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Organ Dose Evaluation of Head Computed Tomography Scans Using a Male Anthropomorphic Phantom

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Abstract: Computed Tomography (CT) has been one of the most used exams for radiologic diagnostic in medicine. The increase in CT scans is a global concern due to the increase in radiation doses in the population. The head CT scans helps to diagnose disorders that affect the brain, including tumors, infarction, bleeding within the brain, hematoma, and other diseases. The aim of this work is to verify the reduction of absorbed dose in patients in head CT scans with the use of bismuth shielding and positioning with the head tilted. An anthropomorphic male phantom model CIRS ATOM 701 were used to perform the head CT scans, from the cervical vertebra C1 to the top of skull, in a Toshiba CT scanner, Prime Aquillion model with 80 channels. Radiochromic film strips were used to evaluate the doses in the organs such as lenses, thyroid, hypophysis, spinal cord, breasts and salivary glands. Three head CT scans were performed, with the phantom in supine position, using the same acquisition protocol, with and without bismuth shielding and with the head tilted without the bismuth shielding. The results of these experiments showed absorbed doses ranging from 0.66 to 47.16 mGy. The highest dose of 47.16 mGy were in the lenses without bismuth shielding and with bismuth shielding was 33.01 mGy. Also, the dose with the head tilted was 20.42 mGy. The recorded doses were lower with the head tilted for all organs, mainly in the lenses. The analysis of noise in the image of the head central slice presented acceptable values for soft tissues, less than 1%.

Keywords: Computed Tomography, Dosimetry, Bismuth Shielding

1. Introduction

Computed Tomography (CT) is the most frequent technique used for diagnostic purpose. It is a very fast test that performs high quality images. However, the increasing demand for CT testing has a considerable impact on the doses delivered to patients and on the exposure of the population as whole [1, 2]. According to the report of the International Commission on Radiation Protection, the main disadvantage of the CT is the relatively high dose radiation compared to other X-ray imaging modalities [3]. According to some studies report, CT contributed 49-68% of the collective dose from diagnostic radiology examination [4]. It is estimated that 25 to 33 people die from fatal cancers caused by ionizing radiation during this radiological examination process in every 100,000 examinations [4, 5]. Many factors collaborated to the increased demand for CT scans, including the technological evolution of the equipment associated to greater availability and a relative tendency to decrease exam costs [5]. Dose assessment in CT is one of many steps that can help reduce the patient's dose.

The head CT scans are often used, and some people may need several head CTs in their lifetime for diagnosis of traumatic head injuries, infections, and other diseases with instability. Then it can be associated with a high radiation dose to organs such as lenses, parotid gland, and hypophysis, when compared with conventional radiology. The absorbed dose in organs with higher radiation sensitivity levels are object of continuous discussions, because of the risks that this can bring to health issues [5, 6]. The lens is one of the organs located in the skull with relatively high radiosensitivity and receive the X-ray primary beam during a head CT scan. To prevent radiation induced injuries to the lens, CT eye shields made of bismuth, barium, or lead have been used [7]. The purpose of this work was to analyze the variation of absorbed dose in patient at head CT scan without and with the use of bismuth shielding, and with the head tilted.

2. Materials and Methods

The experiments were conducted using a Toshiba CT scanner Prime Aquillion model, with 80 channels. An anthropomorphic male phantom model CIRS ATOM 701 was used in the head scans from the cervical vertebra C1 to the top of skull. This phantom is built with different polymeric materials that simulate human tissues. The body and head are structured in transected horizontally into 2.5 cm thick slices. The slices that make up the body phantom have holes that allow placing dosimeters within the phantom [11-13]. The parameters of the acquisition protocols are shown in Table 1. The distance used for head CT scans with and without bismuth shielding were 140 mm and with the head tilted 120 mm.

Table 1. *CT scan parameters.*

Voltage (kV)	Electric current (mA)	Tube Time (s)	Pitch	Thickness beam (mm)	Reconstruction
120	175	0.8	0.984	40	2.5

All CT scans were performed with the same acquisition protocol with the phantom placed in the isocenter of gantry. In Figure 1 is shown the phantom placed in the gantry isocenter. In a it is positioned in supine without bismuth shielding, in b with the eye bismuth shielding and in c with the head tilted without bismuth shielding.

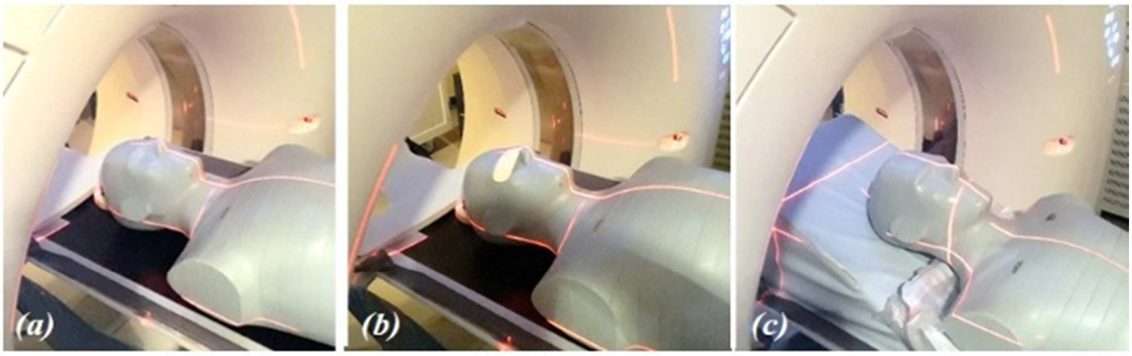

Figure 1. *Positioning of the phantom in the gantry: without bismuth shielding (a), with bismuth shielding (b) and with the head tilted (c).*

In this work, dose measurements have been performed using the radiochromic film model GAFCHROMIC® XR-QA2, manufactured by ASHLAND, which is specific for diagnostic radiology. This film has high sensitivity to ionizing radiation with doses in the range of 1.0 to 200 mGy and can be used in X-ray beams generated by voltages of 20 to 200 kV. Therefore, it can be used to observe dose deposition in CT experiments.

The films were cut into 1.0 x 0.5 cm^2 strips and subsequently placed at each point of interest inside the phantom or on its surface, according to the proximity of the desired organ [8, 9].

Radiochromic films used in dosimetry are not sensitive to visible light. This feature facilitates the work of analyzing data collected after irradiation and provide greater spatial resolution in the sub millimeter range. Figure 2 shows two radiochromic film strips, one not irradiated (a) and another irradiated (b). They have been used extensively in combination with flatbed document scanners to measure absorbed doses in patients [9-11].

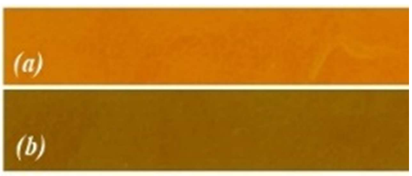

Figure 2. *Radiochromic film strips: not exposed or background (a) and exposed (b).*

Metrological reliability of the radiochromic films was demonstrated through homogeneity and repeatability tests and by calibrating it in a reference radiation for CT (RQT9) that were reproduced in the Calibration Laboratory of the Development Center of Nuclear Technology (CDTN/CNEN) [14].

Digital images of the film strips were obtained using a HP Photosmart C4480 reflective type scanner. The scanning parameters used were RGB mode (48 bit) and 300 ppi. The red channel was selected to measurement because these radiochromic films have a main absorption peak in the red region of the visible spectrum (636nm) [15].

Calculations of the absorbed dose of CT were made using the calibration curve of the Equation 1 by the darkness intensity from the film strip [15-16]. The punctual absorbed dose values (DT) were acquired by subtracting the doses recorded in the film strip placed in the organs of the background (BG) absorbed dose.

$$D_T(mGy) = \left(5{,}30587\left(\frac{-Meanofvalues}{-50{,}69695}\right)\right) + (11{,}38213) \quad (1)$$

After obtained the absorbed dose recorded in the film strip, the BG dose value was subtracted. Finally, the acquired results were multiplied by a Correction Factor (CF), to correct the air Kerma value for absorbed dose in soft tissues. The CF value was obtained through data of linear attenuation coefficients for X-rays that can be consulted on the website of the National Institute of Standards and Technology (NIST). The to the CF used in this work was 1.042 [17].

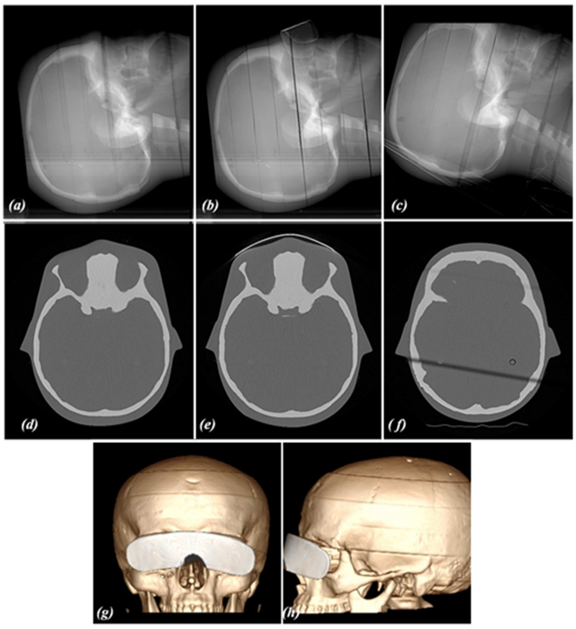

Figure 3. *CT head images: without eye shielding (a, d), with eye bismuth shielding (b, e) and head tilted (c, f). The 3D reconstruction image with bismuth shielding: frontal (g) and lateral (h).*

The head CT images of this work are shown in Figure 3 with three lateral radiographies *(scout*) in *a, b* and *c*, three axial head images from slices of 1 mm thick in *d*, *e* and *f*. The images *a* and *d* are from the CT scan without bismuth shielding, *b* and *d* with the bismuth shielding and *c* and *f* with the head tilted. The images *g* and *h* are frontal and lateral view of a 3D reconstruction using the bismuth shielding on the eyes.

To validate the quality of the image by CT was done the noise analysis from the image of the central slice of the phantom head in each of the experiments to determine the influence of the secondary radiation in the quality of the image. The RadiAnt DICOM Viewer software, which is an image format viewer of the Digital Imaging Communications (DICOM), was used in this evaluation.

3. Results

Absorbed doses in the organs are shown in the Table 2. Based on these results, it can be concluded that the use of the bismuth shield resulted in a reduction of the absorbed dose deposited in the eye and in all the organs studied. Even with the head tilted, the absorbed dose was lower in all organs.

Table 2. *Absorbed dose in organ positions in head CT scans.*

Organ	**Average absorbed (mGy)**		
	Without bismuth shielding	**With bismuth shielding**	**Head tilted**
Eye Lenses	47.16±0.55*	33.02±0.62	20.42±0.78
Hypophysis	30.43±0.93	26.67±0.92	18.17±0.85
Pharynx	14.45±0.44	11.60±0.85	5.99±0.88
Spinal Cord	5.62±0.58	4.86±0.74	3.70±0.59
Parotid Gland	46.01±0.58	43.40±0.65	4.48±0.73
Salivary Glands	7.55±0.66	6.23±0.93	3.15±0.78
Thyroid	2.22±0.50	2.11±0.89	2.02±0.51
Breasts	1.27±0.61	1.16±0.78	0.66±0.43

* Standard deviation.

The absorbed doses varied from 0.66 to 47.16 mGy. The highest recorded dose was 47.16 mGy and occurred in the eye lenses, which emphasized the situation of unnecessary radiation exposure. The influence of bismuth shielding, and positioning of the head resulted in a reduction of the absorbed dose of 33.02 mGy and 20.42 mGy, respectively. For organs such as the lenses, pharynx, parotid glands, and hypophysis, the influence of the head tilted in absorbed dose is greater compared to the use of bismuth shielding.

When comparing the absorbed dose results between bismuth shielding and tilted head with the male phantom, the absorbed doses of the lenses were 29.9% and 57.7% lower when bismuth shielding and tilted head were used, respectively. The highest recorded dose was 47.16 mGy in the eye lenses, which emphasizes the situation of unnecessary radiation exposure. The parotid gland was reduced by 5.6% with shielding and 90.2% with tilted head. In the region of the hypophysis the differences in absorbed dose were 12.3% with the use of shielding and 40.2% with the head tilted. For the salivary gland region, differences of 17.4% with bismuth shielding and 58.2% with tilted head were determined. Dose values measured in the pharynx differed from 19.7% with shielding and 58.5% with tilted head. The thyroid gland showed minor variations to small dose values compared to the values of directly irradiated organs, and more distant organs such as the spinal cord and breasts did not show significant dose variations.

It is expected that eye shielding would degrade image quality and increase image noise. However, the result of this work suggests that it might be an acceptable method for dose reduction, especially in CT examinations where radiation-sensitive organs are exposed to high doses. Analysis of image noise in the central slice of the head revealed acceptable values for the soft tissues, less than 1%.

Using the graph in Figure 4, it is possible to verify that CT scan with the head tilted results in a significant reduction in absorbed dose in the eye lens, parotid gland, hypophysis, and pharynx. In the thyroid, breasts, salivary gland and spinal cord, the use of bismuth shielding with the head tilted results in a small reduction in absorbed dose.

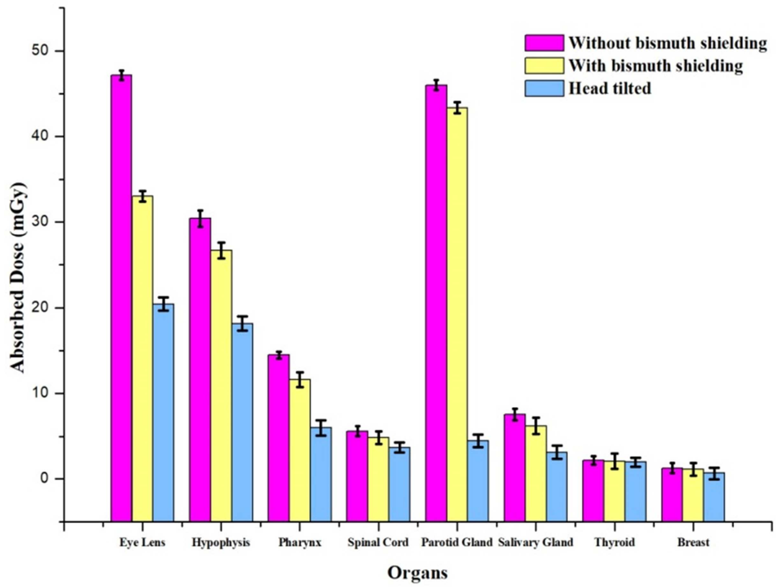

Figure 4. *Absorbed doses in the organs.*

4. Conclusion

Absorbed doses were determined during head CT scans with and without eye bismuth shielding and with the head tilted of a CIRS ATOM male anthropomorphic phantom.

The use of bismuth eye shielding in head CT scans proved effective in reducing the absorbed doses in the organs studied and especially in the lenses. The quality of the images had noise rates of less than 1%, being adequate for medical diagnosis.

The proposed technique of tilted the patient's head to reduce the dose in CT head scans proved to be the best option to reduce the absorbed doses of the lens and organs studied in this work. It is important to emphasize that this technique is more viable than tilting the gantry, since tilting is not routinely used in radiologic imaging centers, although studies have demonstrated the efficiency of this technique.

The data obtained from the use of bismuth shielding and with the tilted head endorse that absorbed doses can really be minimized and that process optimization is possible.

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