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Radioprotection in Chest CT

An Approach with Bismuth Breast Shield

The main goal of this study was to assess the viability of the bismuth breast shield in chest computed tomography (CT) examinations. Dose measurements on a phantom (Cardinal Health 76 415) with an ionisation chamber were performed with and without bismuth breast protection in different configurations using the routine chest CT protocol. Image quality control was performed using a phantom (Gammex 464). In all measurements with bismuth protection (no sponges), we observed a dose decrease of 22.6%. Dose decreased by 19.9% with protection (one sponge), 17.6% with protection (two sponges) and 28.2% with the protection coupled to the gantry. It is therefore appropriate to implement the protection configuration coupled to the gantry as a protective measure for patients undergoing chest CT scans.

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The indiscriminate use of ionising radiation for diagnosis and therapy purposes has increased significantly due to the fast development and easy access of CT equipment, and, in several cases, to weak justification of these examinations.

Since 1993 the number of CT exams in the United States has tripled to 70 million exams per year. Approximately 29,000 of the US population are at high risk of developing cancer as seen by the CT scans conducted (Berrington de González et al. 2007). In Europe, a survey about European population doses from medical imaging took place in 2015 (European Commission 2015). The participating 36 countries reported the average frequencies per 1000 of the population, for the top 20 groups, compared with similar data from the 10 European countries in the Dose Datamed 1 project and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Health Care Level 1 (HCL1) countries.

In all CT groups, average frequencies have significantly increased, and in some cases have more than doubled (for CT trunk, the increase was approximately threefold). These CT examinations represent a total of 55% of relative contributions of the four main groups (plain radiography, fluoroscopy, CT and interventional radiology) to overall collective effective dose.

A CT scan subjects the human body to between 150 and 1,100 times the radiation of a general x-ray, or around a year's worth of exposure to radiation from both natural and artificial sources in the environment (Storrs 2013). Therefore, there is a need to create measures and procedures to protect the patient from the biological effects of ionising radiation, which varies according to the cells' radiosensitivity and the absorbed radiation dose. At the same time, it should be noted that the tissue weighting factor (W_T) value has changed in the publications of the International Commission on Radiological Protection (ICRP) from 0.05 to 0.12 (Wrixon 2008).

The development of biological effects occurs in two ways: 1) the deterministic effects, caused by high doses of radiation in a short period of time (eg radiodermatitis) and 2) the stochastic effects caused by doses received over a long period of time (eg cancer). Thus the main objective of radiation protection is to avoid the occurrence of deterministic effects and guarantee that stochastic effects are kept to an acceptable level (Canevaro 2009; Lima 2009).

> “NEED TO CREATE MEASURES AND PROCEDURES TO PROTECT THE PATIENT FROM THE BIOLOGICAL EFFECTS OF IONISING RADIATION”

The use of bismuth protection presents some controversies regarding its practical application (Tappouni and Mathers 2013; Zhang and Oates 2012). In 2012 McCollough, Wang and Gould published a Point/Counterpoint, which consisted of a debate with favourable and unfavourable views relative to bismuth protection (McCollough et al. 2012). Gould advocated the use of bismuth protection in CT scans, since no evidence of diagnostic error due to the use of bismuth protection was published. In addition, the radiographers training to use this protection found the image interpretation relatively simple. However, McCollough refutes the application of bismuth protection when using Automatic Exposure Control (AEC). The author argues that the protection of bismuth in the breast during CT examinations decreases the image quality, verified through the increase of Hounsfield Units (HU) and noise.

Given the above, the aim of this study was to determine the percentage of dose reduction obtained by the phantom using a bismuth breast shield in different configurations. It was also to assess their viability in

Figure 1. Phantom Cardinal Health 76-415 with bismuth shield coupled to the gantry, next to the detectors window

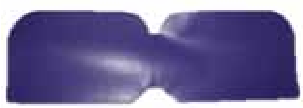

Figure 2. Bismuth Breast Shield

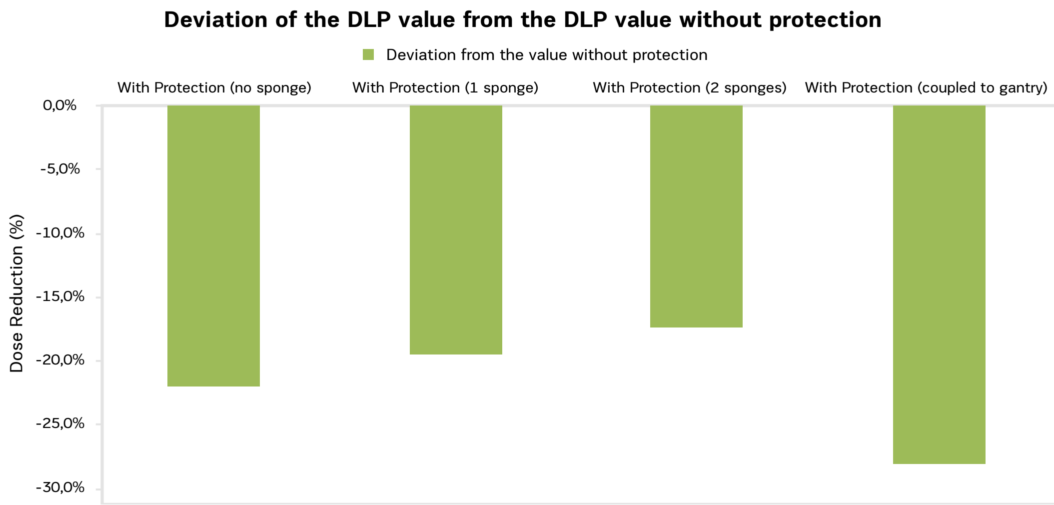

Figure 3. Distribution of the percentage reduction of DLP value with bismuth breast shield in different configurations in relation to the DLP value without protection

chest CT examinations through the evaluation of image quality, taking into consideration a broad range of scanner parameters (HU value or CT number accuracy; low and high contrast resolution, noise and artifacts).

Materials and Methods

135 measurements were made using a 16-slice CT scanner with and without bismuth breast shields in different configurations (**Figures 1 and 2**):

- Configuration 1: without bismuth breast shield
- Configuration 2: with bismuth breast shield, without sponge (directly on the phantom)
- Configuration 3: with bismuth breast shield, with one sponge (1cm of thickness)
- Configuration 4: with bismuth breast shield, with two sponges (2cm of thickness)
- Configuration 5: with bismuth breast shield, attached/coupled to the detectors window at the gantry

Dose measurements were performed on a phantom (Cardinal Health 76-415) with an ionisation chamber, taking into consideration the configurations indicated above using the routine chest CT protocol (130 kVp, 70 mAs; collimation of 4x1.2mm, rotation time of 0.6 sec. and Pitch=1). This phantom is 32cm in diameter and 15cm in length. The placement of the bismuth breast shield was only made after acquisition of the topogram, due to the automatic exposure control (AEC).

- To determine and evaluate the dose, $CTDI_w$, $CTDI_{vol}$ and DLP values were calculated:.
- $CTDI_W$ value was calculated using the weighted mean of CTDI values obtained at the centre of the phantom and at the four peripheral points (equation 1):
  $CTDIW=13\times CTDI_c+23\times CTDI_p$
- The $CTDI_{Vol}$ value was calculated taking into account the pitch value used in the acquisition (equation 2):
  $CTDI_{Vol}=CTDIW_{pitch}$:
  $CTDI_{Vol}=CTDIWpitch CTDI_{Vol}=CTDIW_{pitch}$
  Finally, the DLP value was obtained considering the range length (L) (equation 3): $DLP=CTDI_{Vol}\times L$:

Image quality control tests were performed using the phantom (Gammex 464) for the same configurations, using the chest and abdomen routine protocol. This phantom consists of solid water (0 ± 5HU) with a length of 16cm and diameter of 20cm, and is divided into four modules (Supertech 2013):

- Module 1: To evaluate the positioning and alignment, CT number accuracy (HU values in cylinder material equivalent to bone, polyethylene, water, acrylic and air) and slice thickness. The measurement was made using the window WW=400 and WL=0, and a region of interest (ROI) of 200mm^2 was placed on each material in different configurations. The analysis of HU was calculated by the means obtained for each material and its compliance was determined from the tolerance interval values presented by the American College of Radiology (ACR) CT accreditation phantom instructions (2013).
- Module 2: Low contrast resolution. This features a series of cylinders with different diameters (2, 3, 4, 5, 6 and 25mm), all at 0.6 % (6HU) difference from the background material. Using a window of WW=100 and WL=100, it was possible to visualise the cylinder with the largest diameter (25mm) and place the ROI of 100 mm^2 on that cylinder (A) and place another ROI on the left (B) of the cylinder. The contrast in the image was obtained through the contrast-noise ratio (CNR) of both ROIs where

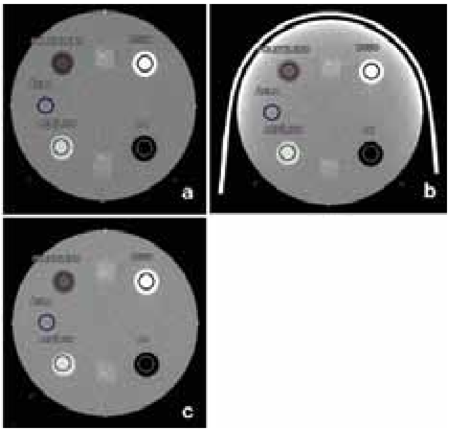

Figure 4. Regions of interest for each material on module 1 in different configurations: (a) without protection (b) with protection and one sponge (c) the protection attached to the gantry

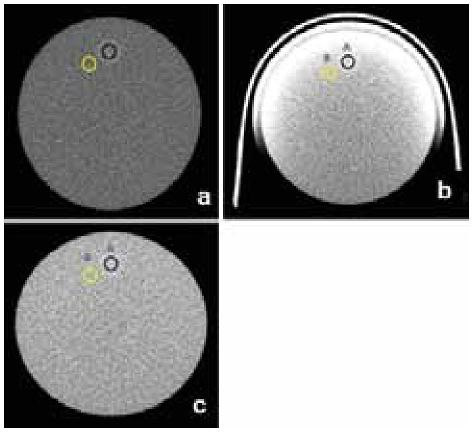

Figure 5. Regions of interest for each material related to module 2 in the different configurations: (a) without protection (b) with protection and one sponge (c) with protection coupled to the gantry

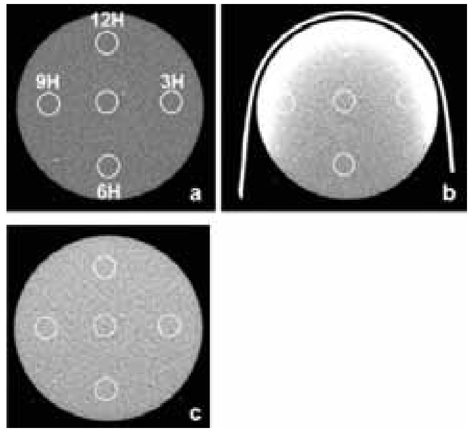

Figure 6. Regions of interest for each material related to module 3 in the different configurations: (a) without protection (b) with protection and one sponge (c) with protection coupled to the gantry

SD is the standard deviation of ROI B (equation 4). As it was not intended to evaluate the CT equipment quality, the CNR values were compared with bismuth shield against the CNR value obtained without protection in the phantom:

- CNR=|A-B|*SD*:
- Module 3: CT number uniformity assessment. This includes two small targets for testing plane distance measurement accuracy. With a window of WW=100 and WL=0, five 400mm^2 ROIs were positioned as follows in the phantom: 12H, 9H, 6H, 3H and in the centre. Values were assessed by comparing the periphery ROI values with the central ROI, where the ROI value should be between -7 HU and 7 HU. Peripheral ROIs must be within ± 5 HU in relation to the average obtained in the central ROI.
- Module 4: High contrast (spatial) resolution. This contains eight high contrast solution patterns of 4, 5, 6, 7, 8, 9, 10, and 12 line pairs per cm (pl/mm). With a window of WW=100 and WL=1110, with reduced room illumination to facilitate analysis, we observed the maximum amount of pl/mm in the image of the phantom with and without the bismuth shield in the different configurations. According to the ACR phantom testing instructions (American College of Radiology 2017), more than 6 pl/mm should be visualised for the chest protocol, and at least 5 pl/mm should be visualised for the abdomen protocol.

Results

Dose Assessment

In this study, we evaluated the dose rates for the routine chest protocol by taking into consideration the dose received by the phantom with and without the bismuth breast shield in the different configurations. The values of $CTDI_{Vol}$, DLP are presented in **Table 1**.

The DLP values in the configurations present different variations, such as: configuration 1 (5.04 mGy.cm), configuration 2 (3.90 mGy.cm), configuration 3 (4.04 mGy.cm), configuration 4 (4.15 mGy.cm) and configuration 5 (3.62 mGy.cm). The percentage of deviation from the DLP to the value without protection was, as shown in **Figure 3**, 22.6 percent with protection but without sponge; 19.9 % with protection and with one sponge; 17.6 % with protection and with two sponges, and 28.2 % with protection coupled to the gantry.

It was found that the percentage of dose reduction was higher when sponges were not used, compared to when they were used. When coupled to the gantry, the bismuth shield reduced the dose in the phantom by 28.2 %.

Configuration	$CTDI_{vol}$ (mGy)	Standard Deviation to the value without protection	DLP (mGy.cm)	Standard Deviation to the value without protection
1. Without protection	2.52	0.0%	5.04	0.0%
2. With bismuth breast shield (no sponge)	1.95	-22.6%	3.90	-22.6%
3. With bismuth breast shield (1 sponge)	2.02	-19.9%	4.04	-19.9%
4. With bismuth breast shield (2 sponges)	2.08	-17.6%	4.15	-17.6%
5. With bismuth breast shield coupled to the gantry	1.81	-28.2%	3.62	-28.2%

Table 1. $CTDI_{vol}$ and DLP values in different configurations, and a comparison with the value without protection for the chest CT protocol

Image Quality Control

The evaluation of image quality control in this study was performed by comparing the images obtained with the phantom when no protection was used with when the bismuth shield was used in the different configurations.

In module 1 it was found that with the bismuth shield, HU values for polyethylene, acrylic, air and water are not within the tolerance range for both chest and abdomen protocols. Bone was the only material within that range (**Figure 4**). In module 2 (**Figure 5**), the CNR values without the protection were 0.8 and 1.5 for the chest and abdomen protocol, respectively. Small changes in CNR values were observed with protection in the different configurations and both protocols: configuration 2 (1.2 and 2.0); configuration 3 (1.1 and 1.6), configuration 4 (0.9 and 1.4) and configuration 5 (0.7 and 1.1). As the protection of the phantom shifts away, CNR value tends to approach the CNR value without protection.

In module 3 (**Figure 6**), it was observed that without protection on the phantom, all the ROIs (12H, 9H, 6H, 3H and centre) were within the tolerance range. When the bismuth shield was placed on the phantom without and with a sponge, there was no uniformity of the periphery ROIs in relation to the central one. With the bismuth shield coupled to the gantry, it was found that periphery ROI values were within the tolerance range, except the central ROI.

In module 4, for both protocols, it was possible to identify 7 pl/mm in all configurations using a B41s kernel (soft tissue) and 9 pl/mm for a B50s kernel (lung parenchyma).

Overall results indicate that the dose values obtained with one sponge and two sponges did not reduce the dose as expected, which was influenced in some way by the interaction of radiation with the bismuth shield. The backscattering effect is what best explains this phenomenon, in which the photons when exiting the x-ray tube interact with a surface and produce secondary/scattered radiation. This, when produced in all directions, can be limited by the use of protection. Due to the presence of the sponges, a propagation medium was created, resulting in an absorption of some radiation dispersed by the phantom, and leading to a dose reduction of only 19.9% and 17.6%.

Another possible reason comes from the fact that in these two configurations, the 360° x-ray tube rotation, when emitting the primary beam in the posterior region of the phantom, allowed the secondary radiation released in the anterior region to collide with the bismuth protection and resume being absorbed by the phantom.

Once the protection was placed near the detector window, the above-mentioned effects were found to be lessened, contributing to a greater percentage reduction of 28.2% of the dose.

Conclusion

In this study, the reliability of the bismuth protection in the different configurations was verified, percentage of dose reduction was determined, diagnostic image quality was checked and the influence of bismuth breast shield coupled to the gantry in the normal functioning of CT scans was tested.

In the configuration with bismuth shield but without sponge, a dose reduction percentage of 22.6% was observed. However, the image quality was adversely affected with respect to the uniformity and presence of streak artifact. Although the configurations with one or two sponges are slightly better than the previous configuration in terms of image quality, the benefit in terms of dose reduction percentage is low.

The configuration with protection coupled to the gantry was the most acceptable in this study, proving that the low contrast resolution, noise and the spatial resolution were in agreement, without negatively affecting the image quality. It was also found that streak artifacts were lessened in this configuration.

In conclusion, and having obtained acceptable results in image quality with a decrease in radiation dose in the phantom, it would be pertinent to implement this protective measure in CT examinations as a routine procedure, especially considering that it allows a reduction in breast irradiation. ■

KEY POINTS

- ✓ A theoretical framework on the use of bismuth shield presents some controversies regarding its practical application (Zhang & Oates 2012)
- ✓ The results of this study suggest that radiographers should use a bismuth breast shield coupled to the gantry during chest CT examinations as a radioprotection measure
- ✓ Radiation dose decreased between 17,6% and 28.2% in several configurations of bismuth breast shield using the routine chest CT protocol
- ✓ Image quality with acceptable results for diagnostic purposes was obtained using a bismuth breast shield coupled to the gantry

REFERENCES

For full references, please email edito@healthmanagement.org or visit the website