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AN EVALUATION OF IN-PLANE SHIELDS DURING THORACIC CT

S. J. Foley^{1,*}, M. F. McEntee² and L. A. Rainford¹

¹School of Medicine and Medical Science, University College Dublin, Dublin 4, Ireland

²Faculty of Health Science, Discipline of Medical Radiation Sciences, University of Sydney, Darlington, NSW 2006, Australia

*Corresponding author: shane.foley@ucd.ie

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The object of this study was to compare organ dose and image quality effects of using bismuth and barium vinyl in-plane shields with standard and low tube current thoracic CT protocols. A RANDO phantom was scanned using a 64-slice CT scanner and three different thoracic protocols. Thermoluminescent dosimeters were positioned in six locations to record surface and absorbed breast and lung doses. Image quality was assessed quantitatively using region of interest measurements. Scanning was repeated using bismuth and barium vinyl in-plane shields to cover the breasts and the results were compared with standard and reduced dose protocols. Dose reductions were most evident in the breast, skin and anterior lung when shielding was used, with mean reductions of 34, 33 and 10 % for bismuth and 23, 18 and 11 % for barium, respectively. Bismuth was associated with significant increases in both noise and CT attenuation values for all the three protocols, especially anteriorly and centrally. Barium shielding had a reduced impact on image quality. Reducing the overall tube current reduced doses in all the locations by 20–27 % with similar increases in noise as shielding, without impacting on attenuation values. Reducing the overall tube current best optimises dose with minimal image quality impact. In-plane shields increase noise and attenuation values, while reducing anterior organ doses primarily. Shielding remains a useful optimisation tool in CT and barium is an effective alternative to bismuth especially when image quality is of concern.

INTRODUCTION

Use of computed tomography (CT) has grown dramatically in recent years⁽¹⁾ since the introduction of multislice technology, which has facilitated improved scanning at higher spatial and temporal resolutions and in the process enabled a variety of new examinations. Owing to their non-invasiveness, speed of scanning and reported sensitivities in detecting disease^(2–6), angiography procedures such as CT pulmonary angiography (CTPA) and coronary CT angiography (CCTA) in particular are gaining widespread popularity, making thoracic CT one of the most common CT examinations currently being performed⁽⁷⁾.

Although growing in acceptance and availability, concerns still exist as to the radiation doses resulting from CT techniques with reports of total effective doses up to 30 mSv⁽⁸⁾ associated with cardiac scanning alone and individual organ doses in excess of 60 mSv^(9, 10). In fact, recent studies have shown that cardiac CT is associated with the greatest potential for cancer induction as a result of CT scanning⁽¹¹⁾, because of the high doses involved and the presence of two of the most radiosensitive organs⁽¹²⁾ within the scan range. While these theoretical risks from radiation use are believed to be significantly smaller than the direct benefits accruing from such imaging⁽¹³⁾, maximising this gap would obviously be

desirable. Adherence to the basic tenets of radiation protection obliges all CT professionals to optimise techniques where possible to keep patient doses low in compliance with the as low as reasonably achievable (ALARA) principle⁽¹⁴⁾. Many techniques have been tested and implemented to date in an effort to minimise radiation dose from thoracic CT scanning, such as the use of prospective ECG gating, lower tube potential, automatic exposure control, iterative reconstruction algorithms as well as organ-based tube current modulation⁽¹⁵⁾.

A long-accepted method of dose minimisation during radiographic examinations is the use of shielding to protect superficial organs from scatter radiation. Increasing research has gone into the development of shields that can be utilised within the CT scan range^(16, 17). These shields allow a reduction in dose to superficial organs through the absorption of lower energy dose contributing photons, while not degrading image quality. Bismuth has been the most studied material, with reports of a 30 to 57 % dose reduction to the breast alone when used during thoracic CT^(16, 18–22). However, concerns are increasingly being raised as to its efficacy especially in relation to its impact on image quality⁽¹⁹⁾. Bismuth has been reported to cause beam hardening artefacts and streaking and may also artefactually increase the CT numbers below the shield⁽²³⁾. Indeed more

recently, some professional organisations completely discourage its use in cardiac CT⁽¹⁵⁾, while others recommend alternative methods⁽²⁴⁾ of dose minimisation, especially when tube current modulation is also being used.

Barium, on the other hand, has an atomic number of 56 and is thus less dense than bismuth ($Z = 83$) or lead ($Z = 82$) and should theoretically attenuate the primary radiation beam less, with fewer image quality effects. This work aimed to investigate the suitability of using barium vinyl as a superficial shield during a variety of thoracic CT examinations. Its impact on both organ dose and image quality will be compared with the impacts of standard bismuth shielding, standard dose as well as a low-dose protocol, during routine thoracic CT, CTPA and CCTA scanning.

MATERIALS AND METHOD

Institutional exemption from ethics was first obtained as the work did not involve patients.

Phantom

A sectional anthropomorphic phantom (RANDO® phantom, Alderson Research Laboratories, Salem, New York) was used for the experimental phase. This phantom is constructed with a natural human skeleton cast within radiologically equivalent soft tissue material and has the advantage of simulating human attenuation properties, while permitting the insertion of dose measuring devices at precise organ locations. A 2-cm-thick moulded breast phantom was positioned anteriorly on the phantom chest wall to best approximate the supine breast position (Figure 1).



Figure 1. RANDO phantom and breast phantom *in situ* on CT table. TLD packets and ionisation chamber also in position.

In-plane breast shields

A commercially available 60×42 cm bismuth-based in-plane breast shield (Breast Shield Medium, F & L Medical Products, Vandergrift, PA) was used for this study. This shield consists of sheets of latex impregnated with bismuth oxide of 0.06 mm lead equivalence and mounted on a 10-mm foam base. The foam offset is used to decrease streak artefacts, which have previously been noted in the regions adjacent to the surface in contact with the shield. A prototype barium-based in-plane shield (Kemmetech Ltd, Kent, UK) was obtained, which consisted of a barium-impregnated vinyl of 0.07-mm lead equivalence and was set on a 7-mm foam backing. The barium shield was cut to size to exactly match the dimensions of the bismuth shield (Figure 2). Both shields are lightweight, approx 200 g in total, and should not disturb the patient's comfort during a CT examination nor should they interfere with the patient's respiration.

Dosimetry

Organ radiation doses were recorded by thermoluminescent dosimeters (TLDs). Standard TLD 100 ($3 \times 3 \times 0.8$ mm) lithium fluoride chips and a Harshaw 5500 TLD reader (Thermo Fisher Scientific, Reading, UK) were used. The TLDs were first calibrated in air with an ionisation chamber (Radcal 9095, Radcal Corporation, Monrovia, CA). Calibration was performed at the centre of rotation in the gantry of the CT scanner, using 120 kVp. Ten TLD's were irradiated to known doses and measured. This allowed a conversion factor to be calculated to convert the TLD readout into a milliGray dose.

TLDs were placed in groups of three within protective PVC pockets, labelled and positioned at the



Figure 2. Barium shield *in situ* overlying breast tissue.

surface and at a depth of 2 cm centrally within the breast attachment. TLDs were also positioned in three locations within the lung tissue, anteriorly, centrally and posteriorly at slice 19, which corresponded to the centre of the heart position. Following scanning, the TLDs were removed and read in the TLD reader within 24 hr. For each scan, an entrance surface dose and absorbed breast and lung radiation dose were recorded. The volume computed tomography dose index (CTDI_{vol}) and the dose length product (DLP) were recorded directly from the CT console on completion of examinations. The 6-cc ionisation chamber (as above) was also positioned between the breasts on the surface of the phantom to record entrance surface dose (Figure 1).

CT protocol

Scanning was performed on a single-source 64-slice multidetector CT scanner (Somatom Sensation 64, Siemens Medical Solutions, Forchheim, Germany), using three different thoracic CT protocols, namely routine thorax, CT pulmonary angiography (CTPA) and coronary CT angiography (CCTA). All scans were performed using 120 kVp and 64 × 0.6 mm collimation with the craniocaudal scan range being selected on the basis of the initial topogram for each scan. The remaining scan parameters are listed in Table 1.

For the CCTA protocol retrospective electrocardiograph (ECG) gating was used with ECG-tube current modulation ('minDose' feature was not available on our scanner at the time of this study). For each examination, the phantom was first scanned using the standard protocol, but following this the TLDs were replaced and scanning was repeated with (a) bismuth (b) barium shielding in place over the breast tissue and (c) a reduced overall tube current used (Figure 3). The reduced overall tube current was calculated by measuring the dose reduction achieved on the ionisation chamber when barium shielding was used and then reducing the quality reference tube current-time (mAs) product accordingly. Quality reference mAs is the Siemens parameter used to stipulate the desired image quality, so any adjustments in this will result in an increase or decrease in noise within CT images. This resulted in

80, 200 and 700 Quality reference mAs being utilised for the thoracic, CTPA and CCTA scans, respectively. All scan projection radiographs were obtained without the shields in position to avoid the automatic exposure control system increasing the tube current to compensate for the attenuation increase with shielding present.

Image quality analysis

A single reader placed nine circular regions of interest (ROI) (2 cm²) within homogenous regions of the phantom to measure both the average Hounsfield units and the standard deviation in each region. Standard deviation measures can be used as a quantitative measure of noise within CT images and collecting the average Hounsfield units will check for variations caused by the presence of the breast shields. ROI were placed in both the subcutaneous tissue (three anteriorly, two laterally (middle) and three posteriorly) and centrally in the cardiac region, on five consecutive slices at the midpoint of each scan range (Figure 4). Central ROI measurements were also taken on ten consecutive image slices during the thoracic CT examination to evaluate noise at the level of the shoulders and the liver between the routine and lower tube current protocols. ROI within the lung region were precluded from the image quality analysis as this region is inhomogeneous and the measures cannot be accurately compared between slices.

Statistical analysis

Statistical analysis was performed using the SPSS software (SPSS 18.0, Chicago, IL). Quantitative variables are expressed as means ± standard deviations. Dosimetry and image quality results were checked for normality. The parametric dose data were analysed using one-way ANOVA with post hoc Bonferroni testing, while the non-parametric image quality data were analysed using Kruskal–Wallis tests with pairwise comparisons done using the Mann–Whitney *U* test. Noise measurements at the shoulder and the liver levels were compared using

Table 1. Summary of standard CT protocols applied.

Examination	Quality reference (mAs)	Rotation time (s)	ATCM	Scan length (mm)	Pitch
Chest	100	0.5	Yes	300	1.4
CTPA	250	0.37	Yes	200	0.85
CCTA	850	0.33	No	120	0.2

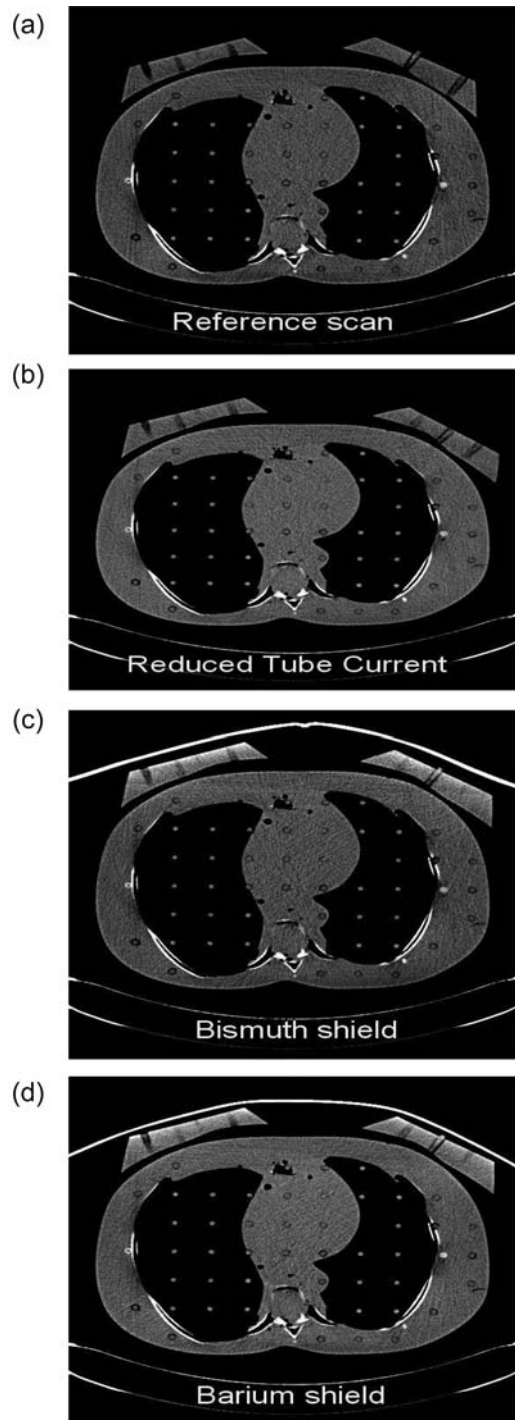


Figure 3. (a–d) Axial CT images from each of the four CT protocols investigated: (a) reference protocol, (b) reduced tube current (c) bismuth shield *in situ* and (d) barium shield *in situ*.

one sample *t*-testing. Statistical significance was defined as a *p* value of ≤ 0.05 .

RESULTS

Results of the TLD dosimetry for each CT examination are shown in Tables 2–4.

Image quality analysis

In total 45 ROI measurements were made at the level of the breast tissue in each of the four experimental techniques for all the three CT examinations. An additional ten ROI were positioned to evaluate the liver and the shoulder regions in both the reference and reduced tube current techniques during the CT chest examination, totalling 580 measurements for comparison. Figures 5 and 6 detail the results, with error bars indicating one standard deviation from the mean.

Kruskal–Wallis testing followed by pairwise comparisons using the Mann–Whitney *U* test showed that when compared with the reference protocol, the use of barium and bismuth shielding resulted in statistically significant increases in Hounsfield unit measurements in the anterior ROI during all the three examinations. Bismuth also resulted in significant increases in the middle ROI during both thorax ($p = 0.011$) and CTPA ($p = 0.031$) examinations and the cardiac ROI during thorax ($p = 0.035$) and CTPA ($p = 0.005$) examinations.

Noise measures increased throughout when shielding was used, with significant increases noted in the anterior ROI for all examinations again when bismuth was used as well as the posterior ROI ($p = 0.004$) during the CCTA examination. The only significant increases in noise noted when barium shielding was used were for the anterior ($p = 0.002$) and posterior ROI ($p = 0.028$) during the CTPA examination. When a reduced tube current was used, no changes were noted in the Hounsfield unit measures with the sole statistical increases in noise being for the anterior ROI during chest ($p = 0.025$) and CTPA ($p = 0.041$) examinations. ROI analysis between the reference and reduced tube current protocol also demonstrated a statistically significant difference in noise at the level of both the shoulder (10.5 vs. 13.8, $p = 0.001$) and the liver regions (24.7 vs. 28.3, $p = 0.003$).

The $CTDI_{vol}$ and DLP showed very little variation between scans when either the bismuth or the barium breast shields were present, as these values are determined from the scout radiographs. When reduced tube current was used, both the $CTDI$ and DLP values dropped by an average of 20 % as expected.

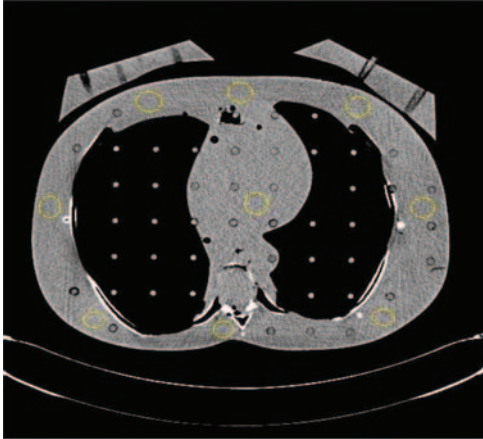


Figure 4. Regions of interest positioned anteriorly (three), laterally (two), posteriorly (three) and centrally (one) within axial CT slices.

DISCUSSION

Radiation dose remains a concern within CT, given the dramatic rise in its use worldwide⁽²⁵⁾. Despite the introduction of newer technologies, there has been a reported increase in average CT dose with the advent of multidetector technology⁽²⁶⁾, and consequently, the total radiation burden to the population also continues to rise⁽²⁷⁾. Importantly, thoracic CT also involves irradiation of two of the most radiosensitive organs in the body, the breast and the lung tissue⁽²⁸⁾, and therefore, any efforts to reduce dose to these organs will be of particular benefit in obviating the deleterious risks that CT poses^(11, 29).

Results of this study show that even with modern CT equipment, absorbed breast doses can reach as high as 60 mGy during cardiac scanning. This equates to almost twenty times the radiation dose from standard mammography⁽³⁰⁾, despite the fact that the breast tissue is not even the target organ during CT scanning and receives this radiation dose as a by-product of its anatomical location anterior to the heart tissue. This correlates well with other studies that have both measured⁽³¹⁾ and estimated^(9, 10, 32) the absorbed breast dose during cardiac CT, thus demonstrating the usefulness of TLD dosimetry to directly measure organ doses. While not as high as during CCTA examinations, breast dose during CTPA (22 mGy) and that during routine thoracic scanning (10 mGy) are also relatively large, especially when compared with breast-specific imaging techniques. Lung doses recorded here are similarly substantial, with a maximum of 54 mGy found during cardiac CT and an average of 21 and 10 mGy found in CTPA and thoracic examinations, respectively, again similar to other work in

Table 2. Absorbed organ dose results (milliGray): thorax examination.

	Reference	Bismuth	Barium	Red. mAs
Left breast	9.6 ± 0.4	5.6 ± 0.2*	7.3 ± 0.5*	7.9 ± 0.3*
Right breast	10.2 ± 1.0	6.8 ± 0.2*	6.4 ± 0.3*	7.9 ± 0.4*
E.S.D	9.5 ± 0.8	6.0 ± 0.1*	6.6 ± 1.6*	7.2 ± 0.3*
Lung anterior	9.5 ± 0.4	7.5 ± 0.2*	9.1 ± 0.2	7.5 ± 0.2*
Lung middle	9.9 ± 0.4	8.5 ± 0.4	8.3 ± 0.8	7.3 ± 0.3*
Lung posterior	9.1 ± 0.4	8.6 ± 0.3	8.9 ± 0.6	6.8 ± 0.5*

*Statistical significance, $p < 0.05$, when compared with the reference scan. 'Red. mAs' signifies reduced reference tube current protocol.

cardiac⁽⁹⁾, CTPA⁽³³⁾ and thoracic scanning⁽³⁴⁾. The scale of the absorbed organ doses demonstrated here thus reinforce the need for optimisation within the modality, and any technique that can reduce the extent of such doses to these radiosensitive tissues deserves consideration in compliance with the ALARA principle, with the caveat that image quality is not adversely affected.

Shielding

This study is the first to evaluate the use of barium shielding during thoracic CT scanning and has done so using three of the most commonly used thoracic CT protocols. Results of the dosimetric analysis show that barium shielding results in a reduction in mean absorbed dose to the breast tissue of 19–31 %, to the lung of 1–10 % and to the skin of 11–31 % (entrance surface dose) for the three examinations investigated. As expected, dose savings were most evident anteriorly with only the dose reductions to the breast tissue gaining statistical significance for all the three examinations. Owing to its increased density, larger dose reductions were achieved when bismuth shielding was used, with mean reductions of 33–37 % for the breast, 1–15 % for the lung and 28–37 % for the skin. Bismuth dose reductions were also statistically significant for the breast, skin and anterior lung dose for all the three examinations in agreement with other studies^(33, 35, 36).

Image quality

The main concern with the use of bismuth shielding is the potential negative effects on image quality caused by the preferential absorption of lower energy photons. Conflicting reports exist as to the exact nature of these effects. Fricke *et al.*⁽¹⁸⁾ reported

Table 3. Absorbed organ dose results (milliGray): CTPA examination.

	Reference	Bismuth	Barium	Red. mAs
Left breast	24.2 ± 1.0	14.7 ± 0.5*	16.7 ± 0.7*	17.2 ± 0.5*
Right breast	20.3 ± 2.2	15.3 ± 0.2*	19.3 ± 0.8	17.9 ± 0.6
E.S.D	19.5 ± 1.4	12.6 ± 0.1*	17.2 ± 1.1	14.0 ± 0.0*
Lung anterior	20.7 ± 1.8	17.1 ± 0.9*	18.6 ± 1.0	15.4 ± 0.3*
Lung middle	21.0 ± 1.0	19.4 ± 1.7	18.4 ± 0.2	15.0 ± 0.6*
Lung posterior	20.1 ± 1.3	19.3 ± 1.6	18.6 ± 1.3	14.4 ± 1.1*

*Statistical significance, $p < 0.05$, when compared with the reference scan. 'Red. mAs' signifies reduced reference tube current protocol.

Table 4. Absorbed organ dose results (milliGray): CCTA examination.

	Reference	Bismuth	Barium	Red. mAs
Left breast	60.0 ± 2.7	40.3 ± 0.8*	46.2 ± 2.5*	49.8 ± 2.4*
Right breast	57.2 ± 4.4	38.8 ± 1.6*	49.4 ± 1.0*	45.5 ± 1.0*
E.S.D	53.6 ± 4.3	38.7 ± 4.5*	48.0 ± 1.5	44.3 ± 1.1*
Lung anterior	53.8 ± 2.1	44.0 ± 3.7*	44.0 ± 2.4*	42.9 ± 1.2*
Lung middle	47.1 ± 2.8	45.4 ± 1.9	48.3 ± 1.8	43.4 ± 1.7
Lung posterior	38.6 ± 0.2	48.6 ± 0.1*	45.9 ± 1.7*	41.0 ± 3.1

*Statistical significance, $p < 0.05$, when compared with the reference scan. 'Red. mAs' signifies reduced reference tube current protocol.

no increase in noise within the lung with the use of bismuth shielding, although this study was investigating the use of such shields with paediatric patients, in whom the doses are generally much less. Midgley *et al.*⁽³⁶⁾ also reported preservation of image quality with mild streaking seen, although no quantitative analysis was performed. Gelejin *et al.*⁽¹⁹⁾ reported increases in image noise, while Kalra *et al.*⁽²³⁾ reported potential for streak artefacts, artefactually increased attenuation values as well as significant increases in image noise. The results of this work appear to support the latter in that both image noise and attenuation values are increased for each of the examinations investigated, and mild streak artefacts were observed especially when bismuth was used, but these were confined to superficial tissues especially within the breast tissue, which is likely due to the presence of the foam backing on the shield.

Noise

Noise was increased in all regions of interest across all the three examinations (Figure 6a–c) when bismuth was used in comparison with the reference protocol. This was most evident in the anterior chest wall ROI, directly below the shield which saw statistically significant increases noted for all the three examinations and a mean noise rise of 27 %, from

16.1 to 20.4. This confirms the results from other research^(33, 37, 38) whereby the absorption of lower energy photons by bismuth reduced the overall quanta available for image formation in the area immediately beneath the shield. Such increases in noise within the image, while quantitatively small, have the potential to impact on the diagnostic information available in CT scans by decreasing the low-contrast detectability within images. Image quality has to be maintained for dose-saving techniques to be widely accepted, and therefore, users have to have confidence that optimisation methods will not adversely affect the image quality. The use of barium shielding resulted in lower mean increases in image noise (13–19 %) across all the three examinations with only the anterior and poster ROI of the CTPA examination recording statistically significant changes. Such an increase in noise in the subcutaneous region is much less likely to have a clinical impact on the diagnostic information gained from thoracic CT scanning. There were also fewer streak artefacts observed with its use in comparison with bismuth shielding.

Attenuation values

This study also confirms reports^(23, 38) that bismuth can result in an increase in the CT attenuation values in tissues beneath the shield. Mean

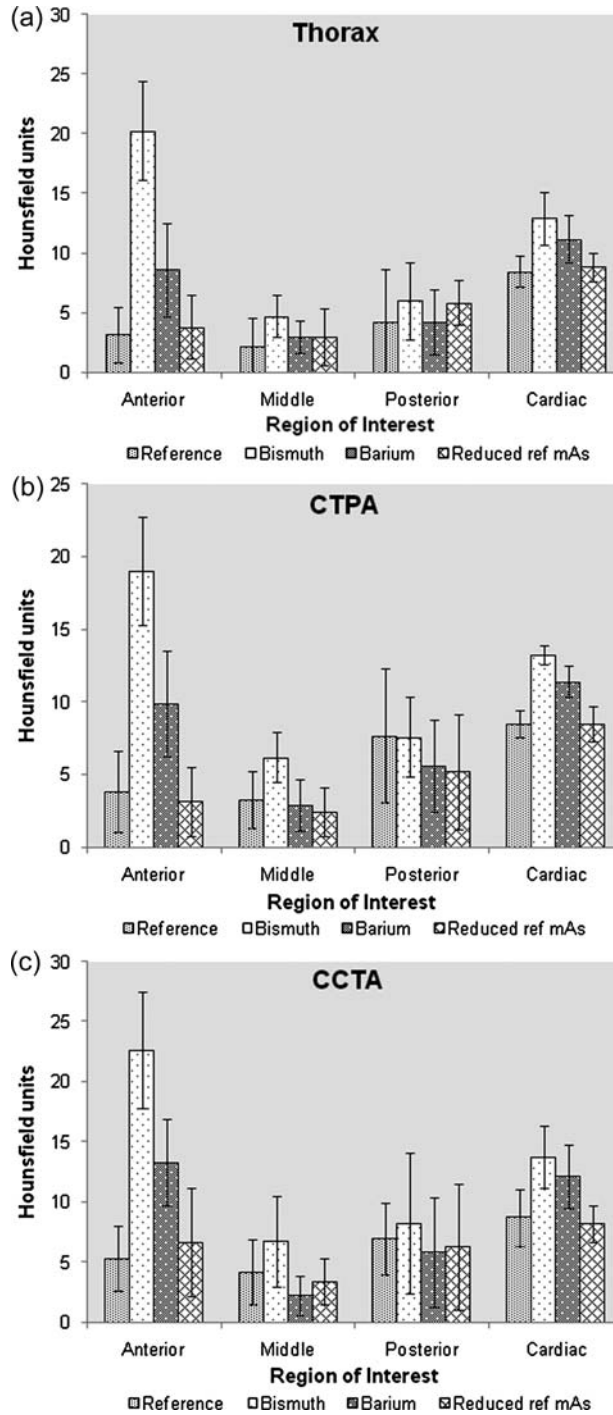


Figure 5. (a–c) Graphs of mean Hounsfield units recorded in each region of interest for the four protocols investigated during (a) routine thorax (b) CTPA and (c) CCTA examinations.

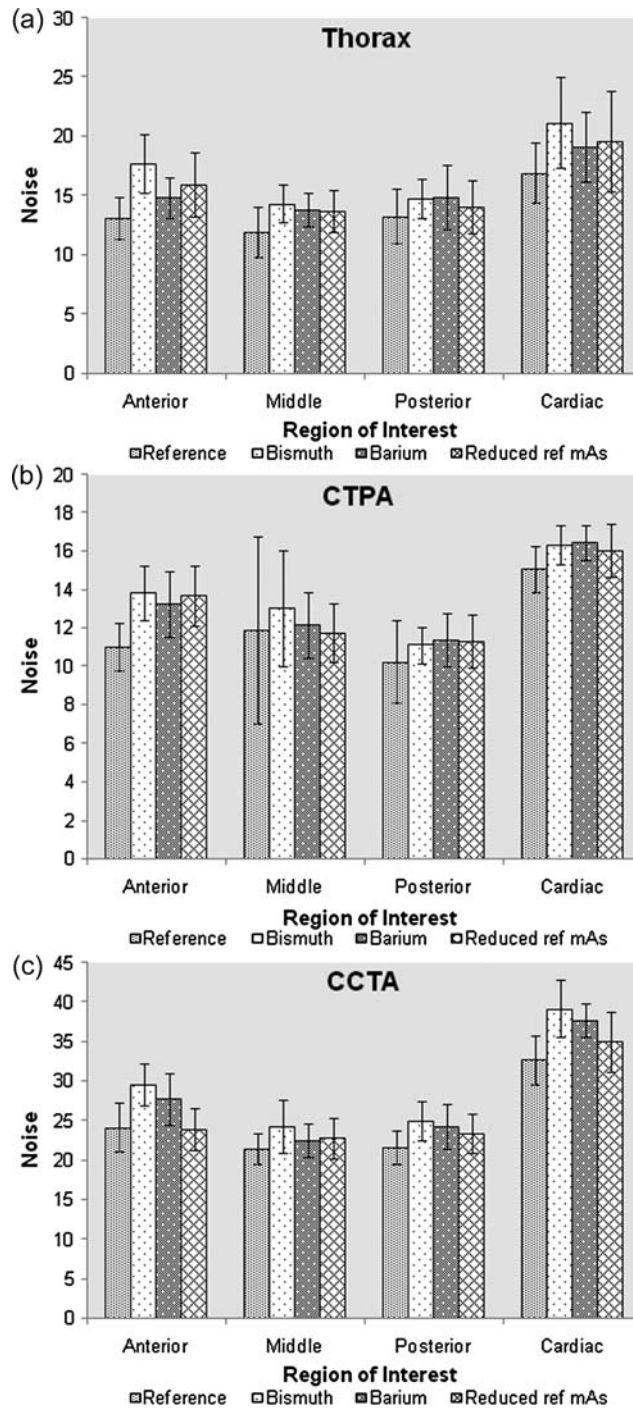


Figure 6. (a–c) Graphs of mean noise measurements (standard deviation of Hounsfield units) recorded in each region of interest for the four protocols investigated during (a) routine thorax (b) CTPA and (c) CCTA examinations.

attenuation values were increased in all ROI across all the three examinations when bismuth was used. This was statistically significant in the anterior regions (Figure 5a–c) for all the three examinations, as well as in the middle and cardiac ROI for both the thoracic and CTPA studies. The largest increase was in the anterior chest wall ROI, where the mean Hounsfield units for all the three examinations increased more than five-fold, from 4.1 to 20.6 ($p = 0.001$). The other increases were all considerably less (16–84 %) but are none the less worthy of note. CT numbers have previously been used to differentiate benign from malignant processes⁽³⁹⁾, and although studies have shown that absolute CT numbers may be unreliable, with large variations in accuracy⁽⁴⁰⁾ and considerable discrepancies between scanners and manufacturers⁽⁴¹⁾, radiologists need to be mindful of this, especially if conducting quantitative analysis in tandem with breast shield use. Barium shielding, on the other hand, resulted in much lower increases in attenuation values than bismuth with significant differences from the reference only in the anterior ROI, where the average Hounsfield unit increased from 4.1 to 10.6 ($p = 0.001$), a two-fold increase. The remaining changes in Hounsfield units were in the range from -1 to $+3$ and are thought to be of little clinical significance. Therefore, this work would support the recommendations of the Society of Cardiac CT⁽¹⁵⁾ against the use of bismuth during cardiovascular scanning and suggests barium as an alternative, especially during initial diagnostic scans or if considering using quantitative analysis during thoracic CT examinations. While alternative materials have been investigated as potential shields during thoracic CT⁽¹⁷⁾, the results here would suggest that higher attenuation materials are more likely to impinge on CT image quality.

The AAPM states that the use of bismuth shielding along with automated tube current modulation (ATCM) can have unpredictable and undesirable effects on both image quality and dose⁽²⁴⁾, as tube currents may potentially increase in response to the presence of superficial shielding within the scan range⁽³⁵⁾, especially if shielding is placed prior to the topogram. For this reason, shielding was positioned only following the topogram for each examination here. As the proprietary ATCM system used in this study also incorporates z-axis modulation, there was also the possibility that this would affect tube currents once the added density of the superficial shield was detected during the scan. However, no such increases in tube current or overall dose were noted for the examinations investigated.

It was not possible to include a comparison with organ-based tube current modulation in this work, as the software was not currently available on the CT scanner. This software works by reducing the tube current when the X-ray tube is in the anterior

position with the aim of reducing the radiation dose to superficial anterior organs such as the eyes, thyroid and breast. However, to maintain the same level of image quality throughout, the reduced anterior tube current is compensated for by increasing the tube current from a posterior direction, which has the effect of increasing doses posteriorly. Thus, its potential benefits should be carefully examined to ensure that there is a net dose reduction in terms of effective dose when the sum of all the organ contributions is considered.

Decreasing the overall tube current has been proposed as an alternative to shielding^(19, 42), the benefit being that the radiation dose to all the organs within the scan range is reduced and not just the dose to those below the superficial shield, while producing similar quantities of additional image noise. Here the overall tube current was reduced by an average of 19 % for each of the three thoracic examinations with a resultant decrease in dose length product of 20 % per scan also. Such a tube current reduction achieved measured organ dose reductions of 14–26 % (Tables 2–4), which were statistically significant for the majority of the measured sites (breast, skin and lung) for each of three examinations. Reducing the overall tube current resulted in surprisingly little quantitative effect on image quality with statistically significant increases in noise seen in the anterior ROI for the thorax ($+2.9$ HU ($+22$ %), $p = 0.004$) and CTPA ($+1.6$ HU ($+16$ %), $p = 0.022$) examinations, as well as at the shoulder ($+3$ HU (31 %), $p = 0.0001$) and liver regions ($+3.6$ HU, 15 %, $p = 0.003$) of the thoracic examination. Importantly, the attenuation values did not change and no streak artefacts were observed. This implies that reducing the overall tube current has the potential to reduce the total radiation dose while giving comparable image noise to shielding and can be a much better method of dose optimisation within the modality.

Already some authors have investigated acceptable levels of noise within thoracic CT images, such as Tack *et al.*⁽⁴³⁾, who found that tube current selection did not influence pulmonary embolus (PE) detection, although Mackenzie *et al.*⁽⁴⁴⁾ noted the opposite. Chapman *et al.*⁽⁴⁵⁾ investigated thoracic CT and found no relevant difference in acceptability of images when dose reductions of up to 60 % were performed when examining paediatric patients for pulmonary nodules. Further studies into optimisation of tube current values for various patient types as well as clinical indications are necessary to determine acceptable noise levels within all thoracic CT images for both adult and paediatric patients. This would allow further refinement of CT protocols and permit examinations to be individually customised. It must be remembered though that there may be differing image quality requirements even within one scan range, depending on the anatomy included. For

example a much higher level of noise may be tolerated in the high-contrast region of the central lung than in the region of the liver where noise may impact on the detection of low-contrast lesions. Therefore, care has to be taken to ensure that the entire image dataset is analysed for acceptability. Alternatively, use of superficial shielding can offer an innovative solution to this predicament, as shielding applies only to the mid thorax so that the dose can be maintained at optimal levels outside of the region of the breasts, i.e. at the shoulders and through the upper abdomen, where noise may not be as well tolerated and low-contrast detectability is more important. Therefore, the possibility exists for both tube current reduction and superficial shielding to be used complementary to each other to optimise doses during thoracic imaging.

Recommendations

Global reductions in the tube current would, therefore, appear preferable to superficial shielding because of the added benefit of reduced organ doses throughout the scan range at comparable noise levels. Reducing the overall tube current also has the significant advantage of not affecting the CT attenuation levels, which is important when absolute CT values are required such as when performing coronary calcium scoring or any other quantitative chest analysis. Although both bismuth and barium shielding have a proven dose-reducing effect especially on the breast, skin and anterior lung dose, perhaps both techniques are better suited to follow up scanning or for younger females, once tube current levels have already been optimised. Bismuth in particular should not be used when quantitative analysis is desired due to its effect on CT attenuation values and barium may be a more useful alternative. However, shielding may prove beneficial when further reducing the global tube current would negatively impact on the low-contrast detectability of anatomical regions not covered by the shields such as the shoulders and liver.

Limitations

This work had a number of limitations. Firstly as a phantom study, image quality assessment has been limited to quantitative measures and a clinical study with the addition of qualitative analysis would have strengthened the results. Also, this work was performed on just one CT scanner, from one vendor, and while the authors would anticipate similar results across scanners based upon a theoretical knowledge of their operation, it would also be important to verify these results, especially in relation to the operation of automated tube current modulation systems whose mode of operation differ quite significantly

between vendors. The lung doses reported here reflect only the lung regions directly below the shields located in the centre of the chest. It is expected that lung doses outside of this region will remain within the normal range but experimental work would be beneficial in validating this. Therefore, this study rather reports the maximum lung dose savings, especially during the routine thorax examination and the overall lung dose may be less.

In conclusion, superficial shields can play an important role in dose optimisation during CT scanning, particularly to anterior organs. Dose reductions achieved with bismuth shields are larger than with barium but at the expense of both an increase in image noise and the Hounsfield units within the scan range. Reducing the overall tube current has greater optimisation potential, as dose to all the organs within the scan range can be reduced while only contributing to an increase in image noise.

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