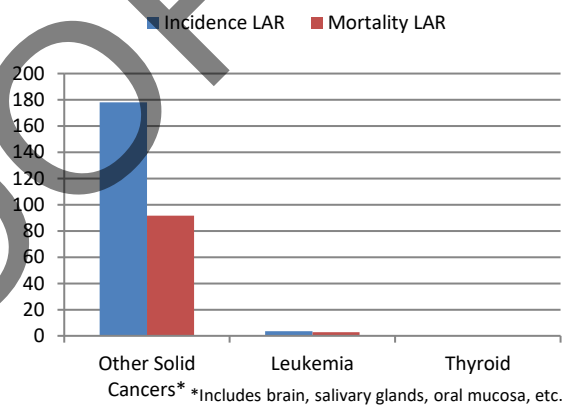

Figure 2. Breakdown of the lifetime attributable risk (LAR) of cancer incidence per 100,000 exposed individuals from a single head and neck CT scan, stratified by cancer category. The "other solid cancers" category (primarily brain, salivary glands, oral mucosa, and other head/neck tissues) accounts for approximately 98% of the total LAR (178.13 per 100,000; 95% CI: 170.50–185.76). Thyroid cancer and leukemia contribute only marginally. Values are based on BEIR VII models adjusted for Iranian life-tables (mean population estimate across all ages and genders, n=429)

Females showed a consistently higher LAR of cancer incidence than males across all age groups (Figure 3), with an overall mean difference of 15.5% ($p < 0.01$). This gender disparity is attributable to higher tissue weighting factors for the female breast (even from scatter), slightly higher organ doses in smaller body habitus, and gender-specific differences in baseline risk models per BEIR VII. The LAR decreased exponentially with increasing age at exposure, following the expected pattern due to

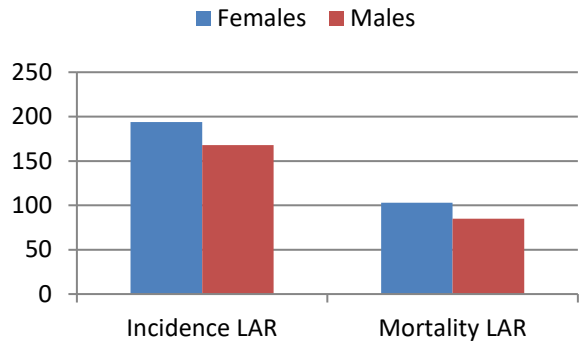

Figure 3. Lifetime attributable risk (LAR) of cancer incidence per 100,000 exposed individuals as a function of age at exposure and gender. Females consistently exhibited higher LAR values than males across all age groups (mean difference 15.5%, $p < 0.01$). The relationship follows an exponential decline with increasing age (fitted exponential model: $LAR = a \times e^{(-b \times age)}$, $R^2 = 0.93$). Data points represent mean values per age group; error bars indicate 95% confidence intervals derived from bootstrapping

shorter remaining lifespan and lower organ sensitivity in older individuals. The exponential fit ($LAR = a \times e^{(-b \times age)}$) yielded $R^2 = 0.93$, confirming a strong age dependence that is robust across the seven age groups analyzed.

4. Discussion

This is the first comprehensive Iranian study to use advanced Monte Carlo dosimetry (NCICT + SSDE) for cancer risk assessment in head and neck CT, a major methodological strength compared to earlier studies relying on simple conversion coefficients [7, 8].

Our approach aligns with prior Iranian efforts to establish local diagnostic reference levels (DRLs) for CT examinations, such as those proposed for brain scans in Mazandaran province, where mean $CTDI_w$ values of 42.16 mGy and DLP of 535.6 mGy·cm were reported across seven hospitals, with significant inter-hospital variations due to differences in mAs, scan length, and pitch; DRLs were set at 59.5 mGy for brain CT—values comparable to our proposed national benchmarks of 48.31 mGy for $CTDI_{vol}$ and 752 mGy·cm for DLP [14].

Our proposed DRLs ($CTDI_{vol}$ 48.31 mGy, DLP 752 mGy·cm) are consistent with recent European values [13] and can immediately serve as national benchmarks for dose optimization. The significant discrepancy (7.3%) between the effective dose calculated by the K × DLP method and the NCICT software underscores the importance of using patient-specific, phantom-based tools for accurate dosimetry, particularly in diverse populations [10, 15].

Furthermore, our proposed national DRLs for head and neck CT ($CTDI_{vol}$ 48.31 mGy, DLP 752 mGy·cm) are in close agreement with the recently established Iranian national DRLs by Sina et al. for head CT ($CTDI_{vol}$ 49 mGy, DLP 685 mGy·cm), derived from a comprehensive retrospective analysis of multiple domestic studies encompassing various imaging modalities. This consistency validates the representativeness of our multicentre findings and emphasizes the need for widespread adoption of these benchmarks to facilitate dose optimization, ALARA compliance, and mitigation of population-level radiation risks and Iran's high CT utilization rates [16].

The observed 15.5% higher cancer risk in females can be explained by several factors: a higher tissue weighting factor for breast tissue (even though it receives only a scatter dose) and a slightly smaller average body size leading to higher organ doses for identical scanner output as modeled in BEIR VII [3, 17].

This gender disparity is consistent with findings from Iranian digital radiography studies, including skull and cervical X-rays (effective doses 0.01–0.70 mSv), where females exhibited elevated Lifetime Attributable Risks (LAR) for thyroid and other head/neck-related cancers (e.g., 2.2 per million for cervical radiography vs. 1.2 per million for males), due to similar age- and sex-dependent risk modeling with thyroid and esophagus showing the highest organ-specific risks [18].

Although the individual risk is modest (~1 in 550), the extremely high utilization rate of head and neck CT in Iran (>5 million procedures annually) suggests that several thousand future radiation-induced cancers could occur—a significant public health concern. This aligns with global studies highlighting the population impact of frequent CT use [19]. The dominance of the "other cancers" category in the risk profile underscores the critical need for optimized protocols to protect the brain and salivary glands.

Our findings strongly support the need for strict adherence to the ALARA principle. Key recommended actions include the adoption of the proposed DRLs, mandatory use of automatic exposure control and iterative reconstruction, preferential use of alternative modalities (e.g., Magnetic Resonance Imaging (MRI)) when clinically feasible, and special protection considerations for younger patients and females.

5. Conclusion

This study has several limitations. The BEIR VII risk coefficients are derived from Japanese atomic-bomb survivors and U.S. populations, and differences in baseline cancer rates and lifestyle factors in Iran may introduce uncertainty. Future studies should develop Iran-specific risk models. Furthermore, the NCICT phantoms are based on Western anthropomorphic data, which might introduce a small systematic bias for the Middle-Eastern body habitus.

This study provides robust, nationally representative data on radiation doses and associated cancer risks from head and neck CT scans in Iranian patients. Despite relatively low individual risk, the extremely high utilization rate translates into a considerable population-level burden. Immediate implementation of the proposed DRLs, alongside widespread adoption of dose-reduction technologies and justified imaging practices, is crucial to substantially reduce future radiation-induced cancer while maintaining high diagnostic quality.

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