ORIGINAL ARTICLE

Reduction of Radiation Risk to Cardiologists and Patients during Coronary Angiography: Effect of Exposure Angulation and Composite Shields

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Abstract

Purpose: This study aimed to design an improved form of a composite shield with different materials and shapes and simultaneously reduce the radiation dose to both the patient and operator.

Materials and Methods: A female phantom study was performed with and without bismuth belt-shaped composite shields on the breast region at different beam projections used in coronary angiography. Dose measurements were conducted using GR-200 thermo-luminescence dosimeters, dose area product (DAP), and air kerma (AK) over regular and large breast locations, with and without using bismuth shields. An electronic personal dosimeter was used for operator dose assessment. Patients received doses between 2.27 mSv and 3.38 mSv, depending on the size and strength of beam projections.

Results: The use of the developed shields caused a dose reduction of 18%–25% of sensitive breast tissue due to breast size and shield type. During coronary angiography, the mean values of DAP and AK were 2.02 (1.24-2.80) mGy.m^2 and 314.1 (202.8-500) mGy, respectively. The highest recorded dose was at the LAO/CRA and LAO/CAU beam projections for both the patient and operator. After applying a belt shield, the operator's radiation dose was decreased by approximately 32%. We found a statistically significant correlation between the radiation dose received by the operator and the patient's breast radiation exposure dose ($p<0.001$, $r2=0.93$).

Conclusion: The designed belt shield can be a potentially promising protective device for decreasing the radiation risk to the patient's breast and the operator during coronary angiography. However, further studies will be considered before the application of this shield in standard clinical practice.

Keywords: Bismuth Composite Shield; Breast Shield; Coronary Angiography; Radiation Protection; Operator Dose.

DOI:

1. Introduction

Cardiovascular Diseases (CVDs) are a significant cause of premature deaths worldwide. It is estimated that 44% of the adult population will have at least one CVD event by 2030 [1, 2]. With the increasing prevalence of CVDs and subsequent increase in morbidity and mortality, the drive to combat CVDs has led to the increased development of various diagnostic and therapeutic invasive cardiology procedures worldwide. Invasive Coronary Angiography (CA) is currently the "gold standard" procedure for detecting obstructive coronary artery lesions [3]. However, this has led many patients to undergoing angiography twice or more annually according to physician requests relating to the patient's current disease state.

Diagnostic and therapeutic interventional coronary procedures are generally performed under fluoroscopic guidance. According to several reports, fluoroscopic procedures are considered the largest occupational radiation exposure sources observed in the medical field [4]. During these procedures, interventional cardiologists, operators, and patients are exposed to high radiation doses [5-7]. Radiation dose levels in diagnostic and therapeutic CA are well known. CA and angioplasty can expose a patient to radiation levels of 300 and 1000 chest scans, respectively. Recent reports have documented that an experienced interventional cardiologist in a high-volume center has an exposure of approximately five mSv per year [8].

Venneri *et al.* [8] selected dosimetry data of 26 (7 women, 19 men; age 46 ± 9 years) workers of a cardiovascular catheterization laboratory with an effective dose >2 mSv. Their lifetime attributable risk of cancer was estimated using the Biological Effects of Ionizing Radiation (BEIR) 2006 report VII. It was found that cardiac catheterization laboratory staff represented 67% of the six workers with yearly exposure of >6 mSv. Of the 26 workers with exposure of >2 mSv, 15 had complete records of at least 10 (up to 25) consecutive years. For these 15 mentioned subjects having a complete lifetime dosimetry history, the median individual effective dose was 46 mSv (interquartile range = 24-64). The median risk of (fatal and nonfatal) cancer was 1 in 192 (interquartile range = 1 in 137-1 in 370). So, they reported that cumulative radiological dose is associated with a non-negligible lifetime attributable risk of cancer for the most exposed contemporary cardiac catheterization laboratory staff.

Longer fluoroscopy times and shorter distances from the X-ray tube increase the dose received during coronary interventions. Cardiologists and operators who perform many procedures every year are subject to radiation-induced damage, including DNA damage [9]. Engin *et al.* [10] studied the genomic instability of γ- and X-ray-exposed hospital staff. They presented that chronic exposure to ionizing radiation, even at lower levels than the accepted limit, could induce oxidative stress and increased apoptosis compared to no exposed personnel. Therefore, protection from radiation exposure is an essential requirement in cardiac catheterization departments.

Many techniques have been attempted to reduce the operator radiation dose. These approaches include using a single catheter to reduce radiation time during CA. One may also utilize an extension tube to increase the distance between the patient and the X-ray tube [11] and deploy a shield device to absorb the scattered radiation [12, 13]. However, in CA procedures, the heart, within the field of the primary X-ray beam, is the objective organ, and susceptible breast tissue, which is not the subject of interest for diagnosis or treatment during these procedures, is in the main beam field and subsequently directly exposed to radiation. Despite the high radiation dose to the operator and patient, radioprotection is not used for patients undergoing cardiac procedures. Several studies have shown that shields can reduce the operator dose without reducing the dose received by the patient [14, 15]. Using a composite shield is currently the recommended approach for reducing radiation doses to patients during medical imaging examinations [16]. The investigators reported that breast Bismuth (Bi) composite shields reduce the skin and glandular radiation dose by 30% during Coronary Computed Tomography Angiography (CCTA), with acceptable noise for the image [17].

A comprehensive dosimetry study found that the breast radiation dose was reduced by 57% during CCTA [18]. Shortt *et al.* [19] assessed the application of commercially available bismuth shields during cerebral angiography. They concluded that the dose reduction to the thyroid and eyes during cerebral angiography examinations was insignificant. The pelvis shield can reduce the operator dose, albeit at the expense of increased patient radiation exposure [20].

Currently, there is no available information on composite shield applications in CA. Therefore, we conducted a comparative dosimetry study of diagnostic and therapeutic coronary procedures. We utilized belt-shaped breast radiation composite shields for patients and evaluated the effects of these newly developed shields on the patients and cardiologists during angiography procedures using phantoms. In this study, by improving the shape and material of the bismuth composite shield, we aimed to increase its efficiency in reducing the radiation dose exposure in CA at different beam projections.

2. Materials and Methods

2.1. Study Design

This study was performed in the cardiac catheterization lab using a monoplane angiography system (Siemens, Artis dFC, Munich, Germany). The angiography system was calibrated for consistency and accuracy using a quality control kit (PTW-Freiburg, Germany) at the commencement of the study. The angiography device was set to Auto Exposure Control (AEC) mode. Further data regarding technique factors such as kVp, mA/mAs, and filtration, concerning data acquired with and without using the breast shield, are referenced in Table 1.

Coronary angiography was simulated on the chest of a female phantom by an experienced interventional cardiologist. CA was simulated with six standard beam projections, as shown in previous studies [21]: Right Anterior Oblique (RAO), 15º/cranial (CRA), 35º; RAO 20º/caudal (CAU), 25º; left anterior oblique (LAO), 40º/CRA, 20º; LAO, 50º/CAU, 30º; LAO, 30º/CRA, 15º; and RAO, 30º). Each exposure comprised 20 s of cine acquisition to simulate the mean cine acquisition times used in clinical studies.

Only the shield and TLDs were replaced in each position, and the phantom was not moved. Four TLDs were placed on each breast. The materials included (phantom and ion chamber) were fixed in each projection. Any change in the positioning of the phantom, shields, and detectors was avoided to reduce bias. Furthermore, the detector for operator dosimetry was at the cardiologist's location close to the patient's bed, where the phantom was placed and fixed during all projections, as shown in Figure 1.

2.2. Characteristics of the Phantom and Breast Composite Shields

The phantom model was designed and constructed by our local medical physics laboratory of the affiliated university [22]. Two different breast models measuring 4 cm and 5 cm were utilized to mimic regular and large breasts. According to Mehnati *et al.*, the optimal foam size of 10 mm was determined for taking acceptable image quality using a Bismuth shield. Using a foam spacer, we created a suitable distance between the shield and the phantom to reduce image noise [23].

We used newly designed bismuth-silicon composite shields with two compositions (10% & 15%), with two shield geometries (20×20 cm^2 & 20×70 cm^2), and two shield placements (under phantom & under + above phantom (combined)). Initially, we assessed the 10% bismuth composite shield using silicon rubber and micro bismuth particles (150 microns) with a thickness of 1 mm and an area of 20×20 cm^2 for patient protection and were studied only for under phantom. Then, based on the obtained results, we decided to fabricate- 10% and 15% bismuth composite shields with a thickness of 1 mm and an

Table 1. The effect of using 10% bismuth composite shields on the technique factors (kVp, mA, ms, and filtration) for each acquisition, with and without shields, when operated under auto exposure-controlled conditions

Projection	With using composite shield			Without using composite shield		
	kVp	mA/ms	filtration	kVp	mA/ms	filtration
RAO/CAU (20º/25º)	67	799/7.0	0.2 Cu	64	654/6.40	0.2 Cu
RAO/CRA (15º/35º)	66	727/7.1	0.2 Cu	63	648/6.50	0.2 Cu
LAO/CRA (40º/20º)	68	719/7.2	0.2 Cu	64	673/6.40	0.2 Cu
LAO/CAU (50º/30º)	68	745/7.3	0.2 Cu	64	680/6.60	0.2 Cu
LAO/CRA (30º/15º)	66	716/6.80	0.2 Cu	64	654/6.50	0.2 Cu
RAO (30º)	66	716/6.80	0.2 Cu	63	675/6.50	0.2 Cu

CAU= caudal; CRA=cranial; LAO=left anterior oblique; RAO= right anterior oblique.

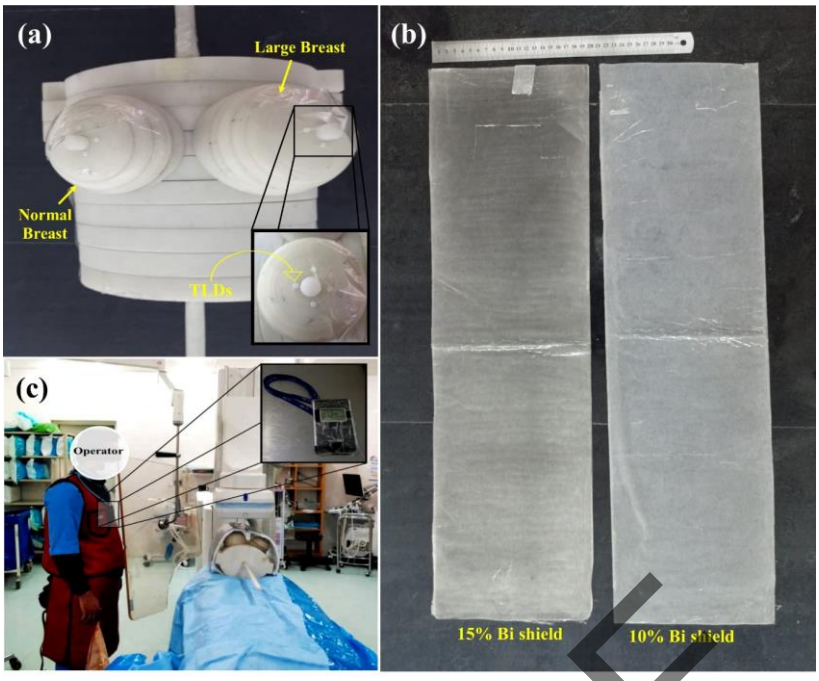

Figure 1. (a) Female chest phantom with normal and large breasts and TLDs location, (b) bismuth composite shields, (c) location of operator's personal dosimeter during experiment, similar to the cardiologist's place over the lead apron on the left upper thoracic region, along with the phantom covered in the combined position using the belt bismuth-silicon composite shield for protection. The number 80 GR-200 refer to needed TLDs for all projections of angiography with two 10% and 15% shields, as well as background TLDs

area of 20×70 cm^2 as belt-shaped shields (Figure 2) that they were studied separately both under phantom & under + above phantom positions for the patient and staff radiation protection. The 20×20 cm^2 shields were only used under the phantom part because they did not completely cover the phantom. The "combined" position was experienced using only a 10% composite belt shield (20×70 cm^2) that completely covered the phantom. The purpose of the combined position is to provide radiation protection for the patient and the operator simultaneously.

The protective properties of bismuth composite shields were experimentally determined using conventional digital radiology. Previous studies have fully described further elaboration on shield preparation, fabrication, and evaluation [24].

This decision was based on previous experiences in making composite shields with different filler percentages, which failed to form a composite in concentrations greater than 15% bismuth. At 15%, the ultimate fusion of silicon rubber and bismuth occurs as a matrix and filler (with our used material and condition). Also, 10% bismuth was selected to build a composite shield as an economical and dose reduction ideal concentration with the ability to maintain the diagnostic value of images compared to 15%.

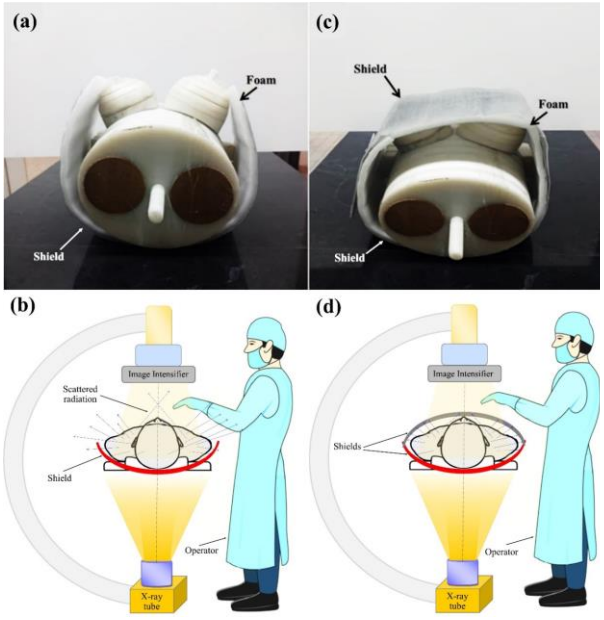

Figure 2. An example of shields was placed in two placements: initially, they were placed under the phantom's back mainly for patient protection (a and b), and subsequently, they were placed under and above the phantom for both patient and operator protection, which we titled as the "combined position" (c and d)

In the present study, the effective parameters in the protection efficiency of composites were investigated quantitatively and qualitatively. Therefore, experiments have been performed to evaluate the size of bismuth particles, the uniform distribution of bismuth particles inside the silicon, and the thickness of the composite shields. In detail, we first weighed 200 grams of silicon rubber (and its hardener) according to the volume of the protection dimensions and then added 15% by weight (30 g) or 10% by weight (20 g) bismuth particles to the silicon matrix.

2.3. Patient Radiation Dose Measurements

Shields were placed in two locations: under the phantom's back, and both under and above the phantom, which we named the "combined position" (Figure 2). The breast radiation doses of patients were evaluated using thermo-luminescent dosimeters (TLDs: GR-200; Frequency Control Electronic Technology Ltd., Hangzhou, China) in different breast areas. TLDs were calibrated regularly by a third-party quality control team. 12 TLDs were used to measure breast skin dose on each exposure; four TLD chips for normal and four TLD chips for large breasts and four chips as control during each projection. Four TLD chips were placed on each breast around the nipple, as shown in Figure 1. The shields were placed under the phantom's back. After reading each TLD, the Element Correction Coefficient (ECC) was applied, and by using the calibration curve, the amount of received dose of each TLD chip was obtained. We also used an ionization chamber dosimeter embedded in the angiography device to measure the AK and DAP.

2.4. Operator Radiation Dose Measurements

This study measured the operator radiation dose using an electronic personal dosimeter device (Smart Rad model: EV-1, Type GM-Tube, Enviro Korea Co., Ltd). To assure the reliability of energy readings, the dosimeter was periodically calibrated with a ^{137}Cs source (at a reference dose rate of 500 µSv/h). The operator dosimeter was placed on the stand in a similar area. A cardiologist would place a dosimeter over the lead apron on the left upper thoracic region to assess the staff's radiation exposure dose (Figure 1). The dosimetry was repeated three times in each projection, and the average was reported. The device settings were set at 15 frames per second and 20 seconds for each projection three times.

2.5. Statistical Analysis

Data were initially entered in a Microsoft Excel worksheet and then transferred into SPSS ver. 27 (IBM Inc., Chicago, IL) for analysis. Descriptive statistical methods with the Chi-square test were used to compare the categorical data, and the results were presented as frequency and percentage. All numerical interval data were initially tested for the presence of a normal distribution by Shapiro testing. A simple paired t-test was then used to compare the continuous numerical data with and without shielding. The numerical variables were presented as mean ± standard deviation. Pearson analysis was used for linear regression between the operator radiation dose and the breast exposure. Statistical significance was set at $P < 0.05$. All graphs were drawn using Graph Pad Prism 8 software (San Diego, USA).

3. Results

The radiation dose of the regular and large breast sizes from TLDs in routine projections of CA, with and without using 10% bismuth composite shields (20×20 cm^2), is shown in Figure 3. The maximum and minimum doses occurred at the LAO/CAU (50º/30º) and RAO/CAU (20º/25º) projections. Before applying the shields, the maximum doses for regular and large breasts were 3.31 mSv and 3.37 mSv, respectively, while the minimum doses were 2.27 mSv and 2.32 mSv, respectively. No significant dose reduction was observed due to the composite shield (20×20 cm)

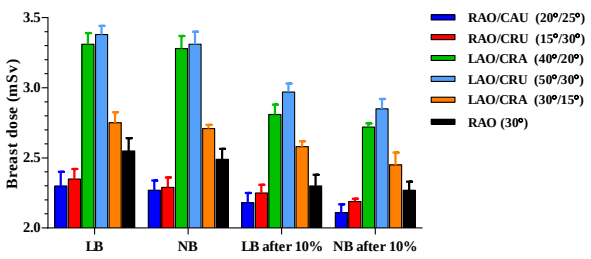

Figure 3. Large breast (LB) and normal breast (NB) radiation dose assessment using TLD dosimeters (mSv) before and after applying 10% bismuth composite shield (20×20 cm^2) according to the routine projections in coronary angiography

(Figure 3). No shielding was used to protect the ion chamber for operator-dosimetry measurements.

The radiation dose of regular and large breasts using TLDs at LAO/CAU (50º/30º) projection at CA, with and without a 10% and 15% bismuth belt-shaped composite shield (20×70 cm), is shown in Figure 4. The dose received by regular and large breasts were 2.79 mSv and 2.89 mSv, respectively, after using a 10% bismuth belt shape and 2.58 mSv and 2.67 mSv, respectively, after applying a 15% bismuth belt shape. The maximum and minimum doses occurred at the LAO/CAU (50º/30º) and RAO/CAU (20º/25º) projections. The position of the tube can explain this result during coronary angiography. Although a dose reduction was shown using a 10% posterior shield, only the 15% posterior shield had a statistically significant dose reduction in the breast (Figure 4). Each of the above projections was completed three times, and the data shown is the average of all three.

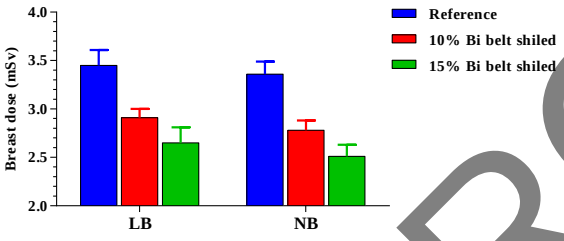

Figure 4. Large breast (LB) and normal breast (NB) radiation doses using TLD dosimeters (mSv) with and without using 10% and 15% bismuth belt composite shields (20×70 cm^2) according at LAO/ CAU projection on coronary angiography. LAO: Left Anterior Oblique; CAU: Caudal

The extent of patient exposure during various projections is summarized as the mean DAP (Table 2) and AK (Table 3). These values were collected in the three groups at different beam projections. There is a direct relationship between DAP and AK. Regardless of the angulation beam, both DAP and AK parameters were similar between the shielded and unshielded groups. There was a significant difference in the amount of radiation exposure between different projections. This difference may be due to changes in phantom thickness and FOV for any projections or distances from the X-ray tube or detector to the object. Due to the activation of AEC, the radiation output will be different at various angles.

The mean operator radiation exposure was 15.9±0.11 µSv. By adding belt shields in the under and combined positions, mean operator doses were recorded at 13.97±0.08 µSv and 13.18±0.12 µSv, respectively, indicating lower radiation exposure from the combined shield group compared to other groups ($p < 0.001$) (Table 4). We only replaced and moved the shields in the operator dose measurement mode. The dosimeter and its location were not touched to reduce error.

There was a difference in the absorbed dose between regular and large breasts ($r^2=0.82$, $p = 0.05$). There was a statistically significant correlation between the operator radiation dose and the patient's breast exposure dose ($p<0.001$, $r^2=0.93$, Figure 5). The relation between the recorded DAP as the patient's skin dose, and the amount of breast dose in a specific point by TLDs is demonstrated in Figure 5-b.

As shown in Figure 3 and Table 2, a similar behavior between amounts of the received dose by breast (TLDs) in different projections with the patient's skin dose (DAP) at the same angles. As it is clear, TLD is point dose but DAP is area dose-measuring. For example, it can be seen that in the LAO/CAU projection, the highest dose received by the breast was recorded with TLD and DAP meter, or in the angle of the RAO, the lowest value was recorded by both TLD and DAP meter. Therefore, a linear correlation can be observed between DAP and TLD results.

4. Discussion

Several studies have suggested bismuth shielding to protect radiosensitive superficial tissues, especially the breast, against radiation damage [25, 26]. This study introduced belt-shaped composite shields, which have the potential for protection from radiation to the patient and cardiologist during CA procedures. We found that dose reduction depended on the size and shape of the shield, bismuth concentration, and the size of the target organ.

The effect of shield size on patient dose reduction in angiography is shown in Figures 4 and 5. The results of 10% bismuth shielding with sizes of 20×20 cm^2 and 20×70 cm^2 showed that the belt shield (20×70 cm^2) provided more radiation protection to breast tissue. It was previously shown that using 10% bismuth belt shields was more efficient than conventional shorter shields in a

Table 2. Patient radiation dose in terms of DAP (mGy.m2) in three groups according to the projection for 20 second

Projection	Without shield	Bi-Si shield 10% (back)	Bi-Si shield 15% (back)	Bi-Si shield 10% (combined)	P-Value
RAO/CAU (20º/25º)	1.57±0.07	1.55±0.05	1.45±0.03	1.49±0.02	>0.05
RAO/CRA (15º/35º)	1.83±0.02	1.80±0.03	1.73±0.01	1.82±0.06	>0.05
LAO/CRA (40º/20º)	2.80±0.05	2.76±0.04	2.69±0.01	2.780±0.02	>0/05
LAO/CAU (50º/30º)	2.65±0.01	2.60±0.03	2.56±0.01	2.59±0.01	>0.05
LAO/CRA (30º/15º)	1.98±0.07	1.92±0.04	1.87±0.06	1.77±0.02	>0.05
RAO (30º)	1.24±0.02	1.24±0.01	1.15±0.05	1.12±0.01	>0.05

CAU= caudal; CRA=cranial; LAO=left anterior oblique; RAO= right anterior oblique.

Table 3. Patient radiation dose in terms of Air Kerma (mGy) in three groups according to projection

Projection	Without shield	Bi-Si shield 10% (Back)	Bi-Si shield 15% (Back)	Bi-Si shield 10% (combined)	P-Value
RAO/CAU (20º/25º)	264 ± 2	254.2±3.2	245 ± 2.2	252 ± 3	>0.05
RAO/CRA (15º/35º)	300 ± 2	295.5±2.2	296.2 ± 2.9	298 ± 2.8	>0.05
LAO/CRA (40º/20º)	382 ± 17	380.1±4.3	379 ± 3.5	374 ± 2	>0.05
LAO/CAU (50º/30º)	500 ± 6	489.8±5.4	485 ± 5.5	486 ± .5	>0.05
LAO/CRA (30º/15º)	272 ± 5	270.2±3.9	265 ± 4.2	268 ± 4.5	>0.05
RAO (30º)	225 ± 4	220±5.4	218 ± 5.3	213 ± 3.2	>0.05

CAU= caudal; CRA=cranial; LAO=left anterior oblique; RAO= right anterior oblique

Table 4. Operator radiation dose (µGy) in three groups according to projection

Projection	Without shield	Bi-Si shield 10% (back)	Bi-Si shield 15% (back)	Bi-Si shield 10% (combined)	P-Value
RAO/CAU (20º/25º)	28.7 ± 5.4	27.2±4.3	25.7 ±0.6	25.2 ± 0.8	<0.05
RAO/CRA (15º/35º)	38.6 ± 1.0	38±1.3	38.0 ± 1.2	36. 2 ± 0.9	<0.05
LAO/CRA (40º/20º)	47.3 ± 2.0	45.6±1.5	43.1 ± 0.3	40.0 ± 2.5	<0.05
LAO/CAU (50º/30º)	58.9 ± 0.6	55.2±1.1	52.4 ± 0.7	48.2 ±1.7	<0.05
LAO/CRA (30º/15º)	31.9 ± 1.6	29.7±2.1	27.4 ± 0.4	25.4 ± 1.1	<0.05
RAO (30º)	24.8 ± 0.1	24.2±1.1	23.8 ± 1.1	23.3 ± 0.7	>0.05

CAU= caudal; CRA=cranial; LAO=left anterior oblique; RAO= right anterior oblique.

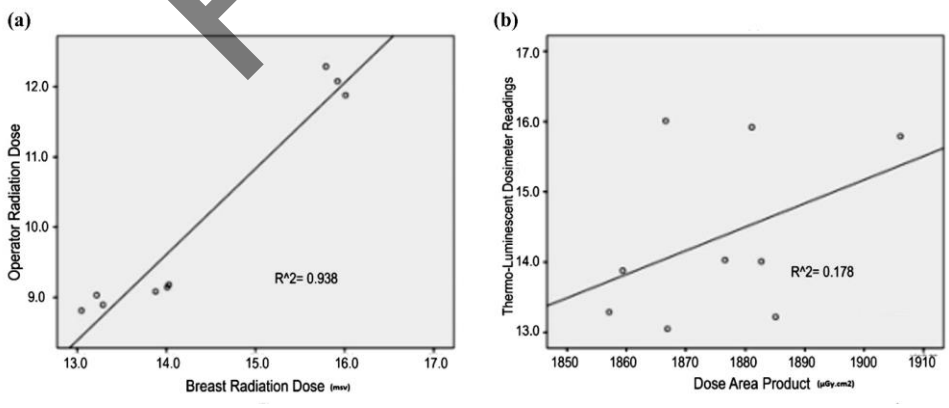

Figure 5. Correlation between patient's breast radiation dose and operator radiation exposure dose (a) and correlation between patient's breast radiation dose thermo-luminescent dosimeters readings and patient's skin exposure as DAP (b)

chest CT scan [27]. It should be noted that the primary administered dose to the breast in interventional fluoroscopy is imparted by scattering and predominantly from the tube side, which is performed"under the patient" position or using an "under the couch" C-arm fluoroscopy system. Therefore, the breast shield must be employed around the patient to cover the back of the

chest. Accordingly, we developed composite shields in belt form.

The breast shields used in our study differed from those commercially available. The first difference was that the percentage of bismuth particles was adjusted. We considered both dose reduction and image quality when designing clinical breast shields. Using these 10% and 15% shields in coronary CT angiography in our previous study, the measured noise was higher with bismuth shields than without shields, yet this difference was insignificant [27]. The second difference was the unique shape of the shields and their positioning method during angiography. Mainly, covering the chest with belt shields halted the amount of scattered radiation, decreasing the radiation exposure to both patients and operators [28]. Also, this study suggests using belt shields in pediatric cardiovascular imaging because the radiation dose measurements in this sensitive group were remarkable [29].

The effect of radiation from the beam projection is an essential parameter in the operator's contribution to the received dose, as shown in Table 4. The most significant shielding effect on reducing operator exposure was observed during the LAO/CRA and LAO/CAU beam projections. This finding was consistent with the results of Leyton *et al.* [30]. They investigated the relationship between the scattered radiation dose of the operator's eye and the dose to the patient for different Angiographies Projections. There was a good linear correlation between the kerma-area product and scatter dose at the lens. An experimental correlation factor of 2.3; 12.0, and 17.6 µSv/Gy cm^2 were found for the AP, LAO/CRA, and LAT projections, respectively. The scatter dose at the height of the operator's eye was 0.52 mSv. They showed a large range of scatter radiation dose at the operator's eye, from 0.37±0.04 to 60.19±6.02 mSv h^{-1}. Therefore, when turning C-arm from AP projection to LAO (45) /CRA (30) projection in cine mode, the factor of increase in scattering dose rate was 163 times. These dose values are consistent with our results. We found that the maximum doses similarly occurred at the LAO/CAU (50º/30º) projection.

These results also demonstrated that the operator radiation dose decreased significantly with bismuth shielding, implemented in either a single or combination mode, compared to the group without a shield. Conversely, the mean radiation dose for the patients was very similar in all three groups. Additionally, the results of using a 10% bismuth composite shield on the exposure parameters (kV and mAs) are presented in Table 1. In the active mode of AEC, the tube voltage and current increase slightly to possibly compensate for the low-energy beams of the spectrum removed by the shield.

Overall, this study introduced belt bismuth composite shields, which have the potential to protect the breasts from inadvertent radiation exposure during CA. The data analysis also showed that using belt shields with the proper positioning of the composite back shield and combined shielding methods reduced the radiation dose to the breasts by 18%–25%, which was statistically significant. It is estimated that the primary radiation dose received by the breasts in interventional cardiology, especially during Chronic Total Occlusion (CTO) lesion treatment, is imparted by scattering and predominantly from the tube side, which is under the patient. Therefore, the breast shield could play an essential role in complex Percutaneous Coronary Intervention (PCI) through radial procedures, which require more radiation time during fluoroscopy. Despite all the efforts and new ideas in the present research, since this study is based on the phantom model, with fixed breast sizes and materials, instead of human patients, who may present as well as with different weight masses, different breast sizes, and textures, may result in slightly different absorbed radiation dose.

Additionally, consideration should be made with the fixed location for the operator positions, along with varying operator characteristics such as heights, which may also affect radiation dose results. Perhaps in future studies and after the ethics committee's approval, a similar study can be performed in the presence of human patients to examine the effect of radiation shielding parameters related to breast size and tissue in this group. There are some limitations in this study, including the availability of devices, we were limited in the amount of time we could utilize the device in the interventional cardiology department due to the high number of patients who were candidates for angiography and angioplasty exams.

5. Conclusion

In conclusion, this phantom study utilized belt-bismuth composite shields approved for dose reduction during coronary angiography for both patients and cardiologists. It seems that this new shield

has the potential to reduce radiation exposure to both the operator and the patient in human coronary angiography and angioplasty, although further studies focusing on the shield's impact on image quality, along with a study with human patients, will have to be considered before further recommendations can be made on the use of these shields in standard clinical practice.

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