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Reduction of Breast Surface Dose, Cancer and Mortality Risks Using Lead Apron during the Head Scanning a Computed Tomography Technique

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ABSTRACT

Introduction: The present study aimed to assess the reduction of breast surface dose, breast radiation-induced cancer incidence, and mortality risks when the lead apron shielding was positioned on the chest regions during head computed tomography (CT).

Material and Methods: In this study, routine head CT scans were performed on 28 female patients with a mean body mass index (BMI) of 25.2 ± 2.8 kg/m^2. The common lead aprons (0.5 mm thicknesses) were folded and positioned in the chest regions. The breast surface doses were measured using six thermoluminescent dosimeters (TLD-100), three TLDs were located above the apron and three ones positioned under the apron. Breast radiation-induced cancer incidence and mortality risks were estimated using the Biological Effects of Ionizing Radiation (BEIR-VII) model. Finally, the measured doses and cancer/mortality risks were compared using Paired sample T-Test in SPSS software.

Results: The breast surface doses under and over the apron were obtained at 0.18±0.06 and 0.49±0.13 mGy, respectively, (P-value<0.05). Although all cancer/mortality risks for both groups (over and under the apron) were very low, using the lead apron could decrease (significantly) breast cancer incidence risk ([1.24±0.32]×10^{-3} % over the apron vs. [0.46±0.15] ×10^{-3} % under the apron) and mortality risk ([0.30±0.08]×10^{-3} % over the apron vs. [0.11±0.04] ×10^{-3} % under the apron) about 63% in all patients.

Conclusion: The use of common lead aprons in the chest regions for patients undergoing head CT scans could significantly reduce the breast surface doses and radiation-induced cancer/mortality risks.

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Introduction

Computed tomography (CT) is considered the most convenient diagnostic tool in terms of availability, efficiency, and cost [1,2]. However, it accounts for one of the main ionization radiation sources in medical procedures. In addition, the use of CT scans has been increased due to the higher diagnostic value [3,4]. Notably, the radiation doses to the patients in CT scans are higher than the other tools which generate ionization radiation like radiography [5]; therefore, concerns about radiation side effects related to CT examinations have been raised.

Some of the organs are considered sensitive due to the high tissue-weighting factor (W_T) following International Commission on Radiation Protection (ICRP) reports [5]. For instance, the W_T of the breast is 0.12, which accounts for a sensitive organ. On the other hand, head CT scans are common procedures and perform in a high number daily to determine the incidence and risk factors, especially after head trauma, to investigate the clinical significance of progressive hemorrhage [6-8]. The breast is one of the organs which undergo scattered and leakage radiation during head examinations; therefore, any simple methods cause to reduce the dose received would be crucial [9].

There are several ways and shielding materials used for breast protection. For example, in a study [10], the breast dose was reduced by 11-31% using split protocols (changing the scanning field location) compared to the standard one. In addition, using a bismuth shield for the breast during chest CT examinations [11], or a new flexible shield named Saba shielding [12] composed of bismuth in combination with other low atomic number metals

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used to reduce the breast surface doses without any side effects on the image quality. However, the mentioned shields are not widely used in routine CT examinations due to the lack of accessibility. Herein, in the current work, we have assessed the impact of the common lead apron positioned in the chest regions to measure the breast surface dose as well as breast radiation-induced cancer and mortality risks during the head CT examinations. It should be noted that the apron used in our study is accessible in all CT centers easily.

Materials and Methods

Patients

Twenty-eight female patients with ages ranging from 23 to 74 years and a mean body mass index (BMI) of 25.2 ± 2.8 kg/m^2 referred to head CT examination for objective medical reasons were selected randomly for this study. The patients with breast surface infections or lesions were excluded.

The current study was approved by the Ethics Committee and National Research Ethics Board with registration number "IR.MUBABOL.REC.1399.484". Written informed consent was obtained from all participants, and the patients were informed that the study protocol was no invasive procedure.

CT scanning

A multi-detector CT scanner (16 slices, Siemens Healthcare GmbH, Erlangen, Germany) was used to acquire the head images. Notably, the patients were positioned supine, and their arms were lying beside their bodies. In a conventional standard head CT protocol, all scans were performed without any contrast agents. Table 1 represents the related parameters for the head CT scanning.

Table 1. CT scan parameters used for brain examination averaged over all participants

Parameter	Value
Tube voltage (kVp)	110
Effective mAs	150
Rotation time (s)	0.6
Pitch	0.95
CTDIvol (mGy)	24.33 ± 1.6
DLP (mGy.cm)	531.81 ± 30
Total scan time (s)	7.35 ± 1.58
Slice thickness (mm)	6
Slice number	30±1
Gantry tilt	-1.5±2.8 (-5 to +4)

Thermoluminescent dosimeter (TLD)

Breast surface doses were estimated using thermoluminescent dosimeter (TLD-100) chips. TLD chips are made of LiF, Mg, and Ti (thickness: 0.9 mm, size: 3 × 3 mm^2) and produced by Harshaw Company (Thermo Electron Corporation, Reading, UK). The TLDs were annealed in a TLD annealing furnace (1 h at 400°C and 2 h at 100°C), and they were pre-heated at 100°C for 20 minutes prior to the readout.

The TLD calibration processes were carried out based on Groves et al.'s study [13]. Briefly, to increase the reproducibility, the element correction coefficient (ECC) values were obtained for the TLDs. A calibrated Barracuda dosimeter (RTI Electronics, Sweden) was utilized for the confirmation of the dose measurement. To obtain ECCs, the TLDs were irradiated three times at the center of the CT scanner. Then, the mean readout values of the TLDs were calculated using the following equation:

$$ECC_i = TLD_i/TLD_{mean} \tag{1}$$

In addition, for obtaining the calibration factor (CF), the TLDs, with the ECC close to 1, were exposed three times to various selected doses, and the average readouts were calculated. After that, a figure was plotted based on the dose (mGy) versus TLD reading (nC), and the CF was obtained using the slope of the curve. Notably, a pair of TLD chips were located more than 3 meters far from the source of radiation (CT room) to measure the background dose. In the end, the surface dose was estimated using multiplying the mean values of the TLD readouts, ECC, and CF.

Dose measurement

Chest regions were covered with two folded lead aprons (0.5 mm thicknesses) during the head CT examination. For each patient, 6 TLDs were used to measure the dose of scatter radiation at the breast surface (one breast for each participant). Three TLDs were attached to the top surface of the apron, and three others, at the same location, were positioned under the apron (Figure 1; a and b).

The above dosimeters represent the received dose of the scattered and leakage radiations from the CT scanner. The TLD dosimeters positioned under the apron present the dose of scattered radiations from the patient's body.

Cancer risk estimation

The breasts' mean doses obtained from TLD measurements were used for cancer risk estimation based on the Biological Effects of Ionizing Radiation (BEIR-VII) report preferred model. This model uses a no-threshold linear relation as the most suitable relationship between low doses of ionizing radiation and the radiation-induced cancer and cancer mortality risks (up to age 90). This report considers various parameters, including cancer type, age at exposure, gender, and time elapsed after exposure, as the moderating factors [14]. Furthermore, a linear-quadratic model was utilized to estimate the risk of leukemia in this model; however, we only evaluated the radiation-induced breast cancer risks. The report uses a multi-risk index estimation model for community-specific risk frequencies [14].

Figure 1. The location of the TLD dosimeters, under the lead apron (a) and over the lead apron (b).

A combination of progressive and incremental models has been used to estimate the cancer risk based on age at radiation time (between progressive and incremental models). The committee has finally presented the life-attributed risks (LARs) for radiation-induced cancer and mortality risks at various cancers sites, ages and gender. The LAR is an estimate of the probability of developing premature cancer from radiation exposure over the life of the subject. These values present the additional risk of different cancers and the total risk of all cancers for ages (at the time of exposure) ranging from 0 to 80 years in both sexes for a dose of 0.1 Gy per 100,000 individuals [14]. Since all CT scans in the current study belonged to adult patients, we evaluated cancer incidence and mortality risk in women aged 20 to 80 years (10-year step) to prepare the related data of head CT imaging. To find the breast cancer risk for patients at various ages, we only multiplied the breast doses with breast cancer LAR values. Based on the preferred method reported in the BEIR-VII model, the organ mean doses were used for cancer risk estimation. TLD measurements on the skin were attributed to an appropriate depth, d, below the skin. The Hp (d) obtained from the TLD reading after the calibration procedure represents the absorbed dose from external exposure in the depth of d. We used the reported conversion coefficients from air-kerma to Hp (7 mm). This dose was considered the organ (breast) absorbed dose and was used for breast cancer risk estimation.

Statistical analysis

The normality of the data was assessed by Kolmogorov-Smirnov (K-S) statistical test. A Paired sample T-test was used to compare the dose received over and under the lead shielding, with the significance level at $P < 0.05$. All tests were performed in SPSS software, version 16 (IBM, USA

Results

All studied patients had good compliance, and none exhibited pain during the experimental shield work. The mean ± standard deviation of the breast surface doses was 0.18 ± 0.06 and 0.49 ± 0.13 mGy, respectively, under and over the lead apron shield during the head CT scanning. The mean dose values were reduced significantly in the presence (over) of the apron (P-value < 0.001), with a percentage of 63.

Lifetime attributed breast cancer incidence and mortality risks due to the head CT scan in female patients under and over the lead aprons at different ages of exposure are presented in Figures 2 and 3, respectively. The results of the pair sample T-test demonstrated that the lifetime attributed breast cancer incidence and mortality risks had significant differences between over and under the lead apron in all ages of exposure ($P<0.003$). Although all the cancer risks for both groups are very low, using a lead apron could decrease breast cancer incidence ($[1.24\pm0.32] \times10^{-3}$ % over the apron vs. $[0.46\pm0.15] \times10^{-3}$ % under the apron) and mortality risk ($[0.30\pm0.08] \times10^{-3}$ % over the apron vs. $[0.11\pm0.04] \times10^{-3}$ % under the apron) about 63% in all patients.

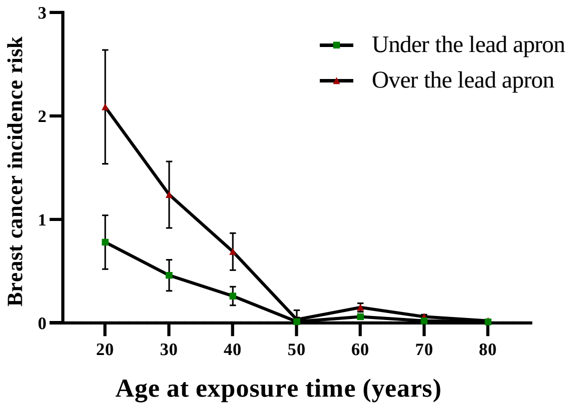

Figure 2. Mean±standard deviation values of lifetime attributed breast cancer incidence risks due to the head CT scan in the female patients over and under the lead aprons at different ages of exposures. Risk values are presented as incidence probability per 100,000 individuals.

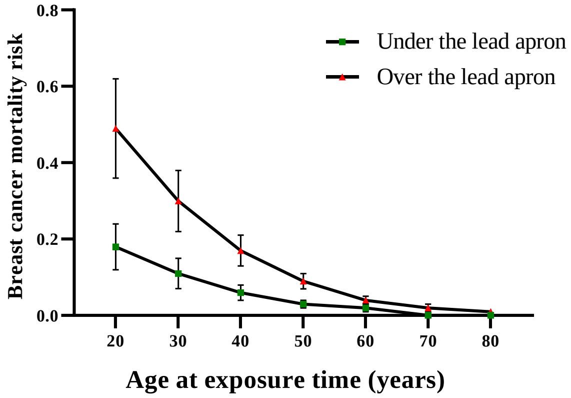

Figure 3. Mean±standard deviation values of lifetime attributed breast cancer mortality risks due to the head CT scan in the female patients over and under the lead aprons at different ages of exposures. Risk values are presented as incidence probability per 100,000 individuals.

Discussion

Previous studies declared that scattered radiation from the organs could be reached the radiosensitive organs. For example, ovaries are inevitably exposed to significant scatter doses during abdominal CT scans, and the thyroid is exposed to head and neck CT examinations [15,16]. Additionally, several studies have reported that the testis can receive the dose from chest CT scans [17-20].

Based on the National Radiological Protection Board (NRPB) recommendation, there is no such thing as a “harmless radiation dose” [21]; therefore, every method which can reduce the dose should be carried out, besides keeping the image quality compared to the primary beam. In this regard, in the present work, breast surface doses during the head CT examinations were estimated when the lead apron (commonly accessible in the radiology centers) was used. Additionally, breast radiation-induced cancer incidence and mortality risks were estimated.

TLDs were used for the dose measurements because of their small size, and the expected doses were sufficiently high to give accurate readings. In addition, a typical lead apron as an accessible tool was used in a way that its impact was reported when it was utilized for the testis regions during the chest examination [19].

In the current study, two TLD groups for measuring the dose values (dose received over and under the lead apron) were positioned from one breast side of each patient to calculate the effect of apron shielding for the same breast. It must be mentioned that the leakage radiations can be different in the spatial positions of the right and left breasts; therefore, comparing each breast with itself can be an appropriate method to avoid this problem.

In line with the current study, a few studies investigated the breast surface dose during the head examination because scattering radiation generated in the patient’s head and the gantry reaches superficial organs, particularly breasts [22]. In a study by Beaconsfield et al. [23], they assessed the effectiveness of a dental-style protective bib in reducing the dose to the radiosensitive organs. In this regard, the radiation doses over the breast (phantom model) were measured with a flat ionization chamber in 110 patients undergoing routine head CT scans. The results were compared with the shielded breast, and the average reduction of 76% in breast dose was obtained. In another study by Zalokar and Mekiš [9], they used a lead shield with 0.5 mm equivalent density for breast during head CT examination on an anthropomorphic phantom. They reported that the lead shield caused a significant dose reduction in both helical and axial CT protocols. In a way that this reduction was 96% in Hospital A and 82% in Hospital B for helical protocol, and 95% in Hospital A and 86% in Hospital B for axial protocol. Brnić et al. [22] found a 57 % dose reduction of the breast during the use of a lead apron (0.35-mm-equivalent lead density) in head conventional CT scanning. The radiation doses were measured by the TLDs located at the surface of the left unshielded breast, and the right breast was covered by a lead apron, in which the TLDs were positioned over the apron. Finally, the amount of scatter radiation was measured for the two breast sides, and the values were compared.

Furthermore, the same method of Brnić et al. was performed in a patient study by Chung et al. [24], and the breast surface dose reduction was obtained at 5.33, 17, 4.26, 5.36, and 2.16%, respectively, during the CT examinations of head, abdomen, lumbar, neck, and dynamic liver. The breast surface dose reduction was obtained at 63% during the head CT scan in our study. Also, there are several studies investigating the percentage of the dose reduction in the breast region during chest examinations using a bismuth shield [11, 25-29]. Figure 4 depicts a summary of the breast (surface) dose reduction in some other related studies performed on the phantom/patient during the head/chest examinations, compared with the present study. Although both patient and phantom studies would measure the breast scattered dose, in vivo (patient) measurement is a real clinical circumstance of patient positioning as well as variations of body geometry, which influence shielding possibilities. In general, the difference in the dose reduction may be attributed to the use of different shielding, various types of dosimeters, study models (phantom or patient), lead apron thicknesses, CT scan modalities (conventional or spiral), and different methods.

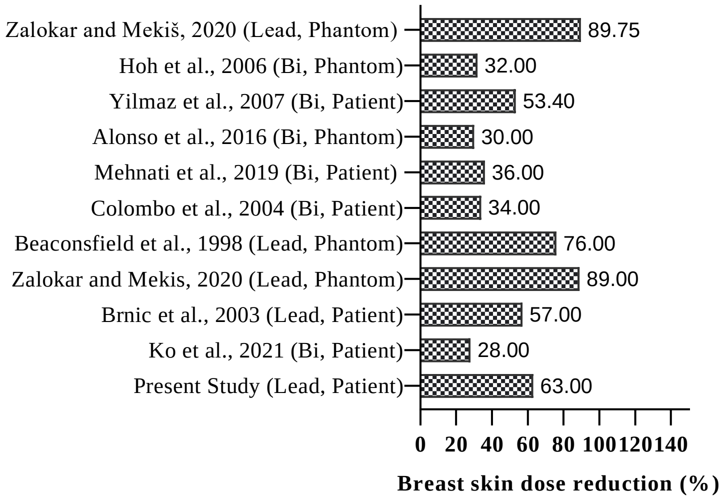

Figure 4. The dose reduction (%) in the breast during the head and chest CT examinations using lead and bismuth shielding in some studies. Patient: Patient study, Phantom: Phantom study, and Bi: bismuth. Bismuth shielding was used during the chest CT examinations, and lead apron was used during the head CT examinations.

Exposure to ionizing radiation is of concern because evidence has expressed that exposure to low-level ionizing radiation at doses utilized in medical imaging develops cancer [30]. Additionally, it has been reported that since the increasing use of CT scans and high exposure per examination, many cases of cancer result directly from CT [30]. Studies also reported that if head CT examinations are performed several times in the lifetime of a patient, the dose to the breasts (especially in younger women with glandular breasts) might accumulate to a significant level [22]. In this regard, breast shielding may be biologically significant in reducing breast radiation-induced cancer incidence and mortality risks during head scans. We obtained these findings when the lead apron was used for breasts during head CT. It is suggested that further study (based on our purpose) should be carried out on children group since their organs are more sensitive than adults.

Conclusion

As the results demonstrated, the common lead apron, a cost-effective tool that could be found easily in every center, reduced breast surface doses significantly (2.3 times) when used during the head MDCT scans in a patient study. Notably, breast radiation-induced cancer incidence and mortality risks were decreased remarkably in the presence (over) of the lead apron. Therefore, this lead apron shield would be recommended in the breast regions during routine head CT examinations.

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