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Lifetime Attributable Risk of Breast Cancer Incidence in Brain CT Scans

Salman Jafari[*♦], PhD, Abbas Alikarami[**], MSc, Michael Faraji[*], BSc, Soheib Rezaie[*], BSc, Karim Ghazikhanlou Sani[*], PhD

[*]*Department of Radiology Technology, School of Paramedicine, Hamadan University of Medical Sciences, Hamadan, Iran*
[**]*Department of Nuclear Physics, Bu-Ali Sina University, Hamadan, Iran*

[♦]**Corresponding Author**
Salman Jafari, PhD
Department of Radiology Technology,
School of Paramedicine, Hamadan University of Medical Sciences,
Hamadan, Iran
Email: sa.jafari@umsha.ac.ir

Abstract
Background: The breast, being a highly radiosensitive organ, is exposed to scattered radiation during brain computed tomography (CT) scans. This study aims to estimate the lifetime attributable risk (LAR) of female breast cancer resulting from brain CT scans.
Method: 90 women participated in this cross-sectional study. The LAR of breast cancer incidence was estimated based on health risks associated with exposure to low levels of ionizing radiation, as per the BEIR VII Phase 2 guidelines. The absorbed dose to the breasts was measured using thermoluminescence dosimeters, and the effective dose was calculated from the dose length product. All brain CT scans were conducted using a 16-slice scanner (SOMATOM EMOTION). Statistical analysis involved the Mann-Whitney test to compare the means of breast dose, effective dose, and LAR at a significance level of 0.05.
Results: The mean age of the participants was 40 ± 22 years, with an age range of 10 to 83 years. The average dose to the breasts without and with shielding was 0.26 ± 0.19 mGy and 0.096 ± 0.13 mGy, respectively ($P < 0.05$). The effective dose was 0.85 ± 0.35 mSv without shielding and 0.79 ± 0.32 mSv with shielding ($P = 0.539$). The maximum LAR was 5.41 cases per 100,000 persons aged 10-15 years without shielding. The average LARs were 1.16 and 0.41 breast cancer incidences per 100,000 persons with and without shielding, respectively ($P < 0.05$).
Conclusion: The LAR of breast cancer in brain CT scans is significant and should not be overlooked. The use of breast shielding can substantially reduce this risk. Therefore, it is recommended to employ radioprotective shields to cover the breasts during this type of scan.
Keywords: Breast neoplasms, Tomography, X-ray computed, Radiation protection

Introduction

Breast cancer is the most prevalent cancer among women in the world.[1] Based on the global cancer observatory platform, the new case incidence of breast cancer in Iranian women is the highest among all cancers, and the 5-year prevalence (all ages) is 134.46 per 100,000 persons.[2] The breast is a highly

radiosensitive organ, and repeated breast irradiation with a dose of 10 mGy before the age of 35 increases the risk of breast cancer by more than 13.6 %.[3, 4] According to some studies, breasts are known as the most radiosensitive organ in the human body which emphasizes the importance of this tissue protection against x-ray.[5] The average lifetime attributable risk (LAR) of breast cancer in female patients has been reported at 7.45 per 100,000 exposures in exchange for a radiation dose of 3.97 mGy in another study.[6]
Computed tomography (CT) scan is a cross-sectional imaging modality with many applications in diagnosing diseases today.[7] Despite the many advantages, the radiation dose is an important and worrying issue in CT scans. CT accounts for a significant percentage of the dose absorbed by patients from medical imaging.[8-12]
One of the most common CT requests is brain CT.[13, 14] In a brain CT scan, some organs, such as brain tissue and eye lens, are exposed to primary radiation.[15] Several studies have investigated the absorbed dose of different organs in brain CT scans.[16-18] Jaffe et al. reported the absorbed dose to the cranium, brain, lens, mandible, and thyroid in brain CT as follows, respectively: 2.57–3.47, 2.34–3.78, 2.51–5.03, 0.17–0.48, 0.03–0.28 cGy.[19]
The interaction of primary photons with the patient and various parts of the scanner, including the collimator, gantry body, air inside the gantry opening, the bed, and the detector, causes the production of scattered radiation. The scatter is distributed in all directions and irradiates sensitive organs such as the breast.[20] Different amounts of irradiation to sensitive tissues, such as the thyroid and breast, have been reported in CT scans of the brain.[21-23] Mazonakis et al. have reported the thyroid dose in head CT from 0.6 mGy to 8.7 mGy.[22] For the breast, the absorbed dose resulting from scatter radiation in brain CT scan has been reported to be about 338.2 μGy and 0.28 mGy in two studies conducted.[21, 23] These doses are significant and increase the breast cancer risk.[24]
Justification of CT prescription, optimization of the imaging protocol, and adherence to the dose limit should be observed to decrease the risk of carcinogenic effects of radiation.[25, 26]
The effect of shielding on the dose reduction of radiosensitive superficial organs in many diagnostic procedures has been reported.[27]
For sensitive organs outside the scan field, such as the breast, a lead apron as shielding can be used to reduce the scatter radiation dose. A lead operon is usually available in the CT scan room and can be easily used. In this study, the dose of women's breasts in brain CT was first measured, the LAR was estimated, and then the efficacy of lead shielding to reduce it was assessed.

Materials and Methods

Measurement of the absorbed dose to the breast

The absorbed dose to the breasts of adult females in brain CT scans was measured using a thermoluminescence dosimeter (TLD). TLD chips used in this study are shown in figure 1.
Before measuring the dose, TLDs were calibrated against a cobalt 60 radiation source using a Perspex phantom under a field size of 35×35 cm^2. Element correction coefficients (ECCs) for each dosimeter were determined as the ratio of the mean reading of all dosimeters divided by the reading of that dosimeter.[28] To obtain the reader calibration factor (RCF), 9 TLDs were selected in each group.
RCF was derived from the calibration curve. Reading of TLDs was done using a TLD reader SOLARO 2A. The breast dose was calculated from the reading of TLDs as follows:[29]

$$\text{Dose} = (\text{reading} - \text{background}) \times \text{ECC} \times \text{RCF} \times \text{Energy correction factor} \quad (1)$$

Reading is the value of TLD reader output in terms of nC, the background is the reading for the background radiation, ECC is the element correction coefficient, and RCF is the reader calibration factor. The energy correction factor of TLDs was 0.726, and the range of their linear response was 10^{-7} to 12 Gy.

Ninety women referred to head CT scans in one of the educational hospitals in Hamadan were included in this cross-sectional study. The study has been approved by the Ethics Committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1397.871). Two GR-200 TLD chips were put directly on each breast during brain CT. Before putting the TLDs on the breast, a written informed consent form was taken from patients. TLDs were packed in rubber holders, and the number of each TLD was attached to it. To investigate the effect of shielding, the breasts were completely covered with a lead apron, and TLDs were placed beneath the apron on the breast.

CT scan protocol

All brain *CT* scans were performed with a 16-slice scanner (SOMATOM EMOTION), and a quality control certificate was attached to the gantry. All patients were in a supine position. Lateral topogram and sequential scan mode were selected for patients unless in emergency cases for which spiral mode was applied. The scan box covered the brain from the foramen magnum to the vertex. Acquisition parameters were those routinely used in clinical practice: collimation 16×1.2 mm, slice thickness 4.8 mm, 110 kVp, rotation time 1 s, reconstruction kernel H31, and cerebrum window.

Estimation of LAR

LAR of breast cancer was estimated according to the BEIR VII report. Using table 12D-1 of this report, the LAR was calculated from breast dose at different age groups.[30, 31] The number of breast cancer cases incidence per 100,000 persons exposed to a single dose of 0.1 Gy (100 mGy) is available in the table. LAR was estimated from the measured dose by the equation below:

$$\mathrm{LAR} = \frac{\text{Absorbed dose to the breast(mGy)}}{100} \times \mathrm{LAR}_{\text{breast at 100 mGy}}$$

$\mathrm{LAR}_{\text{breast at 100 mGy}}$ is breast cancer cases per 100,000 persons exposed to a single dose of 0.1 Gy (100 mGy). Kolmogorov-Simonov's normality test was used to examine if variables are normally distributed. The nonparametric test of Mann-Whitney was used to compare the means of breast dose and LAR ($P < 0.05$).

Results

The calibration curve of TLDs is shown in figure 2. The reader calibration factor was derived from the equation displayed on it.

The average age of all patients who participated in this study was 40 ± 22 years (age range: 10-83 years). These results show that most patients were young or middle-aged during imaging. Scan parameters are shown in terms of shielding status in table 1.

In most cases, sequential scan mode is used. Only 2 and 6 spiral scans have been performed in unshielded and shielded groups, respectively. In this study, 110kVp has been used more than 130 kVp. H31 reconstruction kernel is routinely used for brain CT scans. A combined application to reduce exposure (CAREdose 4D) is an option available on the scanner software to change the mA based on patient thickness in the field of scan and avoid her/him unnecessary radiation. The frequency of use of CAREdose 4d for the two patient groups is the same. For 32 patients, it has been activated; for 13 cases, it has not. In two groups, the scan of patients has been frequently performed using a rotation time of 1.5 s (30 cases) compared to 0.6 and 1 s. $CTDI_{vol}$ is a quantity for estimation of scanner output and can be used to compare the scan dose with DRLs.[32, 33] Table 2 shows $CTDI_{vol}$ in two groups ($P > 0.05$). This means two patient groups have received almost the same dose in the scan area (i.e., brain). Dose length product (DLP) estimates the total absorbed energy in the scan volume. The difference between the means of DLP for shielded and unshielded patients was insignificant ($P = 0.539$).

The average effective dose without shielding was 0.85±0.35 mSv compared to 0.79 ± 0.32 mSv with breast shielding ($P > 0.05$). The product of tube current and exposure time, i.e., mAs, is an important parameter affecting effective CT scan doses. Figure 3 shows the correlation between mAs and effective dose.

Figure 4 shows the results of the absorbed dose to the breasts with and without shielding. The average breast dose in unshielded and shielded groups was 0.26 ± 0.19 mGy and 0.096 ± 0.13 mGy, respectively. The Mann-Whitney test showed a significant difference in the absorbed dose of breast skin between the two groups ($P < 0.05$).

The average LAR of breast cancer incidence was 1.16 per 100,000 persons without any shield, but covering the breasts with a lead apron reduced it to 0.41 per 100,000 persons ($P < 0.05$). The obtained results showed that the highest LAR of breast cancer was dedicated to 10-year-old females. It was about 5.41 and 1.68 per 100,000 persons without and with shielding, respectively. Figure 5 describes the LAR of breast cancer incidence in brain CT scans for all age groups between 10 and 83 years old. The graph describes the effect of breast shielding on LAR reduction in all age groups.

Discussion

Results of this study showed that the mean dose to the breast in brain CT scan performed with 16 slice scanner is about 0.26 ± 0.19 mGy, but shielding reduces it to 0.096 ± 0.13 mGy. Shielding causes a reduction in the LAR of breast cancer incidence by about 63%.

Imaging parameters, including kV_p, mAs, rotation time, pitch factor, collimation, and device geometry, impress the absorbed dose in a CT scan.[34] The dose to the breast in brain CT scan is attributed to scatter radiation. The X-ray spectrum's energy, the body's thickness, and the scan's volume affect the production of scattered X-rays and, consequently, the dose to organs outside the radiation field.[15] Our study showed that the mean breast dose was higher at 130 kVp (0.23 mGy) than at 110 kVp (0.17 mGy). The average energy of the beam is increased at 130 kVp, which in turn leads to more scattered rays.[35] Therefore, lower kVp is suggested to reduce the breast dose considering the image quality. The tube current and scan time are also involved in the absorbed dose. The combined application to reduce exposure (CAREdose 4d) is designed to reduce the absorbed dose of the patient based on mA modulation as a function of patient thickness.[36] optimal use of this software needs more research. In this study, this software has been active in most cases. The pitch factor is the table increment per one gantry rotation divided by the beam collimation. Increasing the pitch factor causes a reduction in the patient's absorbed dose [37]. Sequential scan mode is preferable for the brain unless the patient's condition is emergency or unstable.

CTDIvol and DLP have been used to estimate and compare the dose in the scan field. The quantities of $CTDI_{vol}$ and DLP were lower at 110 kVp compared to 130 kVp. Statistical analysis showed no significant difference in the $CTDI_{vol}$ between the two groups with and without shielding ($P = 0.201$). This means that the radiation parameters for the two groups have been similar, and the efficacy of shielding on the absorbed dose to the breast skin can be better investigated.

In this study, using a lead apron reduced the dose absorbed into the breast. This is due to the absorption of scattered X-rays in different directions. The lead absorbs these X-rays before reaching the patient's skin.

The results obtained in this study are consistent with other studies conducted in this field. The average absorbed dose of breast skin in the study of Z. Brinc et al. was reported to be 0.28 mGy without shielding (dose range: 0.41-0.15 mGy) and 0.13 mGy with shielding (dose range: 0.05-0.29 mGy). They included 49 female patients and one breast shield in their study. The absorbed dose was measured using TLDs.[21] In Zalokar et al.'s study, the absorbed dose of breast skin was measured for two groups with and without shielding in two centers. The absorbed dose of the breast skin was different in two centers. The average dose in two centers without shielding was 338.2 ± 43.7 and 253.1 ± 35.1 μGy, and in the case with shielding, it was 64.3 ± 18.8 and 65.3 ± 16.9 μGy.[23] Beaconsfeld et al. stated a 76% reduction in breast dose using a shield compared to the unshielded state.[38]

In our study, the average LAR of breast cancer incidence was 1.16 and 0.41 per 100,000 persons without and with shielding, respectively. In a study by Vafaei et al., the average LAR of female breast cancer in brain CT was reported to be about 2.5 cases per 100,000 persons, which is twice that of this study.[39] They used constant mAs of 200 in Brain CT compared to effective mAs in our study with an average of 110 mAs. Tahmasebzadeh et al. reported the average LAR of breast cancer in female patients about 7.45 per 100,000 exposures, which is higher than 1.16 cases in this study. The reason is that in a chest CT scan, the breast is directly exposed to primary radiation, but in brain CT, it is outside the field and is irradiated by scattered radiation.[6]

Breast tissue, as a high radiosensitive organ, is exposed to scatter radiation in brain CT scan.[3, 21] High frequent requests of brain CT from one side and very high radiosensitivity of breast tissue on the other side has raised a serious concern about the incidence of cancer. So, applying any strategy to reduce the absorbed fat in the breast without image degradation helps reduce the risk of cancer. The results of those mentioned above and similar studies show that the absorbed breast dose in brain CT is an important issue that cannot be ignored. The slope of the LAR curve decreases rapidly with age. The effect of the shield is more evident at a younger age. In this study, the investigation solely focused on the absorbed dose to the breast and the estimation of the LAR of breast cancer. It is recommended that additional studies be conducted to explore absorbed doses and LAR for other organs, such as the thyroid.

This study's strength lay in measuring breast dose using a real dosimeter in clinical situations. To our knowledge, few studies have assessed the risk of breast cancer in brain CT scans. Many studies have relied on phantoms, software calculations, or simulations, which can be somewhat distant from real-world scenarios. The estimation of the LAR of breast cancer was based on the BEIR VII report. This report provides an overall assessment of breast cancer risk without considering the specific pathology of breast cancer or the impact of time on malignancy induced by brain CT scans. Further research is needed in this area.

Conclusion

The findings of this study indicate that the LAR of breast cancer incidence is discernible in brain CT scans. Using a lead apron as a shielding measure effectively reduces the radiation dose and, consequently, the LAR. Although the absorbed radiation dose in the breast during a brain CT scan is relatively low, given the high frequency of brain CT scan requests and the heightened sensitivity of women's breast tissue, it is strongly recommended to implement breast shielding protocols.

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Conflicts of Interest
None declared.

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Table 1. Image acquisition parameters in brain CT scan in terms of shielding status.

Shielding	Scan mode		Kilovolt peak(kVp)		Kernel			CAREdose 4d		Rotation time(s)		
	Sequential	Spiral	110	130	H31	H41	H70	Active	Passive	0.6	1	1.5
No	39	6	37	8	40	1	4	32	13	7	8	30
Yes	43	2	39	6	40	1	4	32	13	13	2	30

CT: Computed tomography

Table 2. $CTDI_{vol}$ and DLP in CT scan of the brain in terms of shielding status

Shielding	CTDIvol(m.Gy)	*P* value	DLP (m. Gy.cm)	*P* value
No	24.81 ± 13.86	*P* = 0.201	370.93 ± 153.39	*P* = 0.539
Yes	21.66 ± 7.42		346.50 ± 140.30	

CT: Computed tomography; DLP: Dose length product; CTDIvol: Volume computed tomography dose index

Figure 1. This figure depicts the TLD chips utilized in the present study.
TLD: Thermoluminescent dosimeter

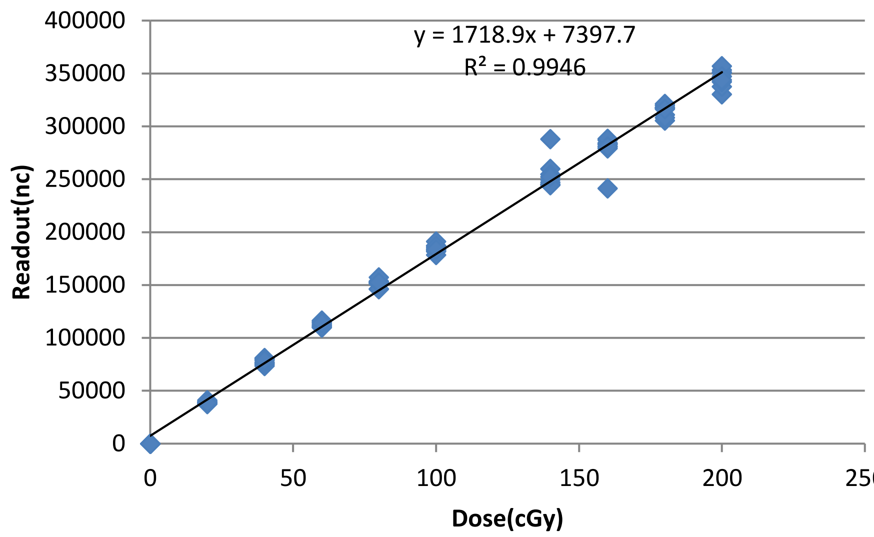

Figure 2. The calibration curve for TLDs demonstrates a robust linear relationship between radiation dose and readout.
TLD: Thermoluminescent dosimeter

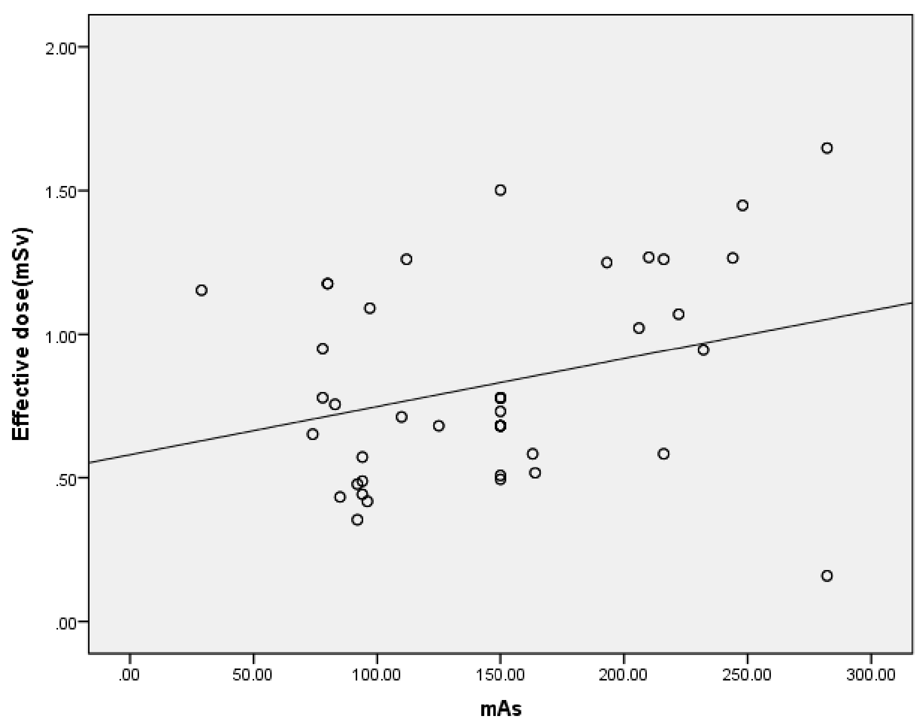

Figure 3. This figure illustrates the correlation between milliampere-second (mAs) tube current and effective dose in brain CT scans.
CT: Computed tomography

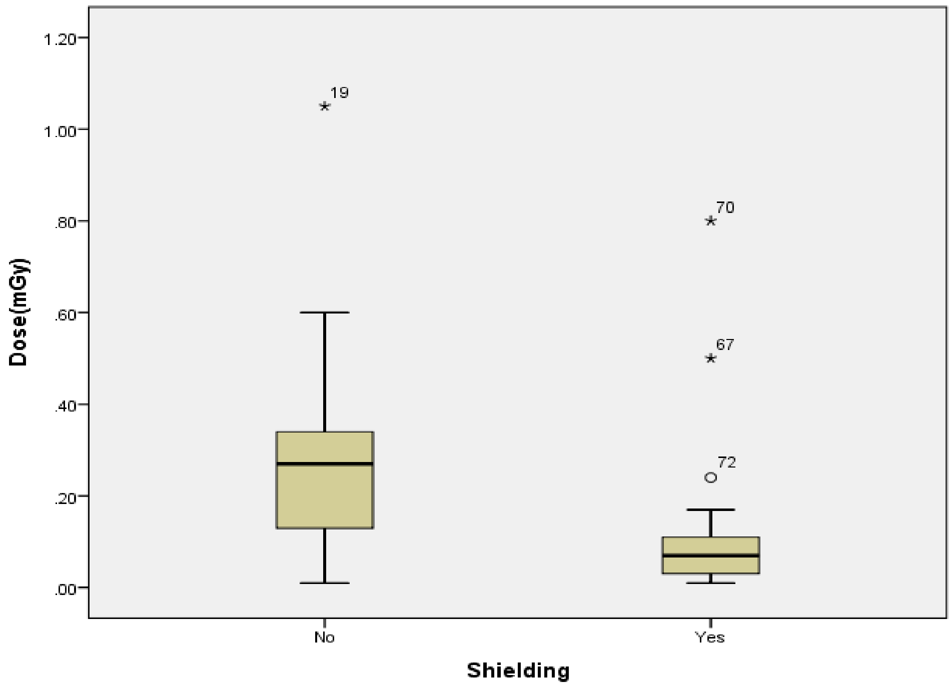

Figure 4. The outcomes of the absorbed dose in the breast for both shielded and unshielded groups are presented. Notably, the mean absorbed dose with shielding significantly exceeds that in the absence of shielding.

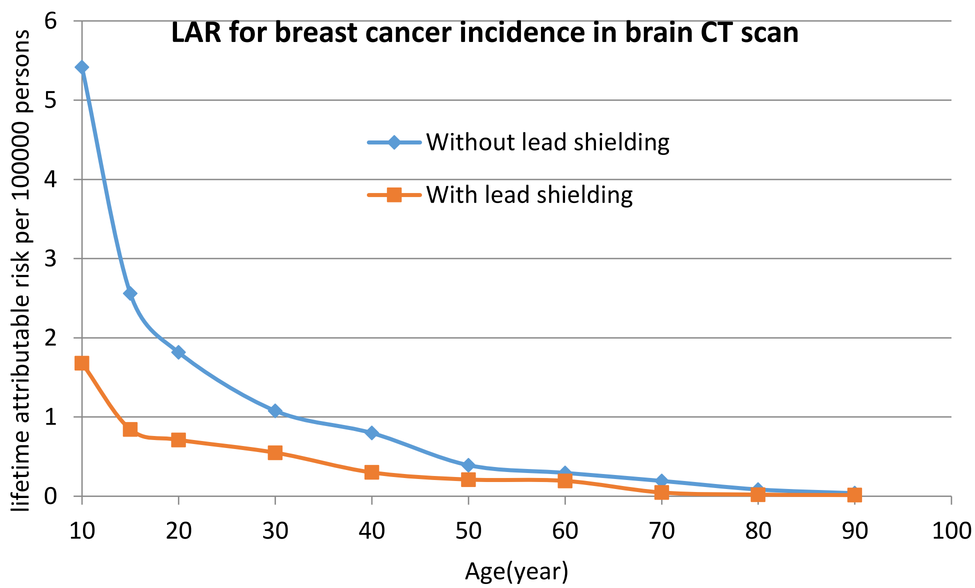

Figure 5. The LAR of breast cancer incidence in brain CT scans is noticeably higher when shielding is absent, as compared with scenarios with shielding, across all age groups.
LAR: Lifetime attributable risk; CT: Computed tomography