ORIGINAL ARTICLE

Evaluation of Cancer Risk Induced by Radiation Exposure from Normal Head CT Scans

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Abstract

Purpose: Radiology examinations are growing significantly every year. Analysis of the CT scan reports can highlight defects and is a good way to develop safety in healthcare. This study aimed to evaluate the rate of normal head Computed Tomography (CT) scans at a hospital radiology department in Shahroud and estimate the cancer risk associated with these normal CT scans.

Materials and Methods: In total, the data of 400 patients referred to the emergency radiology center of Imam Hossein hospital in Shahroud from November 23 to December 10, 2021, were collected. CT scan reports were categorized into three groups according to the interpretation of the radiologist. The BEIR VII model was used to estimate the radiation cancer risk.

Results: Among the 400 patients, 248 (62%) were males and the average age of the patients was 49.05 ± 22.60 years. CT scans in 270 (67.5%) cases were reported normal. The average age of the patients with normal, and abnormal CT scans were 41.86 ± 20.27, and 63.03 ± 20.27 years, respectively and the difference was significant (p-value <0.001). The average effective dose was obtained 1.72±0.09, 1.31±0.11, and 0.87±0.09 mSv for different age groups of 1-5, 5-10, >10-year-old. The average risks of all solid cancers were 7.82 cases per 100,000 patients, while the average risk of leukemia was 0.71 cases per 100,000 patients.

Conclusion: A large percentage of CT examinations are normal in our country which leads to many public health issues in the future years. Therefore, efforts should be made to establish predictor clinical factors to reduce unnecessary radiology examinations.

Keywords: Head Computed Tomography Scan; Unnecessary Radiology Examination; Radiation Cancer Risk.

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1. Introduction

X-Ray Computed Tomography (CT) is a non-invasive imaging modality that produces high spatial resolution images of internal organs and the structure of the body with unlimited tissue penetration. CT is one of the most accessible and fast imaging modalities and could play an essential role in diagnosis, especially in trauma patients [1, 2]. Despite the advantages of CT which make it a gold standard for different medical observation, the CT radiation dose has always been a public health concern [3, 4].

Radiology procedures are now responsible for up to half of the ionizing radiation exposure to the human population and CT carries the most important role than other procedures [5]. A CT scan delivers a considerably higher radiation dose compared to a conventional radiograph [6]. For example, the radiation dose from one abdominal CT scan is equivalent to that of 100 to 250 chest radiographs [7]. The average Effective Dose (ED) from a single CT scan ranges from 2 to 20 mSv, for brain and abdomen-pelvis, respectively, which are equivalent to 1 to 7 years of natural background radiation [8].

Over 80 million CT scans are performed in the United States (US) annually and increase by almost 10% each year [8]. This shows a dramatic increase in the use of CT compared to 3 million scans in 1980 [9]. The impressive and sudden increased use of CT could lead to increased radiation dose effects [3, 10]. The induction of cancer is one of the most important long-term effects of ionizing radiation. Strong epidemiological evidence confirms that low-dose radiation exposure can contribute to increased cancer risk [11]. The US Food and Drug Administration (FDA) has estimated that a CT scan with an ED of 10 mSv increases the cancer incidence by approximately 1 in 2000 [12]. Therefore, 80 million scans would result in about 40,000 future cancer incidents [13]. This illustrates that CT has both useful and harmful aspects.

There are three fundamental principles of radiation protection in healthcare. The first one is justification which means the advantage of the radiology procedure must exceed any possible harm. The second is optimization, i.e. the radiation dose to the patients and staff must be optimized and not exceed the allowable limits. The last one is that the dose must be kept As Low As Reasonably Achievable (ALARA) (ICRP103) [14, 15]. Moreover, based on the quaternary prevention concept, defined as an ‘action taken to protect individuals (persons/patients) from medical interventions that are likely to cause more harm than good [16], the radiation dose of medical procedures should be reduced. The basic way to reduce the CT radiation dose is to decrease unnecessary CT scans [15, 17]. An unnecessary scan refers to a scan with no diagnostic value, where the risks of the scan exceed its benefits [3]. Several studies show that head CT scans have low diagnostic efficiency for non-trauma patients and most of the patients with abnormal head CT has over 65 years old [1, 18]. Analysis of the CT scan reports can highlight defects and is a good way to develop safety in healthcare. A few studies showed that the rate of normal CT scans in Iran is over 80% [19-21]. However, the actual rate of normal brain CT scans and the associated radiation cancer risk is unknown in our country. Therefore, the present study aimed to evaluate the frequency of normal head CT scans at a hospital radiology department in Shahroud and estimate the cancer incidence associated with these normal CT scans.

2. Materials and Methods

2.1. Study Population

This study was conducted in the emergency radiology center of Imam Hossein hospital in Shahroud, Iran. In total, the data of 400 patients that performed a head CT scan from November 23 to December 10, 2021, were collected.

2.2. Data Collection

The data were extracted from patients’ medical records, Picture Archiving and Communication System (PACS), and CT scanner and classified. The data contains patient demographics (age and gender), referral frequency, insurance information, CT scan reports, acquisition and exposure data (technical and exposure parameters), and dosimetric data (volumetric Computed Tomography Dose Index ($CTDI_{vol}$), and Dose Length Product (DLP)). CT scan reports were categorized into three groups according to the interpretation of the radiologist: score 0 had no pathological/brain trauma injury findings representing normal CT scans; score 1 had suspicious findings representing potentially abnormal CT scans, and score 2 had confirmed pathological/brain trauma injury findings representing abnormal CT scans. All head CT scan data were included in this study, except those that had imperfect data.

2.3. CT Model and Protocol

All scans were performed using a Siemens SOMATOM Emotion 6 Slice CT scanner (Siemens Healthcare, Germany). The head protocol was performed using 130 kV, 150 mAs, 6 mm slice thickness for adults, and 120 kV, 50 mAs, and 6 mm slice thickness for children.

2.4. ED Calculation

ED is the most common parameter that estimates the stochastic effects (cancer and hereditary effects) in medical imaging. To calculate ED, we need DLP and conversion factors from DLP to ED (also known as k-factor). DLP values are extracted from the CT scanner and k-factors are derived from Monte Carlo calculations in which simulated CT X-ray beams are transported to the computational human phantoms. K-factors are dependent on tube voltage (kV), scan region, and patient's age. In this study, we used k-factors determined in ICRP publication 103 for adult and pediatric patients [14]. For 130 kV, and head region the k-factors were considered 0.0035, 0.0027, and 0.0019 for 1-5, 5-10, >10-year-old. The ED (mSv) is calculated for the head by the product of the DLP (mGy.cm) and the k-factor ($mSv.mGy^{-1}.cm^{-1}$), as follows (Equation 1):

$$ED = DLP \times k - factor \tag{1}$$

2.5. Cancer Risk Estimation

Lifetime Attributable Risk (LAR) is the probability of an incidence of whole-body or organ-specific cancer induced by radiation in a member of the population. The LAR varied according to a patient's age and sex, and could be calculated for specific organ cancer as well as all cancers. The LAR of cancer incidence was estimated according to the National Research Council Biological Effects of Ionizing Radiation (BEIR) VII report (Table 12D-1) [22]. The LAR demonstrates the incidence of all solid cancers and of leukemia per 100,000 patients exposed to a single dose of 100 mSv. To calculate cancer risk, we first used the interpolation method to estimate the LAR in our population study for males and females of different ages. Finally, the cancer risk per 100,000 persons is estimated as follows (Equation 2):

$$risk = LAR \times \frac{ED}{100} \tag{2}$$

LAR is the incidence of cancers per 100,000 persons exposed to a single dose of 100 mSv.

2.6. Statistical Analysis

For descriptive statistics, the data were presented as mean ± Standard Deviation (SD) for continuous data, and number (percentage) for categorical variables. All statistical analysis was conducted by IBM SPSS version 21 (IBM Corporation, Armonk, New York, USA). Independent t-test, Chi-square test, one-way ANOVA, and Mann-Whitney U test were used to measure continuous and categorical data, respectively. Statistical significance was considered with a p-value <0.05.

3. Results

A total of 400 patients were included in this study, 248 (62%) of whom were males and 152 (38%) were females. Their ages ranged from 2 to 101 years with an average of 49.05 ± 22.60. Besides, the average age of males and females were 45.38 ± 22.62 and 55.44 ± 21.53 years, respectively, and an independent t-test shows that this difference was significant (p-value < 0.001).

According to the study results, 270 (67.5%) patients had normal, 13 (3.3%) patients had potentially abnormal and the remaining 117 (29.3%) patients had abnormal reports (Figure 1). Among normal reports 167 (61.9%) were males and 103 (38.1%) were females. These data for abnormal reports were 77 (65.5%) and 40 (34.5%) for males and females, respectively. Therefore, males had a greater number of normal and abnormal CT scans compared to females and these differences were significant (p-value<0.05), using the Chi-square test. The average age of the patients with normal, abnormal, and potentially abnormal head CT scans was 41.86 ± 20.27, 63.03 ± 20.27, and 76.54 ± 9.89 years, respectively. The differences were statistically significant using one-way ANOVA (p-value <0.001). The demographic data and CT scan reports have been summarized in Table 1.

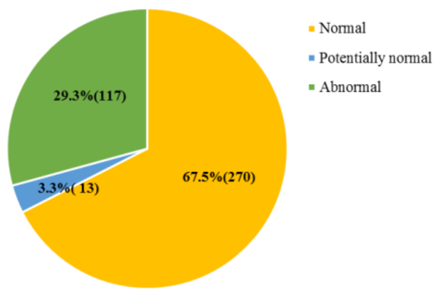

Figure 1. Frequency and percentages of normal, abnormal, and potentially abnormal CT scans reports

Table 1. Demographic data and CT scans reports data

Variable	Mean ± SD[a] / No.(%)[b]
Gender	
Male	248 (62%)
Female	152 (38%)
Age	49.05 ± 22.60
Male	45.38 ± 22.62
Female	55.44 ± 21.53
Normal CT	41.86 ± 20.27
Abnormal CT	63.03 ± 20.27
Potentially abnormal CT	76.54 ± 9.89
CT scan	
Normal	270 (67.5%)
Abnormal	117 (29.3%)
Potentially abnormal	13 (3.3%)
Normal CT scan	
Male	167 (61.9%)
Female	103 (38.1%)
Abnormal CT scan	
Male	77 (65.81%)
Female	40 (34.19%)
Potentially abnormal CT scan	
Male	4 (30.8%)
Female	9 (69.2%)

a: Average ± SD for continuous variables.

b: No.(%) for categorical variables

The mean value of the DLP in mGy.cm given to the study population was 457.53±50.32, which was 463.42±51.83 for males, and 444.51±45.44 for females (Figure 2). Therefore, males receive more

doses compared to females and the difference was significant using an independent t-test (p-value<0.001). There was an inverse correlation between DLP and age (r=-0.09) such that as age increases, DLP decreases, and this correlation was significant (p-value<0.05). Furthermore, the average DLP for normal, abnormal, and potentially abnormal groups were 456.72±49.64, 458.44±52.25, and 434.08±44.61, respectively (Figure 2), and one-way ANOVA showed that these differences were not significant (p-value<0.252). The mean value of the ED of the head region was 0.87±0.09 mSv, which was 0.88±0.09 for males, and 0.84±0.08 for females and this difference was significant (p-value<0.001). Moreover, the average ED was obtained 1.72±0.09, 1.31±0.11, and 0.87±0.09 for different age groups of 1-5, 5-10, >10-year-old (Table 2) which shows an inverse correlation between ED and age (r=-0.11), and this correlation was not significant (p-value<0.02).

The LAR of incidence for all solid cancers and leukemia reported in the BEIR VII report were scaled linearly using data that have been collected. Figure 3

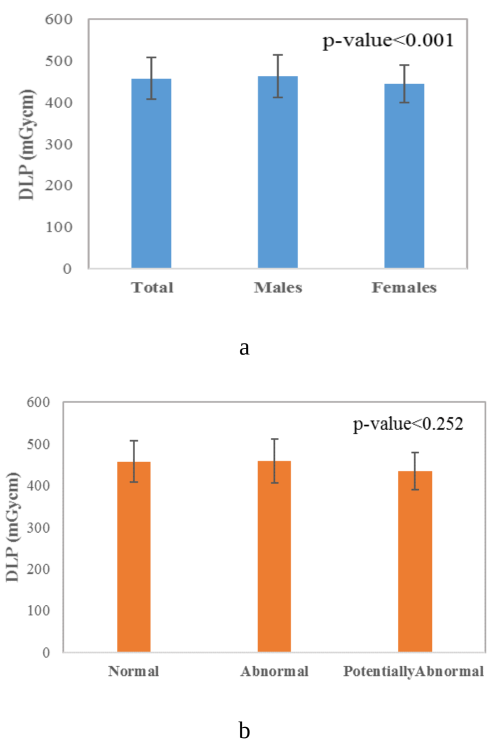

Figure 2. The mean values of DLP (mGy.cm) by a) gender, and b) CT reports

Table 2. The conversion factors and the average ± standard deviation for $CTDI_{vol}$, DLP, and ED for different age groups

Age group	Frequency	Conversion factor (mSv/mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ED (mSv)
1-5	4	0.0035	33±0.00	490.05±25.72	1.72±0.09
5-10	7	0.0027	32.87±0.34	483.69±40.99	1.31±0.11
> 10	389	0.0019	32.35±0.95	456.72±47.63	0.87±0.09

shows the average radiation cancer risk estimates per 100,000 patients due to normal head CT scans for males and females for each cancer site. We can observe significant risks for colon and lung cancers for males, while lung and breast cancer risks for females were substantial. The average risks of all solid cancers were 7.82 cases per 100,000 patients, while the average risk of leukemia was 0.71 cases per 100,000 patients. Figure 4a shows the LAR for incidence of all cancers per 100,000 patients exposed to a single dose of 100mSv as a function of age for males and females. The total radiation cancer risk estimates per 100,000 patients due to normal head CT scans for males and females were presented in Figure 4b. The risk for incidence of all cancers was 7.02±4.80 and 8.30±9.24 per 100,000 patients for males and females, respectively (Table 3).

The referral frequency of the patients ranged from 1 to 27 with an average of 2.56±3.75. Moreover, the average referral frequency of males and females was 2.68±3.89 and 2.37±3.53, respectively, and the Mann-Whitney U test showed that this difference was not significant (p-value<0.47). Insurance data collected showed that 317 (79.2%) patients had different types of insurance, and among them, 206 (76.3%) have normal CT scans. The average referral frequency of the patients with and without insurance were 2.80±3.99 and 1.63±2.44, respectively, and this difference was significant by the Mann-Whitney U test (p-value<0.004).

4. Discussion

All around the world, the number of radiologic examinations has increased due to the advent and development of CT scanners, appropriate health insurance coverage, and an increase in the elderly population. Moreover, CT is the modality of the first choice in emergency and acute clinical diagnoses, and the most requested type is typically head. However, extensive use of CT scans causes many public health concerns about the harmful side effects of ionizing radiation in the future years. There is strong epidemiological data that radiation dose from radiologic examinations results in an increased risk of cancer. Therefore, the risks of CT scan as a large source of radiation among other diagnostic imaging modalities should be considered besides its benefits. It seems that many of normal CT scans are unnecessary without any diagnostic value and contribute to

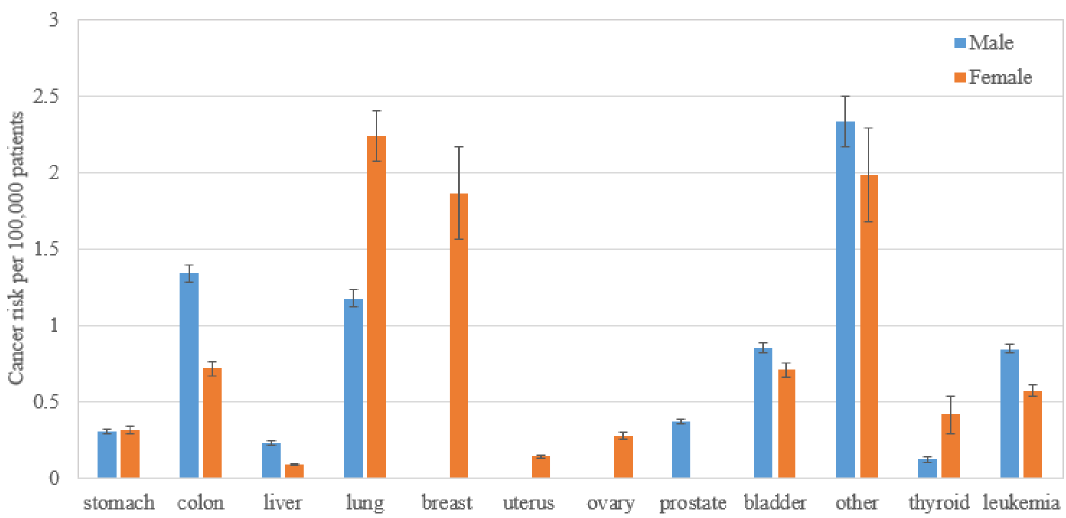

Figure 3. Radiation cancer risk estimates per 100,000 patients due to normal head CT scans for males and females for each cancer site

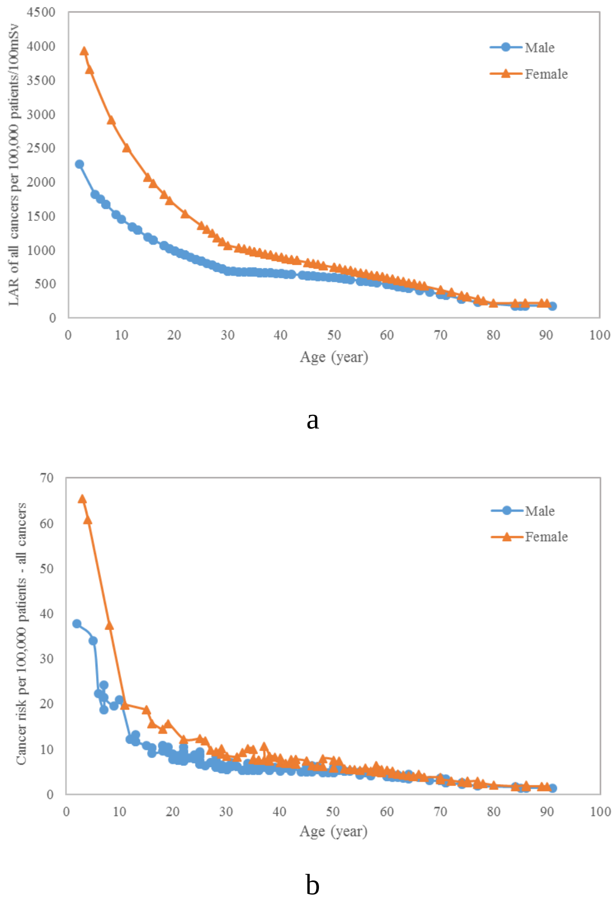

Figure 4. a) LAR for incidence of all cancers per 100,000 patients exposed to 100 mSv, and b) radiation cancer risk per 100,000 patients for all cancers as a function of age for males and females for normal CT scan reports

increasing potential future cancer risk. This study was conducted to evaluate the number of normal head CT scans based on their reports and to estimate the radiation cancer risk related to normal CT scans.

This study has been performed on patients who refer to the emergency department for head CT scans. The ratio between males and females and the age range reflects the characteristics of our population. It seems that more men with a low average age than women refer to the emergency radiology department. One reason for this might be the fact that trauma occurs more frequently among males than females [23].

Among the 400 patients, 67.5% had normal CT scans. Among normal CT reports 61.9% were males which shows that males had more normal CT scans than females. This result is almost consistent with other studies conducted in Iran, such that the ratio of normal CT scans was 88% in the study of Haghighi *et al*. [19], 81% in the study of Chaparian *et al.* [20], and 88% in the study of Moradi *et al*. [21]. Moreover, the rate of normal CT scans was 55.8% and 34% in Turkey [17, 24], 38.2% in Pakistan [3], 86.2% in Canada [1], and 50% and 90% in the US [25, 26]. According to similar studies, the difference in the rate of normal CT scans depends on age, scan region, and considering trauma or non-trauma patients in the population study. For example, Wang *et al*. [1] and Bent *et al*. [26] that has found 86.2% and 90% of CT scans to be normal, respectively, worked on non-trauma patients. Since in the studies performed in Iran both trauma and non-trauma patients have been considered, it can be concluded that the frequency of normal CT scans in Iran is higher than in other countries and a significant number of these normal CT scans may be unnecessary. Therefore, efforts should be made to reduce unnecessary CT ordering. Gimbel *et al*. [25] showed that the CT ordering decreased significantly after the presentation of information about the health risks of ionization radiation. Therefore, we can reduce unnecessary radiation exposure, by providing adequate information about the risks of ionizing radiation used in CT to the physicians, patients, and staff. Furthermore, recently Artificial Intelligence (AI) algorithms have been utilized for medical decisions in requests for imaging not only by analyzing a patient's medical record and determining the appropriateness of imaging but also by providing guidance on which imaging exam may be the most appropriate [27]. Therefore, AI algorithms

Table 3. The mean values of ED, LAR per 100,000 patients /100mSv, and radiation cancer risk per 100,000 patients for male and female for normal CT scan reports

Gender	Age (year)	ED (mSv)	All solid cancers		All cancers	
			LAR	Cancer risk	LAR	Cancer risk
Male	38.02±19.06	0.91±0.15	710.34±340.06	6.76±4.86	738.93±323.86	7.02±4.80
Female	48.34±20.65	0.86±0.14	948.88±758.35	8.88±11.02	897.42±657.57	8.30±9.24

also could be effective in reducing unnecessary radiology procedures.

Our findings showed that the average age of the patients with normal CT scans is fewer than abnormal, and potentially abnormal CT scans. It might be because the incidence of many disease increase with age, so it is more likely to find pathology at an older age. Consistent with our results, Bent *et al.* [26] and Wang *et al.* [1] have reported age over 55 and 70, respectively, as a predictor clinical factor for non-trauma patients who can benefit from head CT.

Furthermore, the results showed that 76.3% of patients with normal CT scans had been covered by different types of insurance. Therefore, excessive health insurance coverage could lead people to perform CT scans without any information about the side effects [17].

The results expressed that the DLP is dependent on sex and also there was a weak negative correlation between DLP and age. Several studies investigated the relationship between DLP, sex, and age of the patients and confirmed these results [28-30]. Our dosimetric results show that the mean values of CTDIvol and DLP are lower compared to those reported for head CT exams [31].

In order to evaluate the radiation cancer risk, the BEIR VII model was applied. We can observe the cancer incidence due to radiation exposure from normal head CT scans for males and females, for each cancer site (Figure 3). The significant risks for colon and lung cancers were observed for males, while lung and breast cancer risks for females were considerable. These results were consistent with a similar study that reported a major risk of lung cancer for men and lung and breast cancer for women [10]. In addition, the risk of other cancers was almost 2 cases per 100,000 patients for both genders. In fact, other cancers mean all other solid cancers except ten cancers shown in Figure 3. The total risk of ten solid cancers in Figure 3 was 4.4 and 6.9 cases per 100,000 patients for men and women, respectively, which is almost 2 and 3.5 times greater than the risk of other cancers. This result is completely consistent with the study of Ghetti *et al.* [10]. Furthermore, in most cancer sites, the radiation cancer risk estimates were higher for men than women. This is because the average age of males was lower than females in our study population and as the risk is directly proportional to the age, so the risk estimates were higher for males in this study. However, in general, the radiation cancer risk was higher for females than males by a factor ranging from 1.7 to 1.2 and the difference is more evident at younger ages (Figure 4b). This is probably because women have a greater sensitivity to radiation than men [22]. In fact, the LAR values in Table 12D-1 of BEIR-VII is higher for female than male at all ages (Figure 4a), while the ED was obtained more in male than female. Moreover, we can see that the cancer risk decreases with increasing age in both genders, and age dependence is clearly evident at younger ages (<25years). This higher sensitivity might be due to a longer life span and having a higher number of dividing cells at younger ages. Similar studies confirm these results [5, 10, 32].

In this study we used prepared data which were not collected for research purposes, therefore, the data were not collected with high accuracy. Furthermore, the BEIR VII model estimates cancer risk based on the linear no-threshold model and several studies emphasize that this method overestimates radiation cancer risk at low-dose radiation typically used in X-ray imaging [33, 34]. Despite these defects, the estimation of radiation cancer risk warns us about the potentially harmful side effects of ionizing radiation to take the necessary actions in this regard according to the quaternary prevention concept.

5. Conclusion

This study showed that the rate of normal head CT scans is higher in our country compared to neighboring countries as well as developed countries. As a consequence, the cancer incidence induced by radiation increases in the future years in Iran. Therefore, a national survey is highly recommended to establish predictor clinical factors to reduce unnecessary radiology examinations.

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