# Doses Delivered to Patients and Associated Risks from Conventional Radiological Scans in Yasuj City, Iran

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**ABSTRACT**

**BACKGROUND**

The vital role of ionizing radiation in the diagnosis and treatment is generally accepted. Increasing use of ionizing radiations requires further attention to the biological effects of radiations, including types of cancers, and genetic mutations affecting later generations. In this regard, it is of paramount importance to degrade the population collective dose. This matter can be achieved by addressing the risks of exposures from varying types of examinations so as to alert physicians, radio technologists, and even patients. The present study was aimed at estimating the risks connected with population exposure to conventional radiographical equipment in Yasuj city.

**METHODS**

A total of 17 radiological rooms in Yasuj city, Iran, were included in this cross-sectional study. At each institution, the technologists were asked to fill out a questionnaire concerning the user-set acquisition parameters for the five most common procedures, and then, by setting the acquisition parameters, the measurement of incident air kerma was performed by a Barracuda package and multi-purpose detector. The PCXMC 2.0 software was used to estimate the organ doses, effective dose, and projected cancer risks for each.

**RESULTS**

The uppermost incident air kerma was measured at lumbar spine scan, and the highest effective dose of 0.55 ± 0.23 mSv was documented for pelvis radiography. However, for both 20-year-old males and females, the maximum risk of exposure-induced death was attributed to a scan of thoracic spine. In comparison with other studies, the estimated effective doses in this study were significantly lower in all the procedures except for PA chest examination.

**CONCLUSIONS**

Although no tissue reaction is expected as a consequence of conventional radiography, stochastic effects are at a significant level. One of the major approaches to reduce the population collective dose is linked to the public knowledge about radiation hazards. This could be improved by the establishment and spread of exposure-induced risks that are more understandable to the public than either organ doses or the effective dose.

**KEY WORDS**

Dosimetry, Radiography, Risk Assessment

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## BACKGROUND

Since the introduction of X-ray to the medical community, it has been vastly implemented for the diagnosis as well as therapeutic purposes. Nowadays, X-ray has become an inevitable part of modern medicine, so that it forms the highest portion of man-made population exposure.[1] Several factors contribute to patient dose from radiological examinations, including but not limited to the imaging modality, type of examination, technologists' expertness, and patient size.[2] Considerable efforts have been made to measure, record, and publish doses received by patients undergoing radiological examinations,[3-6] however, there exists insufficient data concerning the risks projected to the patients.

Although the main aim of radiography is to acquire radiographs from the region of interest with adequate image quality to diagnose the patients, protecting them against the harmful effects of ionizing radiation also remains an area of interest.[7] As declared by several reports, diagnostic imaging contributes significantly to the population exposure from man-made sources,[8-12] as an instance, it accounts for roughly 90 % of United States population collective dose from artificial sources.[13] As claimed by National Council on Radiation Protection and Measurements (NCRP) in report No. 160,[14] medical exposures contribute to approximately half of the US exposure to radiation.

However, no immediate effects are expected to occur on the exposed individual for doses below 100 mSv; they can bear negative consequences such as cancer development and hereditary abnormalities only in the long run.[15,16] The Committee on Biological Effects of Ionizing Radiation (BEIR) in publication VII[17] has by an emphasis on recent researches recommended the relationship between low doses of ionizing radiation and induced cancer risks is consistent with the linear no-threshold (LNT) model. In addition to the controversies in this context, the LNT model is the most acknowledged theory for dose-response relationship by international organizations worldwide.[17-19] Presented by International Commission on Radiological Protection (ICRP), effective dose is a metric that combines both the radiation type and organ sensitivity to give an overall measure of the biological effects arising from exposure to ionization radiation.[20-23]

Although effective dose provides an indicator to compare patients' exposure to ionizing radiation between modalities, it cannot be implemented as a patient-specific risk assessment. Therefore, many researchers have suggested using an alternative metric, such as Risk of Exposure-Induced Cancer Death (REID %).[24-28] The REID is a measure that estimates the risk of death from radiation-induced solid cancer. In addition, the REID shows radiation dose in a concept that is more appreciable to physicians and even patients since it gives a more realistic measured view of the negative aspect of radiological scans.

Much as the REID is a better estimate of patient risk due to exposure, it fails to consider the age at which the patient would develop and die from cancer, and hence cannot be used as an adequate metric to address the population risk. Hence, loss of life expectancy (LLE) was introduced to address this issue. LLE is the difference between the life expectancy of an unexposed and exposed individual at a certain age, assuming that both will survive up to the given age. Although the REID and LLE summarize the hazards of radiation on the population, they do not provide any estimation of detriment among the radiation-induced cancer-developed subjects. Hence, to address the issue, loss of life expectancy among exposure-induced deaths (LLE-REID) was proposed by the researchers.[29]

### Objectives

The impetus for this study was triggered by the fact that the awareness of radio technologists, physicians, and even patients from doses and risks from radiological scans can be regarded as an initiative to further reduce the population exposure.[30,31] Hence, by collecting the data out of the most common radiographical examinations in Yasuj, we have estimated the effective dose delivered to patients and put them in a more tangible form, i.e., the risk metrics, including REID, LLE, as well as LLE-REID were calculated from the data.

## METHODS

### Data Collection

The study used a cross-sectional research design. The present study was conducted by collecting data from all the 17 active radio graphical units in Yasuj city of Iran, including 2 computed radiography (CR), 9 direct digital radiography (DDR), and 6 analog systems. Five radiological procedures were included, i.e., skull (Anteroposterior [AP], Lateral [LAT]), chest (Poster anterior [PA], LAT), thoracic spine (AP, LAT), lumbar spine (AP, LAT), and pelvis (AP).

Specifications of the radiographic systems such as inherent and added filtration, as well as anode angle, were abstracted for each unit. At each institution, the operators were asked to fill in a questionnaire concerning the exposure conditions and acquisition parameters,[32] including kVp, mAs, and focus-surface distance (FSD) for a standard-sized adult patient (e.g., Age ≥ 18 years old; weight = 73.2 kg; height = 178.6 cm (33)) pertinent to the five included procedures. For each setting, incident air kerma (IAK) was measured by a calibrated Barracuda package and a multi-purpose detector (MPD) (RTI Electronics, Sweden) according to the standard dosimetry protocol published by International Atomic Energy Agency (IAEA) at Technical Report Series No. 457.[33] In order to reduce stochastic tolerances, three measurements were made at each exposure condition.

### Estimation of Organ Doses and Effective Dose

With the aim of patient dose estimation, a Monte Carlo simulation of photon transports was performed for all exposure conditions by PCXMC (v. 2, STUK, Helsinki, Finland). PCXMC is a user-friendly software that tracks the particle transportations through a modified hermaphrodite phantom and records the energy delivered locally to the phantom to estimate the absorbed doses.[34] The simulations were performed by tracking a million primaries generated by the input x-ray spectra, and accordingly, 29 organ doses and effective dose were calculated.

### Risk Assessment

The Committee on the Biological Effects of Ionizing Radiation (BEIR) has developed a most recent risk model for radiation-

induced carcinogenesis. The excess absolute and relative models retrieved from BEIR VII combined with the cancer statistics for the Asian population published by ICRP report 103 were implemented by PCXMC to estimate the lifetime risk of fatal cancer incidence caused by the patient exposure. Hence, the age- and sex-specific risk of exposure-induced death, loss of life expectancy as well as LLE-REID were calculated assuming that the doses having been received by the 20-, 40-, and 60-year old patients. Moreover, the number of patients undergoing radio graphical scans that would result in one excess cancer death was estimated.

### Statistical Analysis

The descriptive statistics parameters were analysed by Excel (version 2016, Microsoft Corporation, US). In order to assess whether differences between genders could be considered as substantially significant, independent samples t-test was performed. The normality of data distribution was assessed by using Shapiro–Wilk test; for non-normal distributions, a logarithmic transform was performed. For these purposes, SPSS (version 16, SPSS Inc., Chicago, IL) was implemented, and the probability value (p-Value) lower than 0.05 was considered significant.

## RESULTS

A total of 139 various acquisition protocols were abstracted for the five radio graphical examinations from all the 17 active radiology units in Yasuj city; manufactured by Toshiba (120,300,0.9); Apelem (150,500,1.5); Toshiba (80,250,NA); Mehran Teb (150,500,1.5); Philips (80,300,0.3); DK (125,320,0.9); Varian (125,320,1.5); Mehran Teb (150,500,2.5); Comed (150,500,2.1); Dr Gem (150,500,2.1); GE (125,350,1.2); Toshiba (135,400,1.5); Mehran Teb (150,500,2.5); Toshiba (130,320,1.5); Varian (125,320,1.5); GE (120,300,1.5); GE (125,320,9). The values in parentheses were kVp Max, mA Max and total filtration (mmAl), respectively.

### Acquisition Parameters and Measurements

Table 1: Summarizes the operator-set exposure parameters, including kVp and mAs, averaged over all the institutions. On average, peak kilo voltage (kVp) was identified to be the highest and lowest at spine and skull examinations, respectively (respectively, 71 ± 7, 69 ± 7, and 62 ± 2 kV for a scan of lumbar spine, thoracic spine, and skull). The highest mAs value was also recorded for both the lumbar and thoracic spine examinations (respectively, 35 ± 14 and 34 ± 15 mAs). Hence, as it was expected, the measurements also demonstrated the highest incident air kerma (IAK) to be related to spine scans (6.66 ± 2.70 and 5.32 ± 1.82 for lumbar spine and thoracic spine examinations, respectively).

### Estimated Organ and Effective Doses

Table 2: Illustrates the effective doses from each procedure. As it was expected, the lowest effective dose was estimated for a skull scan (0.02 ± 0.01 mSv), and the highest effective dose was evaluated for a pelvis scan (0.55 ± 0.23 mSv).

| Procedure | Projection | FSD (cm) | kVp | mAs | IAK (mGy) |
|---|---|---|---|---|---|
| Chest | Overall | 131 ± 20 (90,169) | 66 ± 9 (57,90) | 25 ± 10 (13,42) | 0.82 ± 0.60 (0.21,2.30) |
| | LAT | 127 ± 19 (90,146) | 70 ± 9 (60,90) | 31 ± 9 (20,42) | 1.31 ± 0.54 (0.70,2.30) |
| | PA | 135 ± 20 (120,169) | 63 ± 7 (57,77) | 20 ± 7 (13,35) | 0.38 ± 0.14 (0.21,0.75) |
| Lumbar Spine | Overall | 80 ± 5 (71,88) | 71 ± 7 (60,85) | 35 ± 14 (16,64) | 6.66 ± 2.70 (3.33,14.00) |
| | AP | 78 ± 5 (71,85) | 71 ± 8 (60,85) | 24 ± 5 (16,31) | 5.03 ± 1.68 (3.33,8.01) |
| | LAT | 81 ± 4 (75,88) | 72 ± 5 (65,83) | 46 ± 12 (30,64) | 8.29 ± 2.57 (4.07,14.00) |
| Thoracic Spine | Overall | 84 ± 4 (78,89) | 69 ± 7 (60,85) | 34 ± 15 (15,60) | 5.32 ± 1.82 (2.39,9.90) |
| | AP | 85 ± 3 (80,89) | 71 ± 8 (61,85) | 21 ± 5 (15,29) | 4.15 ± 1.12 (2.39,6.30) |
| | LAT | 83 ± 3 (78,89) | 67 ± 5 (60,77) | 46 ± 10 (30,60) | 6.49 ± 1.64 (3.78,9.90) |
| Pelvis | AP | 74 ± 3 (68,79) | 68 ± 6 (58,78) | 24 ± 6 (16,31) | 4.41 ± 1.25 (2.03,6.60) |
| Skull | Overall | 84 ± 3 (81,89) | 62 ± 2 (59,68) | 20 ± 5 (12,33) | 2.10 ± 0.64 (1.00,3.30) |
| | AP | 85 ± 2 (81,89) | 62 ± 2 (59,67) | 20 ± 6 (12,32) | 2.23 ± 0.64 (1.10,3.30) |
| | LAT | 83 ± 2 (81,88) | 63 ± 2 (60,68) | 20 ± 5 (13,33) | 1.97 ± 0.64 (1.00,3.30) |

***Table 1. Mean ± Standard Deviation and Absolute Range (in Parenthesis) of Acquisition Parameters and Incident Air Kerma (IAK) for Five Radiological Examinations Related to All the 17 Institutions***

| Procedure | Projection | 20 Male | 40 Male | 60 Male | 20 Female | 40 Female | 60 Female |
|---|---|---|---|---|---|---|---|
| Chest | Overall | 4 ± 3 | 3 ± 2 | 2 ± 2 | 9 ± 8 | 5 ± 5 | 4 ± 3 |
| | LAT | 6 ± 4 | 4 ± 3 | 3 ± 3 | 14 ± 9 | 8 ± 5 | 6 ± 4 |
| | PA | 2 ± 1 | 2 ± 1 | 1 ± 1 | 4 ± 2 | 3 ± 1 | 2 ± 1 |
| Lumbar Spine | Overall | 20 ± 11 | 14 ± 7 | 12 ± 6 | 21 ± 10 | 14 ± 7 | 12 ± 6 |
| | AP | 25 ± 12 | 17 ± 8 | 15 ± 7 | 24 ± 12 | 17 ± 8 | 14 ± 7 |
| | LAT | 15 ± 7 | 10 ± 5 | 9 ± 4 | 17 ± 8 | 12 ± 5 | 9 ± 4 |
| Thoracic Spine | Overall | 22 ± 9 | 15 ± 6 | 12 ± 5 | 35 ± 15 | 22 ± 10 | 18 ± 8 |
| | AP | 21 ± 10 | 14 ± 6 | 11 ± 5 | 32 ± 15 | 19 ± 9 | 15 ± 7 |
| | LAT | 23 ± 9 | 15 ± 6 | 13 ± 5 | 39 ± 15 | 25 ± 10 | 21 ± 8 |
| Pelvis | AP | 26 ± 11 | 18 ± 7 | 15 ± 6 | 19 ± 8 | 13 ± 6 | 11 ± 5 |
| Skull | Overall | 1 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 |
| | AP | 1 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 |
| | LAT | 1 ± 0 | 1 ± 0 | 0 ± 0 | 1 ± 0 | 1 ± 0 | 1 ± 0 |
| **Overall** | | 13 ± 13 | 9 ± 9 | 8 ± 7 | 17 ± 16 | 11 ± 10 | 9 ± 8 |

***Table 3. Mean ± Standard Deviation of Excess Radiation-Induced Death in Million Exposed Individuals in Terms of the Procedure, Age at Exposure, and Gender***

| Procedure | Projection | 20 Male | 40 Male | 60 Male | 20 Female | 40 Female | 60 Female |
|---|---|---|---|---|---|---|---|
| Chest | Overall | 24.5 ± 0.9 | 22.6 ± 0.7 | 15.9 ± 0.4 | 24.6 ± 3.1 | 25.2 ± 1.4 | 18.0 ± 0.5 |
| | LAT | 23.6 ± 0.1 | 21.8 ± 0.0 | 15.5 ± 0.0 | 21.3 ± 0.5 | 23.7 ±0.2 | 17.5 ± 0.0 |
| | PA | 25.3 ± 0.0 | 23.2 ± 0.0 | 16.3 ± 0.0 | 27.4 ± 0.2 | 26.5 ± 0.1 | 18.4 ± 0.0 |
| Lumbar Spine | Overall | 21.6 ± 0.1 | 19.4 ± 0.1 | 13.5 ± 0.3 | 24.7 ± 0.8 | 21.8 ± 0.5 | 15.5 ± 0.3 |
| | AP | 21.6 ± 0.1 | 19.5 ± 0.1 | 13.3 ± 0.1 | 23.9 ± 0.1 | 21.3 ± 0.1 | 15.3 ± 0.1 |
| | LAT | 21.6 ± 0.0 | 19.4 ± 0.1 | 13.8 ± 0.0 | 25.5 ± 0.0 | 22.2 ± 0.0 | 15.8 ± 0.0 |
| Thoracic Spine | Overall | 24.2 ± 0.7 | 21.9 ± 0.3 | 15.2 ± 0.4 | 25.9 ± 1.4 | 24.9 ± 0.5 | 17.5 ± 0.2 |
| | AP | 24.8 ± 0.4 | 22.0 ± 0.4 | 14.8 ± 0.3 | 25.5 ± 2.0 | 24.5 ± 0.4 | 17.3 ± 0.0 |
| | LAT | 23.5 ± 0.0 | 21.8 ± 0.0 | 15.6 ± 0.0 | 26.3 ± 0.1 | 25.3 ± 0.0 | 17.7 ± 0.0 |
| Pelvis | AP | 22.5 ± 0.1 | 19.7 ± 0.0 | 13.4 ± 0.0 | 24.1 ± 0.1 | 21.3 ± 0.1 | 15.4 ± 0.0 |
| Skull | Overall | 26.2 ± 0.0 | 20.7 ± 0.0 | 13.9 ± 0.1 | 32.9 ± 0.1 | 25.8 ± 0.0 | 17.2 ± 0.0 |
| | AP | 26.2 ± 0.0 | 20.7 ± 0.0 | 13.8 ± 0.0 | 32.8 ± 0.0 | 25.8 ± 0.0 | 17.2 ± 0.0 |
| | LAT | 26.2 ± 0.0 | 20.6 ± 0.0 | 13.9 ± 0.0 | 32.9 ± 0.0 | 25.8 ± 0.0 | 17.2 ± 0.0 |
| **Overall** | | 23.9 ± 1.7 | 21.0 ± 1.3 | 14.5 ± 1.1 | 26.6 ± 3.7 | 24.1 ± 1.9 | 16.9 ± 1.1 |

***Table 4. Mean ± Standard Deviation of Life Loss in Radiation-Induced Cancer-Developed Individuals in Years in Terms of the Procedure, Age at Exposure, and Gender***

Table 2 also reveals the mean organ doses by the type of procedure. On average, testicles absorbed the highest dose (3.83 ± 1.41 mGy) in a pelvis scan followed by 2.51 ± 1.16 mGy delivered to the thymus in an AP thoracic spine scan. The mean dose in the total body per procedure was as follows in descending order: 0.54 mGy for AP pelvis, 0.47 mGy for LAT lumbar spine, 0.34 mGy for LAT thoracic spine, 0.30 mGy for AP lumbar spine, 0.23 mGy for AP thoracic spine, 0.09 mGy for LAT chest, 0.05 mGy for AP skull, 0.04 mGy for LAT skull, and 0.04 mGy for PA chest.

| Procedure | Projection | Effective Dose | Red Bone Marrow | Adrenal | Brain | Breast | Colon | Extrathoracic Airways | Gall Bladder | Heart | Kidney | Liver | Lungs | Lymphatic Nodes | Muscle | Oesophagus | Oral Mucosa |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chest | Overall | 0.08 ± 0.08 | 0.06 ± 0.04 | 0.10 ± 0.06 | 0.00 ± 0.00 | 0.19 ± 0.24 | 0.00 ± 0.00 | 0.03 ± 0.04 | 0.02 ± 0.01 | 0.09 ± 0.11 | 0.10 ± 0.06 | 0.03 ± 0.03 | 0.16 ± 0.12 | 0.05 ± 0.05 | 0.05 ± 0.04 | 0.07 ± 0.07 | 0.00 ± 0.00 |
| | LAT | 0.14 ± 0.09 | 0.08 ± 0.06 | 0.07 ± 0.06 | 0.00 ± 0.00 | 0.38 ± 0.22 | 0.01 ± 0.01 | 0.07 ± 0.05 | 0.02 ± 0.02 | 0.16 ± 0.12 | 0.08 ± 0.06 | 0.02 ± 0.02 | 0.22 ± 0.16 | 0.09 ± 0.06 | 0.07 ± 0.05 | 0.10 ± 0.09 | 0.01 ± 0.01 |
| | PA | 0.04 ± 0.02 | 0.05 ± 0.02 | 0.12 ± 0.06 | 0.00 ± 0.00 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.01 ± 0.00 | 0.02 ± 0.01 | 0.03 ± 0.02 | 0.12 ± 0.05 | 0.05 ± 0.02 | 0.11 ± 0.05 | 0.02 ± 0.01 | 0.03 ± 0.01 | 0.04 ± 0.02 | 0.00 ± 0.00 |
| Lumbar Spine | Overall | 0.37 ± 0.19 | 0.17 ± 0.10 | 0.19 ± 0.10 | 0.00 ± 0.00 | 0.02 ± 0.01 | 0.61 ± 0.35 | 0.00 ± 0.00 | 0.76 ± 0.84 | 0.09 ± 0.05 | 0.33 ± 0.23 | 0.35 ± 0.37 | 0.05 ± 0.03 | 0.38 ± 0.25 | 0.38 ± 0.17 | 0.12 ± 0.08 | 0.00 ± 0.00 |
| | AP | 0.44 ± 0.21 | 0.11 ± 0.06 | 0.19 ± 0.11 | 0.00 ± 0.00 | 0.02 ± 0.01 | 0.78 ± 0.39 | 0.00 ± 0.00 | 1.43 ± 0.69 | 0.10 ± 0.05 | 0.17 ± 0.10 | 0.65 ± 0.30 | 0.04 ± 0.02 | 0.53 ± 0.26 | 0.32 ± 0.14 | 0.17 ± 0.09 | 0.00 ± 0.00 |
| | LAT | 0.30 ± 0.14 | 0.23 ± 0.10 | 0.19 ± 0.09 | 0.00 ± 0.00 | 0.02 ± 0.01 | 0.43 ± 0.21 | 0.00 ± 0.00 | 0.09 ± 0.05 | 0.08 ± 0.04 | 0.48 ± 0.21 | 0.04 ± 0.02 | 0.06 ± 0.03 | 0.23 ± 0.11 | 0.44 ± 0.18 | 0.08 ± 0.04 | 0.00 ± 0.00 |
| Thoracic Spine | Overall | 0.38 ± 0.15 | 0.25 ± 0.11 | 0.21 ±0.11 | 0.03 ± 0.14 | 0.36 ± 0.18 | 0.02 ± 0.01 | 0.34 ± 0.16 | 0.31 ± 0.32 | 0.97 ± 0.64 | 0.19 ± 0.13 | 0.29 ± 0.31 | 0.66 ± 0.36 | 0.37 ± 0.15 | 0.24 ± 0.11 | 0.38 ± 0.19 | 0.09 ± 0.36 |
| | AP | 0.38 ± 0.17 | 0.19 ± 0.07 | 0.18 ± 0.10 | 0.05 ± 0.20 | 0.45 ± 0.20 | 0.02 ± 0.01 | 0.39 ± 0.20 | 0.55 ± 0.28 | 1.38 ± 0.67 | 0.09 ± 0.06 | 0.53 ± 0.26 | 0.44 ± 0.22 | 0.41 ± 0.16 | 0.19 ± 0.08 | 0.36 ± 0.20 | 0.15 ± 0.51 |
| | LAT | 0.39 ± 0.15 | 0.30 ± 0.11 | 0.24 ± 0.11 | 0.00 ± 0.00 | 0.26 ± 0.10 | 0.02 ± 0.01 | 0.29 ± 0.10 | 0.06 ± 0.03 | 0.57 ± 0.24 | 0.28 ± 0.12 | 0.05 ± 0.03 | 0.88 ± 0.33 | 0.33 ± 0.13 | 0.30 ± 0.10 | 0.39 ± 0.17 | 0.02 ± 0.01 |
| Pelvis | AP | 0.55 ± 0.23 | 0.15 ± 0.07 | 0.03 ± 0.02 | 0.00 ± 0.00 | 0.01 ± 0.00 | 1.11 ± 0.49 | 0.00 ± 0.00 | 0.88 ± 0.39 | 0.01 ± 0.00 | 0.12 ± 0.06 | 0.29 ± 0.13 | 0.01 ± 0.00 | 0.44 ± 0.19 | 0.59 ± 0.23 | 0.01 ± 0.01 | 0.00 ± 0.00 |
| Skull | Overall | 0.02 ± 0.01 | 0.04 ± 0.01 | 0.00 ± 0.00 | 0.25 ± 0.10 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.23 ± 0.10 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.08 ± 0.03 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.49 ± 0.24 |
| | AP | 0.03 ± 0.01 | 0.04 ± 0.01 | 0.00 ± 0.00 | 0.22 ± 0.08 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.28 ± 0.10 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.08 ± 0.03 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.65 ± 0.22 |
| | LAT | 0.02 ± 0.01 | 0.04 ± 0.01 | 0.00 ± 0.00 | 0.29 ± 0.11 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.17 ± 0.07 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.08 ± 0.03 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.33 ± 0.12 |
| Overall | | 0.25 ± 0.24 | 0.13 ± 0.11 | 0.11 ± 0.11 | 0.06 ± 0.13 | 0.13 ± 0.20 | 0.27 ± 0.46 | 0.13 ± 0.17 | 0.34 ± 0.56 | 0.25 ± 0.49 | 0.15 ± 0.17 | 0.18 ± 0.27 | 0.19 ± 0.31 | 0.24 ± 0.22 | 0.22 ± 0.23 | 0.13 ± 0.17 | 0.13 ± 0.28 |

*Table 2. Mean ± Standard Deviation of Effective Dose in mSv and Organ Doses in mGy in Terms of the Type of Procedure*

| Procedure | Projection | Ovaries | Pancreas | Prostate | Salivary Glands | Skeleton | Skin | Small Intestine | Spleen | Stomach | Testicle | Thymus | Thyroid | Urinary Bladder | Uterus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chest | Overall | 0.00 ± 0.00 | 0.10 ± 0.11 | 0.00 ± 0.00 | 0.01 ± 0.01 | 0.14 ± 0.08 | 0.10 ± 0.06 | 0.00 ± 0.00 | 0.27 ± 0.27 | 0.12 ± 0.16 | 0.00 ± 0.00 | 0.04 ± 0.05 | 0.12 ± 0.16 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | LAT | 0.00 ± 0.00 | 0.16 ± 0.13 | 0.00 ± 0.00 | 0.01 ± 0.01 | 0.16 ± 0.10 | 0.14 ± 0.07 | 0.01 ± 0.01 | 0.44 ± 0.31 | 0.23 ± 0.17 | 0.00 ± 0.00 | 0.07 ± 0.06 | 0.24 ± 0.16 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | PA | 0.00 ± 0.00 | 0.04 ± 0.02 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.12 ± 0.05 | 0.06 ± 0.02 | 0.00 ± 0.00 | 0.11 ± 0.05 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.01 ± 0.01 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Lumbar Spine | Overall | 0.51 ± 0.36 | 0.50 ± 0.27 | 0.71 ± 0.70 | 0.00 ± 0.00 | 0.50 ± 0.43 | 0.50 ± 0.27 | 0.66 ± 0.47 | 0.83 ± 0.86 | 1.02 ± 0.46 | 0.20 ± 0.12 | 0.01 ± 0.00 | 0.00 ± 0.00 | 1.19 ± 1.18 | 0.68 ± 0.65 |
| | AP | 0.73 ± 0.38 | 0.58 ± 0.30 | 1.25 ± 0.60 | 0.00 ± 0.00 | 0.15 ± 0.07 | 0.29 ± 0.11 | 0.96 ± 0.48 | 0.12 ± 0.07 | 0.97 ± 0.46 | 0.26 ± 0.13 | 0.01 ± 0.00 | 0.00 ± 0.00 | 2.14 ± 0.97 | 1.17 ± 0.59 |
| | LAT | 0.28 ± 0.14 | 0.41 ± 0.20 | 0.16 ± 0.08 | 0.00 ± 0.00 | 0.85 ± 0.33 | 0.70 ± 0.23 | 0.36 ± 0.17 | 1.54 ± 0.67 | 1.07 ± 0.47 | 0.15 ± 0.07 | 0.01 ± 0.00 | 0.00 ± 0.00 | 0.23 ± 0.12 | 0.20 ± 0.10 |
| Thoracic Spine | Overall | 0.00 ± 0.00 | 0.54 ± 0.26 | 0.00 ± 0.00 | 0.09 ± 0.26 | 0.49 ± 0.21 | 0.32 ± 0.11 | 0.02 ± 0.01 | 0.97 ± 1.02 | 0.74 ± 0.36 | 0.00 ± 0.00 | 1.37 ± 1.41 | 1.25 ± 0.76 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | AP | 0.00 ± 0.00 | 0.45 ± 0.24 | 0.00 ± 0.00 | 0.13 ± 0.36 | 0.37 ± 0.13 | 0.26 ± 0.07 | 0.02 ± 0.01 | 0.09 ± 0.05 | 0.58 ± 0.29 | 0.00 ± 0.00 | 2.51 ± 1.16 | 1.76 ± 0.75 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | LAT | 0.00 ± 0.00 | 0.63 ± 0.26 | 0.00 ± 0.00 | 0.05 ± 0.02 | 0.62 ± 0.21 | 0.38 ± 0.11 | 0.02 ± 0.01 | 1.85 ± 0.69 | 0.90 ± 0.35 | 0.00 ± 0.00 | 0.24 ± 0.11 | 0.73 ± 0.25 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Pelvis | AP | 0.77 ± 0.37 | 0.09 ± 0.05 | 1.34 ± 0.60 | 0.00 ± 0.00 | 0.39 ± 0.18 | 0.76 ± 0.24 | 1.01 ± 0.45 | 0.10 ± 0.05 | 0.54 ± 0.23 | 3.83 ± 1.41 | 0.00 ± 0.00 | 0.00 ± 0.00 | 2.04 ± 0.84 | 1.06 ± 0.48 |
| | Skull | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.54 ± 0.21 | 0.19 ± 0.07 | 0.08 ± 0.03 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.04 ± 0.02 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Skull | AP | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.45 ± 0.16 | 0.20 ± 0.07 | 0.09 ± 0.03 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.04 ± 0.02 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | LAT | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.64 ± 0.22 | 0.18 ± 0.07 | 0.07 ± 0.02 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.03 ± 0.01 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| **Overall** | | 0.20 ± 0.36 | 0.26 ± 0.29 | 0.32 ± 0.61 | 0.14 ± 0.26 | 0.33 ± 0.28 | 0.31 ± 0.28 | 0.27 ± 0.46 | 0.46 ± 0.74 | 0.47 ± 0.49 | 0.51 ± 1.34 | 0.31 ± 0.86 | 0.31 ± 0.61 | 0.51 ± 0.97 | 0.28 ± 0.53 |

*Table 2. Mean ± Standard Deviation of Effective Dose in mSv and Organ Doses in mGy in Terms of the Type of Procedure (Continued)*

**Risk of Exposure-Induced Death**

Table 3: Shows the risk of exposure-induced death on a million of 20-, 40-, and 60-year-old exposed individuals for both sexes. On the whole, the projected risks to the women were significantly higher compared to those of men (all the p-values were below 0.0005). Moreover, the risks revealed a descending relationship with the patient's age; the highest risk would thus be expected for the younger females. As demonstrated in Table 3, the scan of thoracic spine showed the uppermost risk (35 excess death per million 20-year-old women), followed by lumbar spine procedure (21 excess death per million 20-year-old women). (Figure 1).

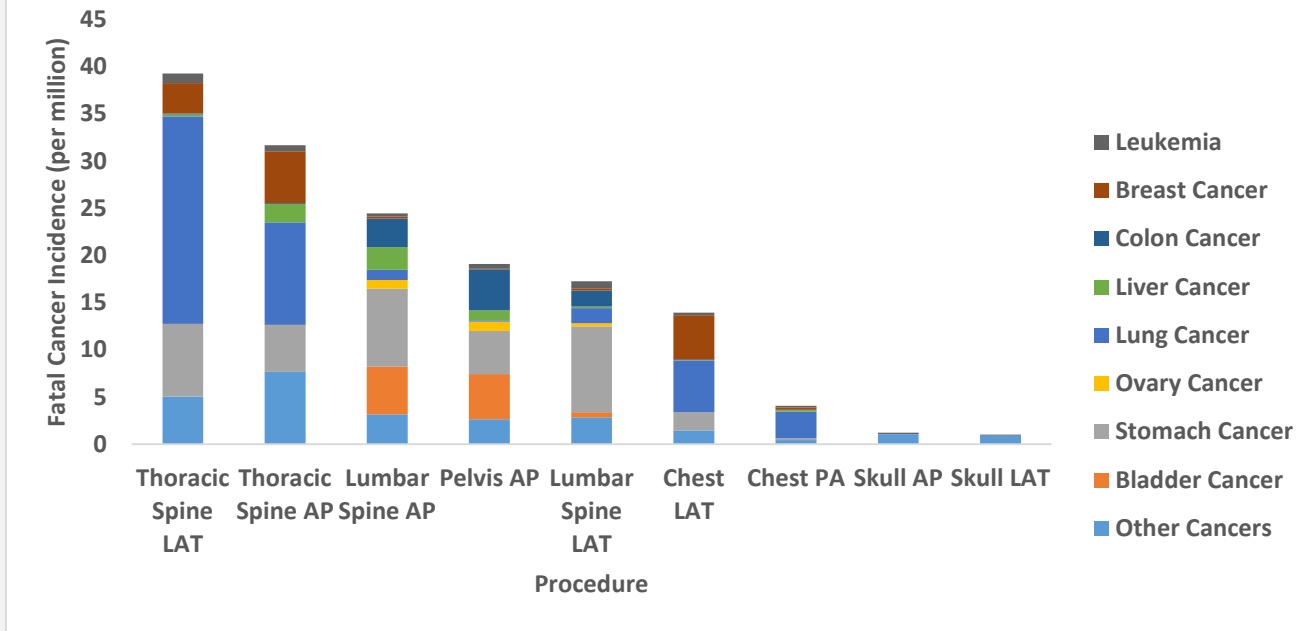


***Figure 1. Site-Specific Excess Fatal Cancer Incidence (per Million) by the Type of Examination for a 20-Year-Old Female***

Generally, the major part of excess risk due to exposure is linked to the cancer of lung, stomach, as well as the breast By categorizing the scans in regard with the scanned anatomical area, women turned out to suffer from a significantly higher risk in the chest and thoracic spine examinations than men; In contrast, men showed meaningfully to be more radiosensitive concerning a pelvis scan. For instance, when a scan of thoracic spine was performed on a 20-year-old female, it would induce roughly 60 % higher risk to the patient compared to a male by assuming both being exposed to the same conditions. However, by increasing the patient age, this discrepancy declined (50 % difference for 60-year-old patients.

The average loss of life expectancy in individuals who developed radiation-related cancer is given in Table 4. As reflected, the highest LLE-REID is related to a 20-year-old female having undergone a LAT skull scan (32.9 ± 0.0 years). In other words, assuming that a radiation-induced fatal cancer impacts a 20-year-old woman by a LAT skull scan, one would expect the patient age to be about 33 years less than the unexposed subject. This metric is highly dependent on age. For instance, The LLE-REID of a skull examination would roughly be degraded to one half when the patient's age increases from 20- to 60-year-old.

## DISCUSSION

In this study, the focus was on the risks associated with radiographical scans. Accordingly, the dose delivered to patients from the five most common procedures was estimated with regard to the risk models published by BEIR VII; the risk metrics, including REID, LLE, and LLE-REID, were estimated.

Comparing the measured incident air kerma with those published by Sonawane et al. for India,[26] most of the procedures have proven no substantial differences. For LAT lumbar spine scan, AP skull scan, and LAT skull scan, 18 %, 42 %, and 33 % lower doses respectively were documented in our study, whereas LAT thoracic spine scan showed 24 % higher. IAK in comparison with Son wane study. The lower doses can be attributed to the fact that the operators in Yasuj set approximately 2 to 3 times lower mAs than Indian radio technologists, even in the case of LAT thoracic spine scan. Interestingly, a substantial lower kVp for the lateral projection of thoracic spine examination was also documented in our study. Since Sonawane et al. have not explained other contributing parameters such as FSD, total filtration, etc., we also failed to explain why a higher IAK was documented for LAT thoracic spine scan in our research.

Except for the PA chest scan, the rest of the radiological procedures have substantially shown a lower effective dose comparing to typically reported extents.[10] In regard to the scan of skull, an average effective dose of 0.1 mSv has been reported by the investigators, whereas in this study, we have documented a 5-fold lower dose. This contradiction was followed by 75 %, 62 %, 20 %, and 8 % lower effective dose for a scan of lumbar-spine, thoracic spine, chest, and pelvis, respectively. Concerning the PA chest procedure, a doubled effective dose was estimated in our study.[10] Note that the documented doses were substantially far below 100; the threshold acknowledged by ICRP 103 as well as BEIR VII in which lower doses not almost always inducing deterministic effects.

As to the discrepancies in patient dose versus similar investigations, several contributing factors could be claimed. The first and foremost reason was connected with the different set exposure conditions. For instance, the results by Osei et al.[35] revealed that the technologists set approximately

four times higher mAs in Yasuj, and subsequently, a 4-fold higher dose is expected. A second factor arises from the differences in approaches as well as different tissue weighting factors implemented for patient dose estimation. In light of the results, the outdated weighting factors from ICRP publication 60[36] would under- or overestimate the patient dose (Range: -67 % to + 34 %).

As evidenced by the findings, the highest patient dose was documented for the scan of pelvis; however, the uppermost exposure conditions were attributed to the spine procedures, and hence, the highest tube output was pertinent to a spine scan (Table 2). This phenomenon can be explained by the organs with high tissue weighting factors that are located in the radiation field of view, including gonads, colon, and bladder.

As for the results and with reference to ICRP publication 118,[37] the organ doses were far below the threshold of tissue reaction (500 mGy) induction. However, the projected cancer risks were not negligible so that millions of such scans can induce tens of fatal cancers to the exposed population and thus has a reverse relationship with age at exposure. Furthermore, women are significantly more sensitive than men. Hence, one would expect higher radiation-induced cancer risks to influence younger women.

Moreover, the highest REID was documented for a thoracic spine scan, whereas across all the procedures, the scan of pelvis, and not thoracic spine, delivered the highest effective dose to the patient on average. This provides reliable evidence to substantiate other researchers who have claimed that effective dose is not a good indicator of patient risk from radiation exposure.[25-28,38]

Although the risk of exposure-induced death is a better index than effective dose to address patient risks associated with radiological exposures, it fails to consider the age at which cancer develops. Hence, life loss was later introduced to fill the gap. The combination of both LLE and REID well represents the risk of radiation-induced carcinogenesis on the population; however, in the context of individual risk, they fail to establish such a plain distinction. Therefore, loss of life expectancy related to exposure-induced deaths was presented to compensate for this shortcoming. LLE-REID is an indicator that represents the total life loss of affected individuals due to radiation exposure.

On an average, it is to be expected that exposure-induced cancers reduce the patient life expectancy up to 33 and 26 years for a 20-year-old female and male, respectively. By establishing these metrics, one is possible to escalate the radio technologists' and physicians' knowledge concerning the radiation risks associated with radiological scans, and subsequently, improve the implementation of justification and optimization principles.[39-41]

Generally speaking, two approaches can be followed to reduce the population exposure from medical tests; improving justification and optimization processes. There is no doubt that the benefits of radio graphical scans almost always far outweigh their risks; however, enough clinical rationale is needed to support the appropriateness of such tests, particularly in the case of multiple-view scans.[39,40]

In the context of optimization, a number of methods have been proposed mainly based on the tilting of exposure and acquisition parameters. Increasing kVp while reducing mAs, limiting the radiation field, increasing the FSD as well as implementing the automatic exposure control (AEC) are such techniques which can be attempted.[41] Briefly, by improving the awareness of physicians, technologists, and even patients regarding the risks associated with radiological scans, it could be expected that the public exercised more attention to lessen the population's exposure to ionizing radiation by better justification and optimization of procedures.

## CONCLUSIONS

This study was conducted to address the tissue reactions and cancer risks connected with conventional radiographical scans. Evidenced by the findings, effective dose is not a comprehensive metric to address the risks projected by ionizing radiation. Concerning the effects of exposure on patients, undoubtedly, no tissue reactions are expected to occur as a result of medical exposure. The results demonstrated that the REID, effective dose, and organ dose were significantly lower than the limits or thresholds set by the international community. Nevertheless, with respect to the linear no-threshold model, the projected cancer risks prove to be considerable. By improving the public knowledge on the radiation risks, more focus is expected to be paid to the population collective dose so as to contribute to a reduction as a result of enhanced justification and optimization processes.

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