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Polyurethane compositions of Bismuth used for breast shields during chest CT

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► ***Original article***

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ABSTRACT

Background: Bismuth Polyurethane composite is a novel shield for breast protection while saving image quality in chest CT. Bismuth different concentrations used for constructing polymer composites breast shields in this study. ***Materials and Methods:*** Bismuth with particle size <150 micrometer used in bismuth polyurethane composite (BPC) with a ratio of 10%, 15% and 1.1, 2.2 mm thicknesses. The BPC was examined on the female chest phantom (skin and fourth layers), 120 kV and 80 mA selected as an exposure factors in chest CT. The dose reduction was recorded by TLD and the image quality was evaluated quantitatively and quantitatively. ***Results:*** Using BPC shields 10% and 15% (2.2 mm) induced to breast dose reduction to 69.1% and 77.5% for skin layer and 44.7% and 52.8% for fourth layer, respectively. The image noise Increasing in BPC for breast and mediastinum areas were 9.43% (P=0.347) and 15.44% (P=0.386), respectively. ***Conclusion:*** Application of Bismuth with different weight ratios in polyurethane composite was useful shield for radiation dose reduction of the breast in chest CT.

Keywords: *Breast shield, chest CT, bismuth polyurethane construction.*

INTRODUCTION

Nowadays, chest CT is used as a valuable tool for noninvasive assessment of mediastinum, lungs and heart disease (1). Replacing chest X-ray in modern radiology, chest CT scans play an important role in the diagnosis and management of patients in critical medical conditions. The biological effects of chest CT are thought to be negligible, but in sensitive organs such as the lung, heart and especially the breast in younger women, it induces high risks of cancer. In the thorax, CT often causes the breast to be exposed to high doses of radiation during the imaging procedure (2-5). On the other hand, breast cancer is the most common cause of malignant disease in women worldwide, with radiation acting as a possible cauasative factor. In comparing chest computer tomography and chest X-ray doses, the ratio between lung dose in CT and radiography, for example, turned out to be 11.56 (6) .

Three accepted methods are available to protect and reduce breast radiation dose. One is the distance between the source of radiation and the sensitive organs. Another is inverse-square law (ISL), but ISL is limited in CT due to constant distance between the X-ray tube and the location of the patient in the gantry device. Still another involves minimizing exposure time, and its selection must be made by considering other expoture factors in patient imaging.

The shields are one of the selective and importante ways to obtain of the radiation protection during chest CT. In ionising imaging centers Lead shields are usually used. This heavy metal covers the organ, protecting it against radiation, but it is at the cost of the organ image. This motivated the researchers to design and construct lead free shields containing bismuth cadmium (Cd), tin (Sn), barium (Ba), tungsten (W) with K absorption edge from 40 to 120 kV (7).

In most articles of chest CT, what is

introduced and used are commercial Bismuth shields for the breast made by certain companies (attenurad, F&L medical Co) [2, 4, 8, 9]. 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 [10]. In the som articles, structure and details of the materials combiend and used in the shields are presented without further explainations about their; some only point to changing of foam thickness to reduce distortion or artifacts on the chest images [11, 12]. In the chest CT by the pediatric and adult phantoms, a decline of breast doses of 21% and %37, respectively, using Bismuth shield has been possible [13]. Researchers in 2016 revealed about 28.5% decrease in the eye lens dose in head CT (in contact shield) with no especial artifact [14]. Non lead shields, especially bismuth, are best for superficial organs such as the breast, thyroid and lens [15]. Using bismuth shields in MDCT for pediatrics, the succeded study in reducing breast dose by 29% found no statistically significant differences in noise between the shielded and non-shielded lung images [16]. Also two studies using Bismuth shields reported 30% [17] and 45% [18] dose reduction in the breast.

The aim of this study was introduce of bismuth polyurethane matrixes as a new shield for potentially protection of breast during chest CTscan examine within image quality study. In this study polymer composite of bismuth polyurethane with different weighting factor and thickness were used for presenting weighting factors and thicknesses effects of new design composite on the chest CT scan dose. The novelty of this work is the new compound material of the shield as well as different weighting factor and thickness.

MATERIALS AND METHODS

Polyurethane was as a matrix with in microparticles of bismuth micrometer metal beads (size <150, Merck Germany;12400 Code).

Polyurethane made by alleles formulation (including several hydroxyl groups, OH is a type of alcohol) as well as isocyanate, an organic compound with the general formula RN - C = O (SELSIL, Turkey).

Bismuth polyurethane composite (BPC) shields were designed and constructed with 10% and 15% of Bismuth metal concentration (210 × 210 mm), with thickness of 1.1 and 2.2 mm shield.

Phantom and dosimetry

The chest phantom in layered form for female was used that constructed before [19]. Dose reduction was measured by thermoluminescent dosimeters (TLD) (LiF: Mg, Ti dosimeters GR-200) on the skin layer (SL) and in the fourth layer (FL) of the breast in the phantom. For preparing, 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 and 140 kVp), and then annealed in the thermal oven to remove the remaining and undesired signals and increase the sensitivity. Also to prevent image artifacts one cm of foam was placed under the shields on the breast phantom.

In supine position, the phantom was placed in the gantry isocenter for chest CT scan. Similar scanning parameters were selected to be used for the chest CT of the patient (tube voltage 120 kv, tube curent 80 mAs, slice thickness 10 mm and a pitch of 1.3). The first stage of scaning, the topogram phase, was performed without a shield. The shields were used after topogram to prevent automatic dose increase due to shield thickness, with AEC method working as a result of the shield being present on the breast.

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

Image quality

The region of the right and left breast and body phantom of the chest images were taken in the quantitative measurements through

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determining image noise and Contrast Noise Ratio (CNR).

A radiologist with 10 years of experience qualified the chest CT images requested for the qualitative imaging process, with and without the shield in chest CT images. Image noise evaluation was performed as detailed explained in article [20].

For data analyses, Kruskal-Wallis and Mann-Whitney Statistical tests with SPSS16 were used.

RESULTS

Bismuth composite shields linear attenuation cofficient (μ) and mass attenuation coefficient (μ/ρ)

Linear attenuation coefficient (μ) and mass attenuation coefficient (μ/ρ) values of BPC were different with the same thickness of 1.1 and 2.2 mm in the shields. The μ for BPC 10% were 7.26 cm^{-1} and for BPC 15% were 8.68 cm^{-1}, as shown in figure 1. The μ/ρ for BPC 10% were 6.61 cm^2/gr and for BPC 15% were 7.81 cm^2/gr, as shown in figure 2.

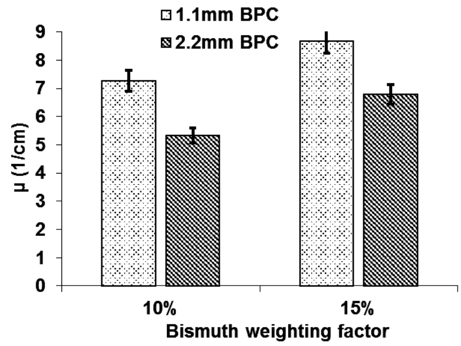

Figure 1. Linear attenuation coefficient (μ, 1/cm) with (±SD) was shown. For in BPC (Bismuth Polyurethane Composite) shields in 1.1 and 2.2 mm thicknesses on the chest phantom during Chest CT.

Meausurment of breast dose using BPC shield in skin and fourth layers

In the absent of the shield the breast dose in the skin layer was 8.32±2.03 mSv and in the fourth layer was 7.63±1.20 mSv from recorted data by TLD. Application of 10 and 15 percent BPC shields with a thickness of 1.1 mm in the skin layer caused breast dose decline to 55% and 61.5%, respectively (table 1). Also, application of BPC shields from 10 and 15 percent induced reductions of 43.3% to 47.9% in the fourth layer of breast dose, respectively. When the thickness went up to 2.2 mm using BPC shields 10 and 15 percent, the breast dose reduction in skin and fourth layers increased as shown in detail in table 1. Also, a significant difference was observed with BPC 10% and 15% with a thickness of 1.1 mm in comparison to the without-shield condition ($p<0.05$). Therefore, when considering the percentage of the Bismuth in the shields, breast radiation dose will be significantly lower in comparison to the without-shields condition ($p<0.05$).

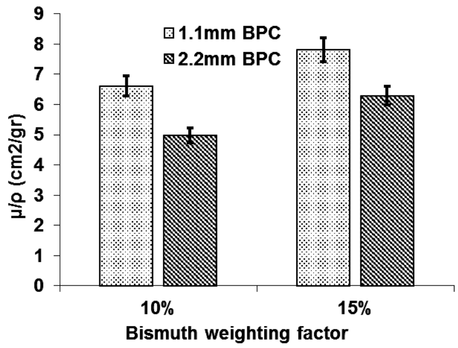

Figure 2. Mass attenuation coefficient (μ/ρ, cm2/gr) with (±SD) was shown. For in BSC (Bismuth Polyurethane Composite) shields in 1.1 and 2.2 mm thicknesses on the chest phantom during Chest CT.

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 polyurethane(BPC) 10% and 15% shields.

Percent Bismuth	thicknece of shield(mm)	TLD Dose (mSv)	Dose Reduction (%)	statistic anlalyses
	Without shield	SL 8.32±2.03 FL 7.63±1.20	---	---
10%	1.1	SL 3.74±0.16 FL 4.32±0.26	55 43.3	p<0.05 p<0.05
	2.2	SL 2.57±0.25 FL 4.22±0.28	69.1 44.7	p<0.05 p<0.05
15%	1.1	SL 3.20±0.43 FL 3.97±0.40	61.5 47.96	p<0.05 p<0.05
	2.2	SL 1.87±0.68 FL 3.60±0.05	77.5 52.8	p<0.05

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Image quality

The average increasing of image noises were 9.20%, 9.43% by BPC 10% and 15% in breast area, in comparison with no shield using in chest CT image. Also the measured average noise values in mediastinum area were 13.00% and 15.44%, for 10% and 15% of BPC respectinely (Figure 3). In comparison to persence and absence of the BPC shields on the noise imaging was showed increaseing that happened while the noise was not significant in the breast and mediastinum locations when BPC shield was added (P>0.05). Also CNR was caculated 22.89% and 23.53% for 10% and 15% BPC shields, respectively.

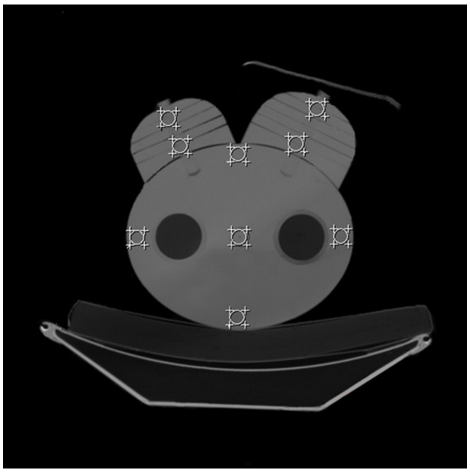

Figure 3. The CT gram presented for image analysis of with and without Bismuth-Polyurethane shields on the chest phantom with selected ROIs. The average HU value and noise were determined for the marked places with an area of 1.9 cm2.

DISCUSSION

Peresent study examed different stages of construction of polyurethane matrixes with the bismuth microparticles capabality of these composite shields for breast protection during chest CT. Also, the different resulting effects upon changing the Bismuth percentages in the Polyurethane matrixes were observed. Results showed that BPC shield have a good potential for reducing breast radiation dose in 10%, 15% of Bismuth in 1.1 and 2.2 mm thicknesses.

By increasing thickness from 1.1 to 2.2 mm of the BPC shield, a higher dose reduction is made possible for skin and fourth layers. Also, in the 15% BPC shield, the variation in dose reduction value is considered to be 41.56% ((3.20-1.87)/3.20) and 9.31% ((3.97-3.60)/3.97) for skin and fourth layers, respectively. In the present study using BPC shield have showed that (μ) and (μ/ρ) were more than BSC shield [20].

Application of BSC (1 mm thickness) for breast shield on the four location of female chest phantom recorted by TLD showed 12% dose reduction [21]. The highest reduction doses were recorded in the skin layer by BPC shields, at 15%, and a thickness of 2.2 mm. Another study, through 5% BSC and BPC, breast dose decline for skin and fourth layers proved to be about twice as different for the two types of shields [22]. Affect of the Bismuth particle size on the protection of organs explaned [23]. Also nano Bismuth shield (50 nm) showed a dose reducton of 7.2% and 13.8% for 0.5 mm and 1 mm thicknesses, respectively [24].

In the current study, scout topogram was performed before placing the shields in BPC as well as TLD, when performing CT examinations of the thorax with AEC modulation. The problem is enhanced when the scanner detects increased density due to the presence of the BPC shield, automatically raising the power to achieve optimum imaging. Nowadays, almost all new CT scanners use automatic tube current modulation for dose reduction purposes [25]. The operator should notice if the selection of AEC system agrees with BPC shield before topogram, so that there is optimal decline in radiation doses. Also, in this study, the last Bismuth percentage was 15%, because selecting more than 15% of bismuth beads was not possible and adding more Bismuth to the composite matrix would trigger a saturation mode in polymer matrixes, with the complex not mixed and constructed properly. Unfortunatly, we could not find any similar studies to compare our constructed shields with other similar composites. Most of them used F&L company shields without details of the compounds such as weighting factor or matrix properting 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

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phantom without shield, but in BPC 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 in dose decline is better in the skin layer [26, 27]. A study demonstrated that using Bismuth shields induces declines in the doses of superficial organs [11]. However, the fact that the breast's glandular tissue is the most sensitive and was placed with a distinct distance from the surface of the skin is cause for finding a method with good performanc shield effect. 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 [2, 9, 12].

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 [11, 26]. One possible reason for the difference in dose reduction in the two layers (skin and fourth) of the breast is the role of shields as a filter for lower, kVp, energy of X-ray polyenergetic beam that triggers decreases in breast skin dose, while the deep layers of the breast received harder X-Ray beams [28].

The image quality variation in Bismuth shields is one of the most important factors in its use in radiology. Using BPC 15% with a thickness of 1.1 mm contributed to 61.5% breast dose reduction in the skin layer, while image noise in the breast area and mediastnum increased to 9.43% and 15.44%, respectively. With the application of bismuth shields for phantom in the chest CT scan, Vollmar *et al.* obtained a reduction in breast dose and increasing of image noise 50% and 40% respectively [29].

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% [1], 55% [28], 26% (8), 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 [8]. 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 [30]. 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.

CONCLUSION

Application of BPC shields as well as changing the bismuth percentages in composites, thickness and type of matrixes are effective factors in reducing breast dose significantly. Thus, bismuth shields with Polyurethane composites have the potential for high rates of dose reduction, are adequate protective shields against radiation effects, and can reduce the risk of breast cancer when engaged in chest CT.

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Conflicts of interest*: *Declared none.

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