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Bismuth breast-shield use in chest computed tomography for efficient dose reduction and sufficient image quality

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Abstract

Background: Radiosensitivity in the breasts increases the risk of carcinogenesis from exposure to the ionizing radiation of computed tomography (CT) administered in the course of medical attention. Bismuth shielding techniques have been used to reduce radiation, but image noise increased, degrading image quality.

Purpose: The aim of this study was to investigate how the use of iterative reconstruction (IR) combined with bismuth shielding influences image quality.

Materials and Methods: Women aged at least 20 years with body mass indexes <28 were recruited and randomly assigned to 1 of 3 CT scanning protocols without shielding, with a bismuth breast shield before the scout view, or with a bismuth breast shield after the scout view. All obtained images were reconstructed using an IR algorithm. To evaluate radiation dose, 2 Gafchromic films were placed over the clothes, 1 near each nipple.

Results: Average dose reduction was significant (27.99%, $P < .05$) when bismuth shielding was applied after the scout view. Using the contrast-to-noise ratio, the image quality was found to be superior when the IR algorithm was applied. Using quantitative evaluations by 2 radiologists applying a 4-point Likert scale, significant differences in image quality were not found among the 3 protocols.

Conclusion: Bismuth breast shields, particularly when used after acquiring scout images, are effective at reducing radiation dose without undermining the diagnostic value of the images when the IR technique is applied.

Abbreviations: ANOVA = analysis of variance, BMI = body mass index, CNR = contrast-to-noise ratio, CT = computed tomography, IR = iterative reconstruction.

Keywords: breast shield, computed tomography scan, image quality, radiation dose, safety

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C-HK and S-Pee contributed equally to the manuscript.

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1. Introduction

Radiosensitivity has become a point of concern for clinicians and radiologists using computed tomography (CT) as a source of pivotal information in early diagnosis and prompt management of disease. The lifetime risk of fatal cancer from the ionizing radiation received during this radiological procedure is estimated to range from 25 to 33 per 100,000 examinations.[1,2] The breast is one of several radiosensitive organs, the others being the lens of the eye, thyroid, and gonads, that commonly receive repeated doses of radiation for diagnostic purposes, and this can lead to a greater stochastic risk of future malignancies.[3,4] Consequently, the importance of reducing radiation dose in all patients undergoing CT studies cannot be overemphasized. In many institutions, bismuth breast shielding is used because it is favorable in cost, effectiveness, and ease of manipulation. Published dosimetry investigations of bismuth shielding used phantoms to assess the dose reduction rate and image quality in pediatric and adult populations.[5–14] The primary drawback of bismuth shielding was a possible degradation in image quality resulting from increased image noise.[10,15,16] Therefore, alternative strategies, including but not limited to organ-based and global tube current modulation and iterative reconstruction (IR) techniques, have been deployed.[4] To our best knowledge, the literature provides no information about the effects of these alternatives, when combined with bismuth breast shielding, on dose reduction and image quality of breast CT scans. Therefore, our aim was to investigate the influence of placing bismuth shields over female breasts on the dose reduction rate, the effect of IR on image quality when the breasts are protected with bismuth shields, and the value of using these techniques in daily practice.

2. Materials and methods

This prospective study was conducted in compliance with the protocol approved by the Ethics Committee of the Joint Institutional Review Board at Taipei Medical University (TMU-JIRB No. 201807003). All participants signed informed consent forms for this study as required by the protocol. All methods were performed in accordance with relevant guidelines and regulations.

2.1. CT Scanner and protocol parameters

All chest CT images were obtained using a 256-slice dual-source CT scanner (SOMATON Definition Flash; Siemens Healthcare, Erlangen, Germany). The protocols were: pitch, 1.2; tube rotation, 0.5 seconds; tube current, 110 effective mAs; voltage, 120 kVp; and use of automated exposure control (Care Dose 4D). Data acquisition was achieved using axial images that extended from the lung apex to the lung base, applying soft tissue and lung windows and a 5-mm thickness. To reconstruct the raw data, filtered back-projection was applied with 2 convolution kernels. One was a medium-smooth kernel (ie, B31f) for the soft tissue window, and the other was a very sharp kernel (ie, B70f) for the lung window. Additionally, a Sinogram-affirmed IR (ie, I31f or I70f) was applied to reduce image noise. This second-generation IR algorithm was used with a strength level of 3 based on the study conducted by Becce et al.[17]

2.2. The breast shield and 3 scanning protocols

A bismuth-based shield phantom was applied to reduce the radiation dose received from routine CT scanning. The shield was 42×16 cm and constructed from a 1-mm thick piece of bismuth-impregnated synthetic rubber with an offset foam base 0.635 mm in thickness. The level of radiation protection was equivalent to that of a 0.06-mm Pb shield. By placing this shield over the breasts, the effectiveness of protection from radiation could be evaluated. Female participants were randomly assigned to 1 of 3 protocols for performing routine CT scans, and image quality and radiation doses were evaluated for each. The 3 protocols were: no use of shielding, placing a bismuth breast shield before obtaining the scout view, and placing the shield after obtaining the scout view.

2.3. Imaging protocols

All protocols are described in detail in Figure 1. Brief descriptions follow:

1. No shielding (Fig. 1A). Perform a routine chest CT scan.
2. Bismuth shield before the scout view (Fig. 1B): Perform a routine chest CT scan with a bismuth breast shield placed

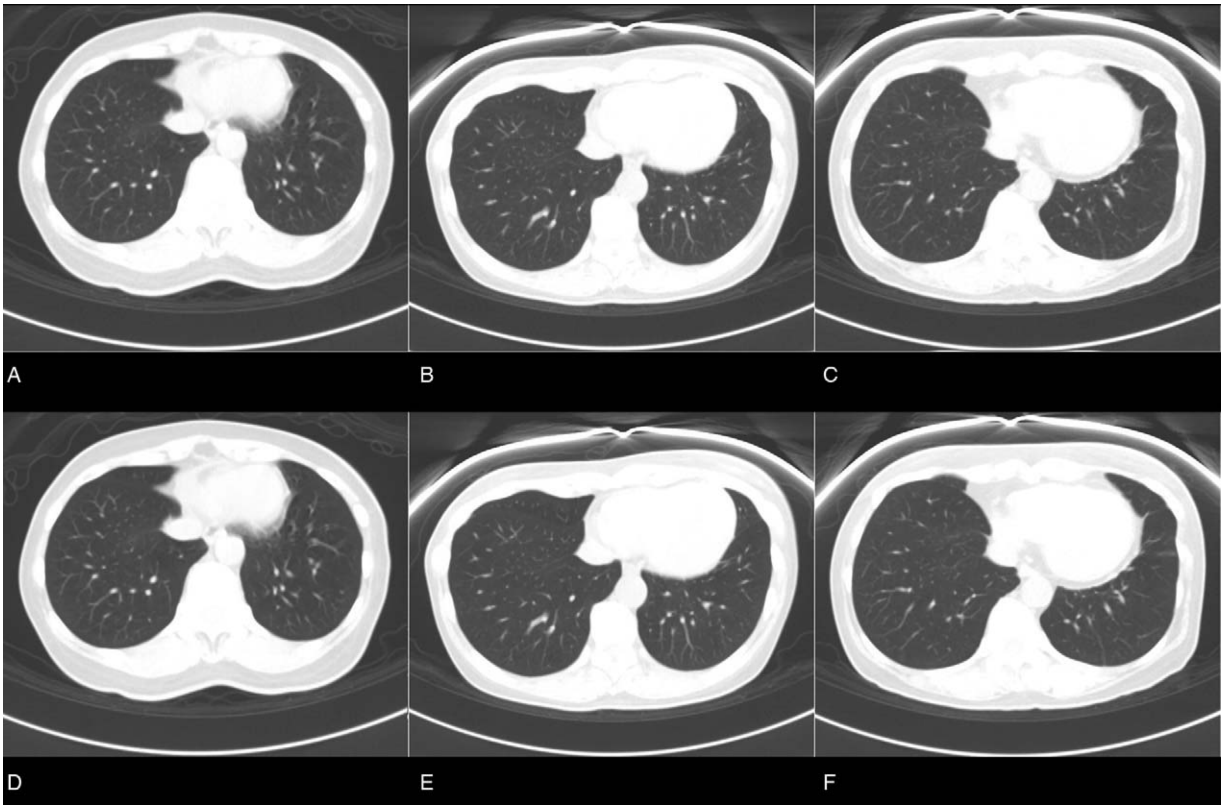

Figure 1. Images belong to 1 of 2 groups: those using the original kernel (ie, the lung window) with either no shield (A), a bismuth shield placed before obtaining the scout view (B), or a bismuth *shield placed a*fter obtaining the scout view (C); or the same images after applying the IR algorithm (D, E, and F, respectively).

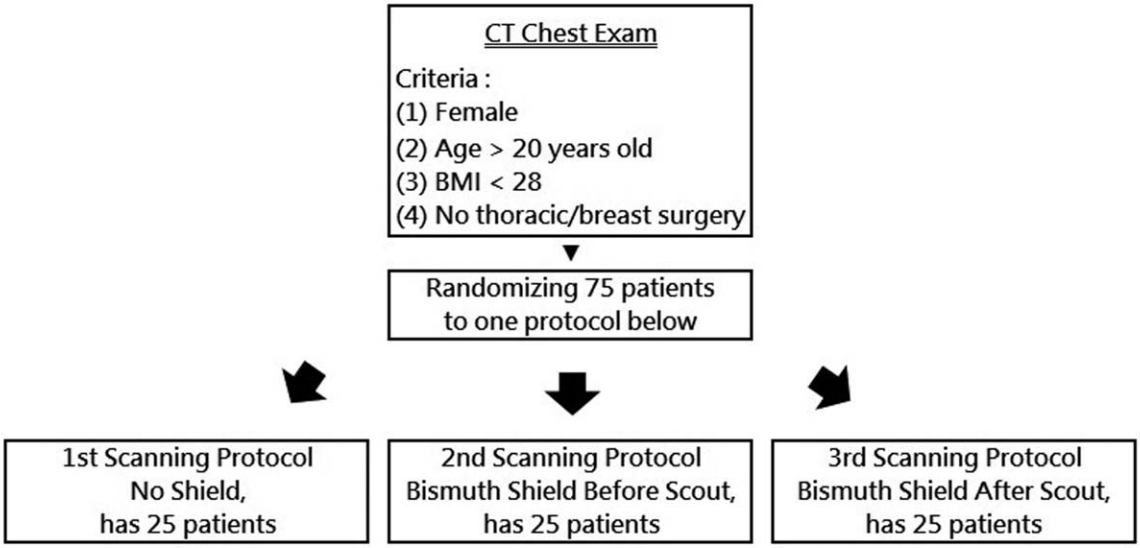

Figure 2. Seventy-five participants were recruited to one of 3 scanning protocols.

directly over the clothes, covering both nipples, before obtaining the scout image.

3. Bismuth shield after the scout view (Fig. 1C): Perform a routine chest CT scan with a bismuth breast shield placed directly over the clothes, covering both nipples, after obtaining the scout image.

Apply an IR Technique (Fig. 1D, E, and F): An IR method was applied to 3 protocols to reduce image artifacts resulting from the breast shielding.

2.4. Participant criteria

Twenty-five randomly selected volunteers were recruited to each of the 3 protocols, resulting in a total of 75 participants (Fig. 2). All participants were referred from other clinical departments to our department to undergo chest CT examinations. Each participant was properly informed and understood the procedure before its performance, and each signed informed consent as required by our institutional review board. The inclusion criteria were age of 20 years or older. Notably, the body mass index (BMI) was <28 in all participants. Measurement each volunteer's body size were BMI, chest width, chest depth, and chest circumference. The latter was measured at the fullest part of the bust, almost covering both nipples, using a manual drawing of the image in the transverse view and the viewer function of the AZE workstation (AZE Inc., Tokyo, Japan). The other 2 dimensions were measured at the same location using the same transverse view: Chest width was the distance from the far left point to the far right point of the circumference, and chest depth was the distance from the foremost point to the hindmost point of the circumference. No participants had thoracic or breast surgeries, but some had fibrocystic breasts, a benign lumpy condition in the female breasts.

2.5. Radiation dose measurement

To measure the radiation dose approximately 1 cm under the skin of each breast, CT body phantoms, each with which a CT ionization chamber and a piece of Gafchromic XR-QA2 film, were employed. The distance between these 2 components was less than 1 cm. One film measuring 10.2 mm × 15.3 mm was placed below the breast shield but atop the clothes near the lateral side of each nipple. The radiation dose reaching 1 cm below the skin of the breasts was measured using these films. Finally, a thermoluminescent dosimeter-fitting model was established by exposing the phantoms to several tube currents, measuring the optical density and radiation dose (Hp(10)) simultaneously, as described elsewhere.[18]

2.6. Image analysis

Image quality was evaluated using the contrast-to-noise ratio (CNR), comparing images before and after applying the IR technique, seeking differences between the three protocols. Subjective assessments of normal chest structures on CT chest images were performed by 2 radiologists (raters 1 and 2, from our department, had 12 and 7 years of experience, respectively) using a 4-point Likert scale to evaluate whether the detail was sufficient for image interpretation.

- Definition of CNR

Two values were defined: *Signal* was defined as the mean of density, in Hounsfield units, inside the drawing area, whereas *noise* was defined as the standard deviation (SD), also in Hounsfield units, of the density in a fat tissue region of interest (ROI) 100 mm^2 in area.

- *Signal(ROIn)* = mean CT number inside the drawing area.
- *Noise* = SD inside a fat tissue area.

The first ROI (ROI1) was drawn as shown in Figure 3B and C, where the subcutaneous fat in the right posterior thoracic area was used to measure *Signal(ROI1)* and *Noise*. Using the same slice, the second ROI (ROI2) was drawn on the transverse view, where the aorta was immediately above the right main pulmonary artery and the pulmonary trunk to measure *Signal (ROI2)*. All measurements at the level of the gray line of the

Figure 3. Chest computed tomography (CT) showing the AP scout view, including the gray line (A). Two views of the axial chest CT using the soft-tissue kernel and IR technique (B31f in [B] and I31f in [C]). The yellow circles are in the aorta and subcutaneous fat.

anterior-posterior view in Figure 3A were used for selecting ROIs in 2 axial images, (B31f and I31f) or evaluating soft tissue.

Finally, CNR was defined as the difference between the soft tissue and fat tissue signals, divided by the fat tissue noise.

- CNR = | *Signal(ROI1)- Signal(ROI2)* | / *Noise*
- Definition of the 4-point Likert rating scale

Similarity between images was assessed by 2 radiologists using a 4-point Likert scale as defined by Pavarani et al[19]: 1 (*severely reduced image quality making reliable interpretation impossible*), 2 (*severe blurring or poorly defined structures with uncertainty about the evaluation*), 3 (*moderate blurring with slightly restricted image evaluation*), or 4 (*excellent image quality with demarcation of structures*).

All positions of interest were located in normal lung and tracheal structures and were scored in the lung window image (ie, the B70f image) and the image after applying the IR algorithm (ie, I70f). Normal lung structures (ie, interlobular septa, lung fissures, centrilobular artery, bronchial wall, and small vessels) and 4 tracheal structures (ie, the trachea and the primary, secondary, and tertiary bronchi) were graded based on the Likert scale.

2.7. Statistical analysis

Means and SDs were found for all participant physical characteristics (ie, BMI and chest width, depth, and circumference), radiation dose to the breast, and CNR. All images from all participants were evaluated; no data were missing. Before statistical testing, the Shapiro-Wilk test was used to determine that each sample group was normally distributed. Statistical differences in all parameters were evaluated using a one-way analysis of variance (ANOVA; $P<.05$). When significant differences were found, a post-hoc test with Bonferroni correction (adjusted $P<.05$) was applied. Furthermore, the paired *t* test was applied to assess the significance of differences between pairs (ie, after applying the soft-tissue kernel and the IR technique). The Kruskal-Wallis test, a rank-based non-parametic test, was used to determine the significance of differences among the 3 protocols using the interrater assessments of normal lung and tracheal structures after applying the soft-tissue kernel and the IR technique. Because the intraclass correlation coefficient and the Kappa coefficient were both inappropriate for evaluating interrater reliability, interobserver agreement was used instead, finding the percentage and its 95% confidence interval. The percentage was calculated by dividing the number of agreements between 2 radiologists by the total number of participants compared. All analyses were conducted using IBM SPSS Statistics 19 (SPSS Inc., Chicago, IL).

3. Results

Table 1 shows the mean BMI, chest width, chest depth, and chest circumference of the participants, grouped according to shield protocol. Between-group differences were not significant for any variable: *P* values were .497, .377, .338, and .320 for BMI, chest width, chest depth, and chest circumference, respectively. Therefore, the 1-way ANOVAs of the 4 variables showed that all participants across the 3 groups were similar in body size.

To quantitatively estimate breast radiation doses (Table 2), the sum of the bilateral breast radiation doses (mGy) and the average reduction in radiation exposure (%) were calculated for each protocol. The former was 10.04 ± 1.54, 8.87 ± 1.76, and 7.23 ± 1.37 (mGy) for No Shield, Bismuth Shield Before Scout View, and Bismuth Shield After Scout View, respectively. All protocols were compared using 1-way ANOVA, showing significant differences between the first 2 ($\mathbf{P}=.03$), between the second and third

Table 1

One-way ANOVA of 4 variables by shield protocol.

Patient conditions	No shield (25) (Mean ± SD)	Bismuth before scout (25) (Mean ± SD)	Bismuth after scout (25) (Mean ± SD)	*P*
BMI, kg/cm^2	21.92 ± 2.26	22.59 ± 1.81	21.96 ± 2.57	.497
Chest width, cm	30.66 ± 3.14	31.66 ± 3.13	30.68 ± 2.28	.377
Chest depth, cm	19.80 ± 2.12	20.31 ± 1.52	19.62 ± 1.48	.338
Chest circumference, cm	86.40 ± 7.16	88.68 ± 5.70	86.37 ± 5.47	.320

ANOVA = analysis of variance, BMI = body mass index.

Table 2

Breast radiation dose and reduction in radiation exposure under 2 shield protocol conditions.

Exposure protocols	No shield (25)	Bismuth before scout (25)	Bismuth after scout (25)
Sum of bilateral breasts dose, mGy (mean ± SD)	10.04 ± 1.54*	8.87 ± 1.76 **	7.23 ± 1.37***
Average reduction rate (%)	Reference value	11.65	27.99

* ***P*** value <.05 is significant between No Shield and Bismuth before scout.
** ***P*** value <.05 is significant between Bismuth before scout and Bismuth After Scout.
*** ***P*** value <.05 is significant between No Shield and Bismuth After Scout.

(***P***=.001), and between the first and third (***P***<.001) protocols. Using the first protocol (No Shield) as a reference, radiation exposure was reduced by an average of 11.65% in the second protocol and up to 27.99% in the third. In other words, the third (applying a bismuth shield after the scout view) resulted in the lowest total exposure (sum of the doses to both breasts).

To assess image quality, CNR was determined, and paired *t* tests and 1-way ANOVAs were used to compare the B31f to I31f methods for each protocol (Table 3). In all analyses, the B31f image gave lower values than the corresponding I31f image, and the differences in these values between methods were significant using the paired *t* test. However, the values for each individual image of each group did not differ when compared among the 3 protocols using one-way ANOVA. In brief, the IR technique (I31f) yielded scans that were superior to those supplied by the soft-tissue kernel (B31f) when CNR was calculated using the aorta and subcutaneous fat as ROIs. In addition, CNRs based on B31f and I31f were determined, and one-way ANOVAs were used to compare the 3 protocols, seeking significant differences (Table 3). In no case was a significant difference found. Because I31f was derived from B31f, differences between them were found by subtracting the CNR after applying I31f from the CNR after applying B31f, finding −2.70 ± 2.10, −3.08 ± 2.01, and −2.55 ± 1.61 for No Shield, Bismuth Shield Before Scout View, and Bismuth Shield After Scout View, respectively. Paired *t* tests were used to compare the 2 CNRs (after applying B31f and I31f) for each protocol (Table 3). In each case, the B31f method resulted in a lower value than the corresponding I31f image, and the differences in these values were significant.

The qualitative scores for normal lung and tracheal structures are summarized in Table 4. No matter the method or protocol, all structures were given scores of 3 or 4 by both raters. Furthermore, using the Kruskal-Wallis test, significant differences were not found among the 3 protocols when the scores for the normal lung and tracheal structures were compared between the 2 images (B70f and I70f). Interobserver agreement between the scores given by the 2 raters was slightly greater for the IR image (I70f) than for the lung window image (B70f) in structures except in the tertiary bronchi.

4. Discussion

Female breasts are radiosensitive because of their glandular tissue composition. With technological advancements, CT has become a major diagnostic tool, but it exposes patients to the highest radiation doses in diagnostic imaging. The carcinogenic effects of radiation in breast tissue must be considered, given the frequency with which they are scanned during CT examinations even when not the target of study. Protecting breast tissues from radiation exposure without compromising the diagnostic value of imaging is paramount. A bismuth cover has been used for shielding breasts during CT scanning for quite some time, prompting discussions around dose reduction of the protected breasts and resultant artifacts. However, to date, the literature does not provide information about image quality when bismuth shields are combined with IR techniques.

Participants were selected based on BMI, chest width, chest depth, and chest circumference and then divided into 3 groups, each scanned using a specific shielding protocol. Because BMI, chest width, chest depth, and chest circumference were similar among the groups, anatomical concerns about the extra volume of laterally located structures that might be exposed to radiation were eliminated. This consistency among participants shows that the radiation dose measured by 2 Gafchromic films placed adjacent to the nipples in each group can rationally be adopted for comparison.

In this study, the use of bismuth shielding during chest CT scans reduced the dose by an average of 27.99% (***P***<.05) in the group receiving bismuth shields after the scout view was obtained. This result agrees with the majority of the literature advocating bismuth shielding after the scout scan (which resulted in dose reductions of 20% to 60%, depending on body type, scanner, shield design, and protocol).[4,16,20–25] Additionally, a significant dose reduction rate was found when bismuth shielding

Table 3

One-way ANOVA for finding significant differences among the 3 protocols in contrast-to-noise ratio based on the B31f and I31f reconstructive methods.

Image analysis	Methods	No shield (25) (Mean ± SD)	Bismuth before scout (25) (Mean ± SD)	Bismuth after scout (25) (Mean ± SD)	ANOVA *P*
CNR	B31f	8.62 ± 3.15	8.90 ± 2.38	7.79 ± 2.27	.304
	I31f	11.32 ± 5.18	11.99 ± 4.28	10.33 ± 3.79	.422
CNR Difference (B31f-I31f)		−2.70 ± 2.10*	−3.08 ± 2.01*	−2.55 ± 1.61*	—

— = not applicable, ANOVA = analysis of variance, CNR = contrast-to-noise ratio.
*Indicated that $P<.05$ is significant in pair *t* test.
Significant CNR difference between B31f and I31f.

Table 4

Qualitative evaluation of normal lung structures.

		No shield (25)				Bismuth before scout (25)				Bismuth after scout (25)				Kruskal-Wallis *H* test	
		4-point Likert scale To A/B rater				4-point Likert scale To A/B rater				4-point Likert scale To A/B rater				*P*	
Methods	Structures	1	2	3	4	1	2	3	4	1	2	3	4	A/B rater	Interobserver agreement (%) (95% CI)
B80f	interlobular septa	0	0	3/1	22/24	0	0	0/3	25/22	0	0	2/3	23/22	0.228/0.537	84 (92~76)
	Lung fissures	0	0	1/1	24/24	0	0	0/4	25/21	0	0	2/5	23/20	0.358/0.228	83 (92~74)
	Centrilobular artery	0	0	0/1	25/24	0	0	0/2	25/23	0	0	0/2	25/23	1/0.809	93 (99 ~87)
	Bronchial wall	0	0	0/1	25/24	0	0	0/2	25/23	0	0	0/3	25/22	1/0.537	91 (97~85)
	Small vessel	0	0	0/4	25/21	0	0	1/6	24/19	0	0	1/12	24/13	0.602/0.037	73 (83~63)
	Trachea	0	0	0	25/25	0	0	0	25/25	0	0	0	25/25	1/1	100 (100~100)
	Primary bronchi	0	0	0	25/25	0	0	0	25/25	0	0	0	25/25	1/1	100 (100~100)
	Secondary bronchi	0	0	0	25/25	0	0	0	25/25	0	0	0	25/25	1/1	100 (100~100)
	Tertiary bronchi	0	0	6/0	19/25	0	0	5/3	20/22	0	0	7/5	18/20	0.805/0.073	65 (76~54)
I70f	interlobular septa	0	0	3/0	22/25	0	0	1/1	24/24	0	0	2/2	23/23	0.585/0.358	88 (95~81)
	Lung fissures	0	0	1/0	24/25	0	0	1/1	24/24	0	0	1/2	24/23	1/0.358	92 (98~86)
	Centrilobular artery	0	0	0/1	25/24	0	0	1/0	24/25	0	0	0	25/25	0.368/0.368	97 (100~93)
	Bronchial wall	0	0	0/1	25/24	0	0	1/1	24/24	0	0	0/1	25/24	0.368/1	97 (100~93)
	Small vessel	0	0	2/3	23/22	0	0	3/5	22/20	0	0	4/5	21/20	0.688/0.693	81 (90~72)
	Trachea	0	0	0	25/25	0	0	0	25/25	0	0	0	25/25	1/1	100 (100~100)
	Primary bronchi	0	0	0	25/25	0	0	0	25/25	0	0	0	25/25	1/1	100 (100~100)
	Secondary bronchi	0	0	0	25/25	0	0	0	25/25	0	0	0	25/25	1/1	100 (100~100)
	Tertiary bronchi	0	0	7/3	18/22	0	0	6/6	19/19	0	0	10/5	15/20	0.447/545	56 (67~45)

was applied after the scout view. This can reasonably be attributed to the fact that tube current varies with the difference in attenuation between bismuth shielding and no bismuth shielding over the chest. Consequently, to achieve the maximum reduction in radiation dose to the breast tissues, it is judicious to cover a patient with a bismuth shield after completing a topogram.

Image quality has long been an important concern about the use of bismuth breast shields to reduce radiation dose. Several studies advocate against the use of bismuth shielding because image noise can interfere with diagnostic processes.[2,21,26,27] For example, Einstein et al[15] reported that increased image noise from bismuth shields hampered the interpretation of coronary artery images. Furthermore, the study performed by Wang et al[16] demonstrated increased noise in the lung and heart, particularly in regions closer to the shields. However, IR techniques were not utilized in these studies. We employed a soft-tissue kernel and IR technique in our study groups and then evaluated the CNR in each group for each kernel and IR technique applied to the images, finding no significant differences in CNRs in any group with or without bismuth shielding no matter the kernel or IR technique applied. Thus, image quality was not significantly affected by the use of bismuth shielding when an IR technique was applied. The literature describes comparable findings. A study by Nikupaavo et al[28] of routine head CT images revealed image noise reduction by 20% when an IR technique was applied. Kim et al[29] confirmed that the combination of bismuth shielding and an IR algorithm, applied when the lens of the eye was examined via CT scans, reduced both radiation dose and image noise. Therefore, it is rational to implement both bismuth shielding and an IR technique simultaneously in daily practice to reduce radiation dose to the breast tissues without compromising the diagnostic value of CT imaging.

Furthermore, no significant differences were found between 2 radiologists, each with more than 7 years of experience, in their qualitative image evaluations of normal trachea, bronchial trees, and lung parenchyma, which were based primarily on lung window images. Interobserver agreement was high except at the tertiary bronchi, where image quality was somewhat discordant. Notably, high-resolution CT is usually the modality of choice to rule in or out suspected conditions in the respiratory system, if any. Thus, employing bismuth shielding along with IR techniques can reduce radiation dose without undermining the diagnostic capability of CT imaging.

This study has some limitations. First, due to our selection criteria (Table 1), only those with similar body size measures (BMI, chest width, chest depth, and chest circumference) participated in the study. For larger people or those with larger breasts, the extra volume of laterally located structures can be exposed to laterally incident radiation, which might not be accommodated by our study design. Therefore, the dose reduction rate we found might be an overestimation. Second, due to variations in attenuation based on the person's body thickness, image quality might be uncertain. Third, due to our imposed age limit, the effectiveness of bismuth shielding of female breasts when combined with IR techniques could be uncertain in patients aged <20 years. Fourth, IR techniques are not yet universally available because of the financial costs of hardware and software upgrades. For this reason, our study results might not be widely feasible. Finally, by virtue of focusing interpretative methods on normal lung parenchyma, the efficacy of detecting lung pathology by combining breast shielding with IR technique is uncertain; additional studies could clarify this.

In conclusion, bismuth breast shields are effective in reducing radiation doses to patients undergoing CT examinations. Furthermore, when combined with IR techniques, bismuth breast shields reduce image noise without reducing the diagnostic value of the images. To increase the utility of CT examinations in female patients, bismuth shielding, particularly after obtaining scout images should be advocated with the use of IR techniques.

Author contributions

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