Designing and construction of breast shields using silicone composite of Bismuth for chest CT

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► *Technical note*

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Revised: December 2018
Accepted: January 2018

Int. J. Radiat. Res., July 2019; 17(3): 499-504

DOI: 10.18869/acadpub.ijrr.17.3.499

ABSTRACT

Background*:** Bismuth composites are new and non-lead shields that are capable of breast dose reduction while preserving image quality. In this study, different percentages of Bismuth were used in designing and constructing polymer composites as breast shields in chest CT. ***Materials and Methods*:** Micro particles of Bismuth with a ratio of 1% to 15% in Silicone matrix with two thicknesses were used as Bismuth Silicone composite (BSC) shield. The female chest phantom and standard chest CT exposure factors were used. Dosimetry was performed by thermo luminescent dosimeters. The image quality was evaluated with two methods. Statistical analyses were performed by Kruskal-Wallis and Mann-Whitney tests using SPSS 16. ***Results: The application of 1% and 15% BSC shields reduced the breast dose to 14.9% and 62.2%, respectively. Increases in image noise in BSC was observed 2.33% (P=0.439) for breast and from 7.13% (p=0.513) for mediastinum areas, depending on the type of shields. ***Conclusion:*** The Application of Bismuth shields with Silicone composite and changing of the Bismuth percentages in composite and thickness are effective factors on the breast dose reduction significantly that can reduce the risk of breast cancer when engaged in Chest CT.

Keywords: *Breast shield, Chest CT, Bismuth Silicone construction.*

INTRODUCTION

Breast is received high radiatin dose during chest computer tomography (CT) [(1)]. Three accepted methods are available to protect and reduce breast radiation dose including distance, time and shield.

One of the best and most effective ways to achieve of the radiation protection in chest CT is using shield. Lead shields and compound lead free shields containing Bismuth Cadmium (Cd), Tin (Sn), Barium (Ba), Tungsten (W) with K absorption edge from 40 to 120 KV were used [(2)].

In most articles of Chest CT, what is introduced and used are commercial breast Bismuth shields the made by certain companies (attenurad, F&L medical Co) [(3-6)]. Recently, some shields were designed and constructed that included composites of Barium Sulfate ($BaSO_4$) with filler particles of Bismuth Oxide (Bi_2O_3) in different thicknesses (0.5 to 2 mm). These shields were applied in Chest CT and showed dose reduction from 13.56% to 66.64% depending on kV and shield thickness [(7)]. In most articles, the shields are presented without further explainations about their structure and details of the materials combiend and used; some only point to using different thickness of foam to reduce image distortion or artifacts on the chest images [(8,9)]. In this study different weighting factor of Bismuth metal and shield thickness effects on the newly designed polymer composites of Bismuth Silicon shields were presented. The novelty of this work is the new compound material of the shield as well as different weighting factor and thickness.

Lead free shields, especially Bismuth, are ideal for superficial organs such as the breast, thyroid and lens [10]. Fricke *et al.* succeded in reducing breast dose by 29% and found no statistically significant differences in noise between the shielded and non-shielded lung images [11]. Other studies using Bismuth shields reported 30% [12] and 45% [13] dose reduction in the breast.

The aim of this study is to examine Silicon composite of Bismuth to assess the quantitative effects of these new shields on breast dose reduction and determine the corresponding percentages of Bismuth in new composites of Silicone matrix.

MATERIALS AND METHODS

Bismuth with uniform particle size <150 micrometer metal beads was used (Merck Germany;12400 Code).

Bismuth composite shields were structured from Silicon as a matrix and microparticles of Bismuth. Silicone was a matrix with the general formula R_2SiO_n where R was methyl or phenyl group of Silicone polymer (LAZIO, Turkey).

For designing Bismuth Silicone Composite (BSC) shields in the size of 210 × 210 mm with 1%, 10% and 15% of Bismuth metal, the matrex of Silicone polymers, were added in the volum to achieve a thickness of 1.1 and 2.2 mm.

Phantom and dosimetry

The layered female chest phantom was used which details presented in a published article [14].

In order to measure dose reduction in skin layer (SL) and fourth layer (FL), Thermo luminescent dosimeters (TLD) (LiF: Mg, Ti dosimeters GR-200) were used. For calibration, the 35 TLDs (GR -200) were calibrated in the Pars Isotope dosimetric laboratory, Tehran, Iran in the range of usually used energy in CT scan (80 -100-120- 140 kVp), and then annealed in the thermal oven to remove the remaining and undesired signals and increase the sensitivity.

The foam with a thickness of 1 cm was placed under the shields directly over the breast phantom to prevent image artifacts.

The first stage of scaning, the topogram phase, was performed without a shield. The shields were used after topogram in automatic exposure control (AEC) systems.

For the evaluation of consturacted shield, linear attenuation coefficient (μ) and the mass attenuation coefficient (μ/ρ) were calculated in the 120 kV and 80 mAs; dose measurment was also carried out with the presence of the shields by Diadose (PTW).

Image quality

The image quality of the phantom scans were evaluated quantitatively [determining image noise and Contrast Noise Ratio (CNR)] and qualitatively [a radiologist with more than eight years of experience].

Image noise was evaluated by selecting thirteen circular ROIs with a diameter of 1.9 cm^3 in the right and left breast, and center of body phantom (mediastinum). The contrast noise ratio (CNR) was calculated from the signals (CT numbers) in the shielded place minus the back ground (bg) CT numbers per noise of back ground (Equation 1).

$$CNR = \frac{CTnumber(test) - CTnumber(bg)}{Noise(bg)} \quad (1)$$

Statistical analyses were performed by Kruskal-Wallis and Mann-Whitney tests with SPSS software (version 16.0, spss); p<0.05 was considered statistically significant.

RESULTS

Linear attenuation cofficient (μ) and mass attenuation cofficient (μ/ρ) for Bismuth Composites shields

Linear attenuation coefficient (μ) and mass attenuation coefficient (μ/ρ) values of BSC were different with the same thickness of 1.1 and 2.2 mm in the shields. The μ for BSC 1% and 15% were 1.46 cm^{-1} and 7.02 cm^{-1}, respectively, as shown in figure 1A. The μ/ρ for BSC 1% and

15%were 1.69 cm^2/gr and 7.19 cm^2/gr, respectively as shown in figure 1B.

Breast dose in skin and fourth layers using BSC shields

Breast dose in the skin layer was 8.32±2.03 msv and in the fourth layer was 7.63±1.20 msv from TLD recording results without shields.

The application of BSC shields 1, 10 and 15 percentages with a thickness of 1.1 mm in skin layer induced breast dose reduction to 14.9%, 46.8% and 53.8%, respectively. Also, when applying BSC shields from 1 to 15 percent, breast dose declined from 5.6%, to 39.7% with a thickness of 1.1 mm in the fourth layer of the breast.

Application of 2.2 mm thickness of BSC induced more dose reduction in the skin and fourth layers of the breast than the 1.1 mm shield. Details of the dose reduction values are outlined in table 1. Breast radiation dose was significantly lower in comparison to the without-shields condition ($p<0.05$).

Image quality

The average increase of image noises by BSC 10% and 15% were 8.91%, 9.35% in breast area, in comparison to the chest CT image without shielding.

The measured average noise values in central body of phantom (mediastinum) for 10% and 15% of BSC were 13.00% and 15.44%, respectinely (figure 2). Results showed that noise increased when using BSC shields in comparison to non- shield condition but data was not significant in the breast and mediastinum locations ($p>0.05$).

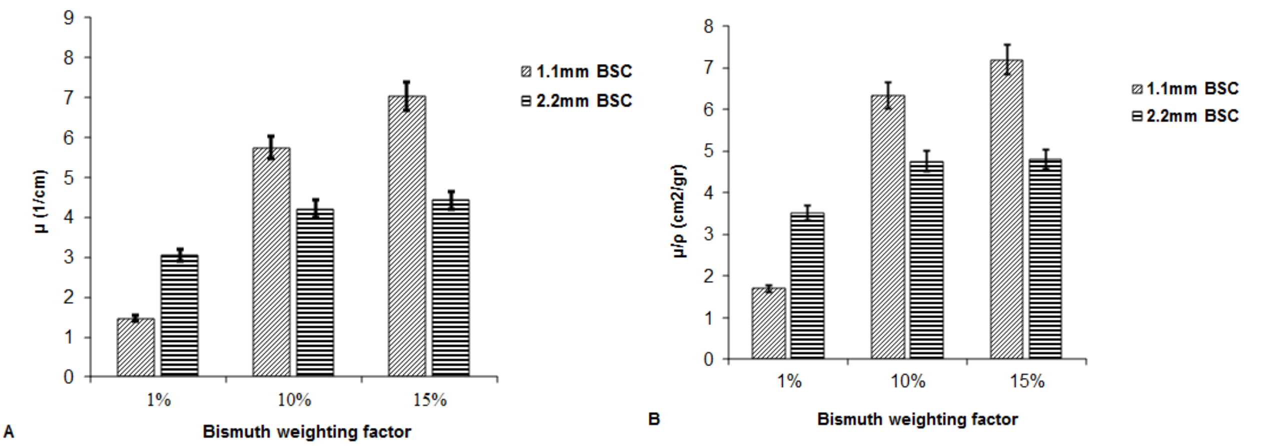

Figure 1. linear attenuation coefficient (μ, 1/cm). with (±SD) as shown in A. Mass attenuation coefficient (μ/ρ, cm^2/gr), as shown in B for in BSC (Bismuth Silicone Composite) shields in 1.1 and 2.2 mm thicknesses on the chest phantom during Chest CT.

Table 1. Assessment of skin layer (SL) and fourth layer (FL) of breast phantom dose during Chest CT using 1.1 mm and 2.2 mm Bismuth Silicon Composite (BSC) 1%, 10% and 15% shields.

Percent Bismuth	thickness of shield(mm)		TLD Dose(mSv)	DoseReduction(%)	statistic anlalyses
-------	Without shield	SL	8.32±2.03	-------	-------
		FL	7.63±1.20	-------	-------
1%	1.1	SL	7.08±0.27	14.9	-------
		FL	7.20±0.12	5.6	-------
	2.2	SL	4.25 ±0.90	48.9	p<0.05
		FL	6.12±0.75	19.7	-------
10%	1.1	SL	4.42±0.16	46.8	p<0.05
		FL	5.56±0.50	27.1	p<0.05
	2.2	SL	3.29±0.16	61.1	p<0.05
		FL	5.18±0.87	32.1	p<0.05
15%	1.1	SL	3.84±0.36	53.8	p<0.05
		FL	4.60±0.35	39.7	p<0.05
	2.2	SL	3.14±0.74	62.2	p<0.05
		FL	4.19±0.67	45.0	p<0.05

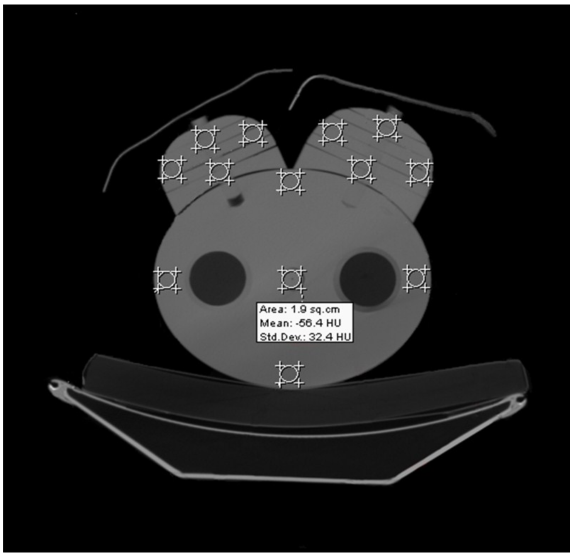

Figure 2. The CT gram peresented for image analysis of Bismuth-Silicon shields on the chest phantom with selected ROIs. The average HU value and noise were determined for the marked places with an area of 1.9 cm^2.

DISCUSSION

In this study, after the various stages of designing and constructing of the Bismuth microparticles in Silicone matrixes, the capability of these composites shields was approved for breast dose reduction during chest CT.

What this study aimed to examine was present of the effect of increasing Bismuth beads from 1 to 15 % (weighting factor) in the composites ability for radioprotection that caused 14.9% to 53.8% dose decline for the skin layer but for the fourth layer of breast, this value was 5.6% and 39.7%, respectively.

The effect of thicknesses on the radioprotecting potential of Bismuth composites shield from 1.1 to 2.2 mm in the 1% BSC shield led to an increase in the amount of dose reduction for skin and fourth layers from 39.97% [(7.08-4.25)/7.08] to 15.00% [(7.20-6.12)/7.20], respectively.

If increasing of the thickness to 2.2 mm and Bismuth percantage to 15% are taken into consideration together in BSC shield, the increasing in the protector effect was 18.22% [(3.84-3.14)/3.84] and 8.91% [(4.60-4.19)/4.60] for skin and fourth layers, respectively.

The BSC shield is most useful when applied after topogram in CT imaging process, because, in considering shield thickness, automatic exposure control (AEC) system increases exposure factors to prevent image quality deterioration, causing dose reduction to be less [15, 5, 16]. In the current study, scout topogram was performed before placing the shields. The problem is enhanced when the scanner detects increased density due to the presence of the BSC shields, automatically raising the power to achieve optimum imaging.

Most articles used F&L company shields without details of the compounds used.

Results showed that in chest CT, the breast's highest dose was recorded at the skin layer, and the lowest dose at the fourth layer in the phantom without shield, but in BSC shieds, less effective radiation protection was observed in the fourth (deep) layer of the breast, in comparison with the skin layer.

The potential of Bismuth shields for dose reduction in different layers has been explained in a few articles. These studies have shown that the dose decline is better in the skin layer [13, 17, 18]. A study demonstrated that using Bismuth shields induces declines in the doses of superficial organs [8]. Present research selected to record the dose in two layers at the same time and position, one for establishing the shields' dose decline potential (skin layer in superficial organs) and one for the fourth layer to find out the glandular dose of the breast. Also, there are some studies that did not measure the radiation dose in the glandular tissue, but pointed out lower doses in the deeper portions of the breast because of X-ray attenuation of the breast tissue itself [3, 6, 9].

It should be noted that, when using Bismuth shields for superficial organs, the dose recorded in the deeper layers of the breast was higher than the skin layer, while the dose without shielding in deeper layer was lower in comparison with the skin layer. This issue was also taken up by Yilmaz and Chang [8, 17].

It seems the role of shields was as a filter for lower kVp while the deep layers of the breast received harder X-Ray beams [19].

The image quality variation in Bismuth shields is one of the most important factors in its use in radiology. In our study, the application of BSC 15% with a thickness of 1.1mm caused a 53.8% breast dose reduction in the skin layer, with increases in noise reaching 9.35% and 15.44% in breast and mediastinum areas, respectively. With the application of Bismuth shields for phantom in the chest CT scan, Vollmar *et al.* obtained a 50% reduction in breast dose by increasing 40% of image noise [20].

Other studies showed that, with the application of various commercial breast shields (details of shields are not presented), dose reductions in the breast were 16–37.5% [15], 55% [19], 26% [5], and increases in noise were 19%–40%, 42%–43%, respectively. Coursey et al showed a diffrentiation of noise in the range of 10.0 to 13.1 HU[5].

Also, Servas *et al.* used a Bismuth breast shield on a 5-year-old phantom in chest CT and reported that dose reduction and increased HU were 15% and 4-6 HU, respectively [21]. In our study, maximum different values of CT numbers (HU) in the breast area and mediastinum with and without shielding were 2 HU and 4HU, respectively.

The advantages of BSC shields are low thickness, non-toxic materials for the body, and economical charactristics.

CONCLUSION

Application of Bismuth shields with Silicone composite and changing of the Bismuth percentages in composite and thickness are effective factors on the breast dose reduction significantly that can reduce the risk of breast cancer when engaged in Chest CT.

Compliance with ethical standards

Funding: This study was funded by Tabriz University of Medical Sciences (5/d/7537). Authors declare that they have no conflict of interest.

Conflicts of interest: *Declared none.*

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