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Original Article

Assessment of Thyroid Cancer Risk After Cervical Computed Tomography: The Impact of Bismuth Shielding

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Abstract

Background: Computed tomography (CT) is vastly applied in X-ray procedures because of its high quality in detecting the anatomical structures of the body. However, it leads to an increase in patient dose, resulting in carcinogenesis. In the head and neck CT, the thyroid is the most important at-risk organ. The aim of this study was to estimate thyroid cancer risk in cervical CT with and without a bismuth shield.

Materials and Methods: After obtaining permission from the authors, data related to the thyroid dose of patients undergoing cervical CT in the study by Santos et al (2019) were used, and then thyroid cancer risk was calculated for different ages at exposure in male and female patients using the biological effects of the ionizing radiation (BEIR) VII model.

Results: Using bismuth shielding reduced thyroid dose by 37% and 39% in male and female phantoms, respectively. Thyroid cancer estimation demonstrated that the risk was nearly two-fold in females compared to males. Finally, bismuth shielding reduced 40% of cancer risk, and it decreased in both genders by increasing age at exposure.

Conclusion: According to our findings, excess relative risk (ERR) up to 0.06% was associated with cervical CT. Although ERR amounts were low, the effect of radiation on thyroid cancer risk should not be neglected. Accordingly, it is suggested that future trials use bismuth shielding to reduce thyroid cancer risk.

Keywords: Thyroid cancer risk, Cervical CT, Bismuth shielding, BEIR VII model

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Introduction

Medical radiation is considered as a major technique for diagnosis and a part of treating certain diseases. The National Radiological Protection Board reported the contribution of artificial sources to medical radiations, among which 90% is associated with X-ray examinations (1).

Computed tomography (CT) is a widespread alternative among X-ray applications in medical imaging due to its high quality in detecting the anatomical structures of the body. Nonetheless, it increases the dose of radiation for the patients, which can be due to the scattered radiation, beam divergence, and the required efficiency of collimators and filtration. In comparison to other X-ray applications, radiology and fluoroscopy cause high doses of radiation to enter patients' bodies. The significant absorbed radiation dose of the CT scan, as compared to other medical imaging procedures, indicates the risk that this procedure can be hazardous in damaging radio-sensitive organs (2, 3).

During the CT examination, depending on the received dose, the organs in the scanned box (body exposed to direct radiation beam) are prone to potential damages, one of which can be carcinogenesis. The thyroid is the most important radiosensitive organ while performing the head and neck CT scan. The highest incidence of radiation-induced cancer has been reported for the thyroid, therefore, decreasing the thyroid dose for medical exposure is highly important. It should be noted that ionization radiation is as important as the changes in the lifestyle, gender, hereditary background, and environmental pollutants on the thyroid cancer risk (4, 5).

Some factors including a reduction in the tube current, short geometry scanner, and a decrease in the scanning length and time reduce the radiation dose in CT scanning. Moreover, some other factors are involved, including scanning modes, collimation, table speed, and pitch, along with shielding. All these factors are related to the scanner except for shielding, and they can be changed to some extent. The use of lead shielding is extremely helpful in decreasing the radiation dose to organs which are out of the scanned box. However, the bismuth shield can be used for the exposed organs that are in this box (6). There is an ample study which proves that bismuth shielding reduces the breast dose range from 37% to 59% during CT examination, especially in coronary CT angiography, but the bismuth shield can affect image quality by increasing noise and CT numbers (7).

An investigation on 680 000 young patients under 20 years of age, who were exposed to the CT examination, showed that the cancer incidence for these patients after a nearly 10-year follow-up was 24% greater compared to the unexposed ones. This increase in cancer was mostly due to irradiation since the cancer was continuing at the end of the follow-up (8). To the best of our knowledge, no study has so far evaluated the risk of thyroid cancer risk in cervical CT by considering bismuth shields. Therefore, this study aimed to estimate the thyroid cancer risk in cervical CT using anthropomorphic phantoms and to evaluate the impact of bismuth shielding on reducing thyroid cancer risk.

Materials and Methods

In our study, the thyroid-received dose in the study by Santos et al was used with permission from the authors. In nominated articles, the radiation dose for thyroid was measured during the cervical CT scan in the anthropomorphic phantom in the study. Based on these measurements, the thyroid cancer risk was estimated using the biological effects of the ionizing radiation *(*BEIR) VII model (9, 10).

Alderson Rando male and female anthropomorphic phantoms were applied for the cervical CT examination. The torso and head are structured into slices and 2.5 cm thick, and these slices make up the body phantom with holes allowing placing dosimeters within the phantom. The physical and chemical properties of these phantoms are similar in the soft tissue of the human body and are extremely useful in medical dosimetry (Figure 1). The radiation parameters were equal for the two phantoms. Slight differences were in these phantoms due to the height and weight of the female phantom compared to the male phantom (the heights in males and females were 200 and 150 mm, respectively).

A general electric (GE) CT scanner (Discovery model) with 64 channels was employed for the required purpose. Table 1 presents the parameters of the used cervical CT protocol in the study by Santos et al (9, 10).

Dose measurements were performed using Gafchromic XR-CT radiochromic film strips for kilovoltage to megavoltage X-rays for the purpose of dosimetry. The energy response of this film for the utilized energy in the CT (100-150 kVp) is relatively constant, indicating the use of a proper dosimeter for the required aim.

Gafchromic film strips are used for registering the individual doses of thyroid and other at-risk organs. However, due to the high sensitivity of the thyroid gland, this study only evaluated the thyroid dose to estimate the cancer risk. Moreover, in the study by Santos et al (9,10), a bismuth shield with the thickness of 1 mm was applied to protect the thyroid during the CT examination, and finally, the thyroid dose was measured with and without the bismuth shield in the cervical CT for male and female phantoms.

The mean thyroid absorbed doses in the cervical CT in male and female phantoms are provided in Table 2. The results demonstrated that the bismuth shield can decrease the absorbed dose.

Several models are suggested for estimating the cancer risk that have basically been modeled by atomic bomb survivors, in patients undergoing radiotherapy for Hodgkin cancer, and the ones who were exposed to and received a low-to-high dose of radiation after the Chernobyl disaster (11-14). The applied model in our study was BIER VII, which is based on the analysis of atomic bomb survivors and is used for doses below 1 Gy and with low linear energy transfer radiation. The BEIR VII model uses the excess relative risk (ERR) to estimate thyroid cancer risk. ERR is defined as the incidence of disease in the exposed population minus the one in the unexposed population. According to the BEIR VII model, the incidence of thyroid cancer is independent of the attained age, therefore, the ERR of the thyroid is a function of the absorbed dose and age. In this study, the risk of thyroid cancer was calculated for patients who

Table 1. Exposure Parameters in the Cervical Protocol (9,10)

	kV	mA	Time (s)	Pitch	Distance (mm)	Thickness Beam (mm)
Male	120	175	0.8	0.984	200	40
Female	120	175	0.8	0.984	150	40

Table 2. Mean Thyroid Absorbed Dose in Different Phantoms

	Mean Thyroid Dose (mGy)	
	Without Bismuth Shielding	With Bismuth Shielding
Male	24.70	15.09
Female	24.59 ± 0.69	15.51 ± 0.33

Note. Standard deviation was not reported by the author for male phantom (9,10).

Figure 1. Positioning of the Male and Female Alderson Phantom Without (Female) and With (Male) the Bismuth Shielding on the Thyroid Gland. *Note*. Copyright permission was obtained from the author and the editor for using these images.

were in the age range of 20-70 years.

$$ERR_{Thyroid\ cancer}(D, s, e) = B_S D \exp(\gamma(e - 30/10))$$

where D, e, and a indicate the average organ dose, age at exposure, and the attained age of disease, respectively. B_S is defined as ERR at age-at-exposure 30 and the attained age of 60, the amounts of which are 0.53 and 1.05 for males and females, respectively. In addition, $\gamma = -0.4$ implies the radiogenic risk of cancer at the age of exposure decreases by about 25% for every decade increase in age-at-exposure up to the age of 30.

Results

After measuring the mean thyroid dose with and without the bismuth shield, the ERR/mGy rates were determined for different ages at exposure. According to the model, thyroid cancer depends on the dose and age at exposure. Therefore, the attained age has no impact on the calculations. Figure 2 illustrates ERR for the age range of 20-70.

Based on the results, the use of the bismuth shield led to a decrease in the received dose of radiation. The highest thyroid cancer incidence was related to the 20-year old females who used no shields.

The use of bismuth shielding is simple and efficient in reducing the absorbed doses and thus the thyroid cancer risk. According to these results, the ERR of thyroid cancer in men was about half of the one in women. High values of thyroid ERR in women can be due to the higher radiosensitivity of the thyroid of females to the radiation exposure. The risk of thyroid cancer is extremely higher in patients undergoing cervical CT for cancers in the third and/or fourth decades of their lives compared to those in other age groups. After 50 years, radiation exposure had no significant effect on thyroid cancer risk.

During the CT examination, the bismuth shield leads to approximately the two-fold attenuation of the primary beam before it reaches the patient. Through attenuating primary X-ray beams, which are defined as beam hardening, this shield reduced dose to only the anterior surface of organs in the scanned volumes. In cervical CT, the bismuth shield reduced the thyroid dose when the tube was located in front of the patient. Nevertheless, this shield did not affect thyroid dose reduction by rotating the tube and positioning it at the lateral and posterior of the patient.

Although the bismuth shield affects image quality by increasing the noise under the shield and the absorption of photons exiting from the patients, changes in image quality due to bismuth shielding are limited to the distance of 1-2 cm from the shield. The effect of this shield on image quality is shown in Figure 3b. The noise could be noticed in the anterior part of the phantoms using the bismuth shields.

Discussion

Thyroid cancer risk was estimated in this study on the cervical CT scan with and without bismuth shielding

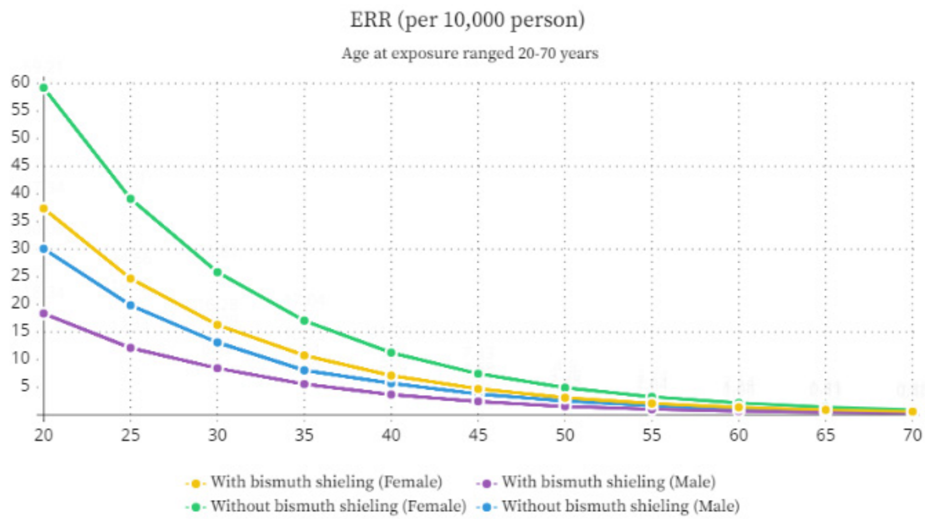

Figure 2. ERR/mGy in 10000 Men and Women Using the Bismuth Shielding. *Note*. ERR: Excess relative risk.

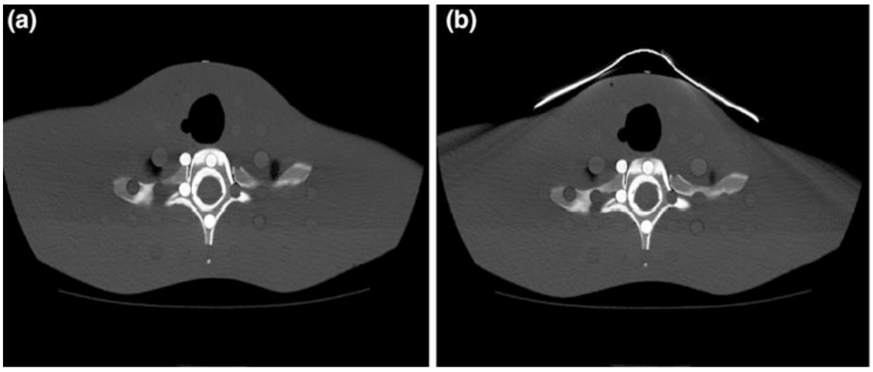

Figure 3. Axial Cervical CT Images: (a) Without and (b) With Bismuth Shielding Over the Neck in a Female Phantom. *Note*. CT: Computed tomography. Copyright permission was obtained from the author and the editor for applying these images.

in male and female anthropomorphic phantoms. The estimation revealed that the ERR of thyroid in females was nearly twice as much as that in males, and reduced with an increase in age in the two genders. The use of bismuth shielding decreased the thyroid radiation dose to 37% and 39% in male and female phantoms, respectively. Bismuth shielding could reduce the ERR of the thyroid up to 40%, but this shield degraded image quality and increased the image noise.

Gender can affect the prolonged response to radiation, and the radiosensitivity of males is lower than that of females receiving similar doses. The most common radio-induced cancer-associated morbidities in females and males were related to the thyroid. However, the thyroid cancer incidence occurs in females of all age groups while it happens in males who are older than 50 years of age (15).

Bismuth shields reduce the radiation dose to superficial organs such as the thyroid or breast in the CT scanning of the head although it affects the image quality and the absorption of photons that exit from the patients in spite of the fact that this effect is not quite obvious. In addition to using the standard protocols in the CT, several approaches are used to decrease the radiation dose for these organs, including bismuth shielding, organ-based tube current modulation, and a decrease in the tube current. The results showed that one layer of bismuth shielding reduced the radiation dose to the anterior surface (26%), and the organ-based tube current modulation decreased the dose to the anterior surface while increasing lateral and posterior surfaces. However, reducing the tube current led to a decline of 30% in the dose to all surfaces (16).

The assessment of the impact of bismuth shielding on decreasing the superficial radiation dose in CT demonstrated that measurements were obtained with the head of *polymethyl methacrylate* phantoms and chamber ionization. The superficial dose in 120 kVp with and without the shield was 2.15 and 3.45 mGy (vs. 0.63 and 1.26 mGy for 80 kVp), respectively, and the bismuth shield could reduce the superficial dose by 38% and 50% for 120 and 80 kVp protocols, respectively. In this study, the dose reduction was lower compared to the study by Santos et al, which could be due to different exposure protocols (17).

Based on the evaluation of thyroid cancer risk from the cervical CT on pediatric patients with trauma, the radiation dose on thyroid was 63.6 and 64.2 mGy in male and female patients during the CT examination, respectively, and the ERR of thyroid cancer was almost two-fold in female patients. The results of this study revealed that the highest ERR of thyroid cancer for the children was in the range of 0-6 years, therefore, shielding is necessary for children (18).

The evaluation of thyroid cancer risk in patients undergoing 64-slice brain and paranasal sinuses CT scan showed that in both brain and paranasal sinuses CT, ERR values in female patients were twice as many as those in male patients. ERR was considerably more in the age range of 20-40 years compared to the age range of 40-60 years since young patients are more radiosensitive in comparison to old patients. Although ERR values are low, impacts on thyroid cancer incidence are not negligible (19).

Mehnati et al assessed the effect of bismuth shielding on dose reduction and image quality in CT and found that bismuth shields were effective in decreasing the patients' superficial radiation dose without significantly lowering image quality. They recommended that performing a foam of optimum 1-2 cm thickness can be effective in decreasing the noise of images acquired with bismuth shielding (20). Therefore, performing bismuth shielding can be an effective technique for reducing thyroid cancer risk in cervical CT.

Conclusion

According to our findings, ERR associated with cervical CT increased up to 0.06% while it decreased from 0.06% to 0.04% and from 0.03% to 0.02% in females and males by adding bismuth shielding, respectively. Using the bismuth shield significantly reduced the thyroid dose and thus thyroid cancer risk. Although ERR values are low, we should not neglect the radiation impacts on thyroid cancer incidence. According to our results, it is suggested that other trials use bismuth shielding to reduce the thyroid cancer risk. However, this shield can affect image quality which is not considerable.

Conflict of Interest Disclosures

The authors declare that they have no conflict of interests.

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Ethical Statement

After obtaining permission from Dr. Santos, data related to the thyroid dose of phantoms undergoing cervical CT were used in our paper.

Author's Contributions

HG: Conceptualization, the original draft writing, investigation, and formal analysis; HG and ZM: Conceptualization, supervision, and project administration; HG, ZM, and SG: Conceptualization, and project administration; HG: Investigation; HG and ZM: Writing including reviewing and editing and investigation.

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Informed Consent

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