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RESEARCH **Open Access**

A dual-modality quantification of scattered radiation from head to female breasts during radiological investigations in a tertiary hospital in Nigeria

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Abstract

Background: To quantify the amount of scattered radiation reaching the breasts during x-ray and CT investigations of the head in order to find appropriate justification for an intended change in practice involving torso shielding.

Results: Scattered radiation from the head reached the breasts in both procedures. The range and mean dose were (CR 1.02–3.61/1.94 ± 0.63 mGy) and (CT 2.20–8.50/3.74 ± 2.28 mGy). Both breasts had enormous dose difference in CR (72.3%) and CT (51.4%) which were statistically significant ($p < 0.05$). Correlation of dose with anthropometric parameters gave weak results.

Conclusion: Despite dose mitigation strategies such as software and hardware modifications in radiological modalities, use of anti-scatter grid, appropriate collimation and dose optimization by radiographers, scattered radiation still traveled from the head to the breasts. These were, however, significantly reduced when shielding was applied. For a dose-safe practice, radiographers are urged, in addition to current strategies at mitigating scatters, to adopt torso shielding during examinations involving contiguous anatomies to the breast.

Keywords: Scattered radiation, Computed tomography, Computed radiography, Head, X-Ray

Background

Cancer is induced by different carcinogens including x-ray photons, an ionizing radiation produced by several radiological modalities [1]. Globally, breast cancer is the second leading cause of cancer mortality amongst women, while in Africa specifically, it is the first. The statistics on survival rates also place Africa at a disadvantage. It is reported to be 86% in developed countries, but ≤ 40% in sub-Saharan Africa due to late diagnoses [2, 3]. Despite the carcinogenic tendencies of x-ray photons, it is accepted that its benefits far outweigh the risks when dose is as low as reasonably achievable, ALARA [4]. However, while the ALARA principle is effective in reducing the likelihood and severity of deterministic effects of radiation, it appears unreliable in the face of stochastic effects which have no thresholds [1].

Scatters are weakly penetrating, multidirectional secondary radiation photons which contribute to stochastic radiation effect [1]. In addition, they degrade image quality by reducing contrast, thereby impeding diagnosis. They are also enhanced by the size or thickness of tissues, the extent of field of view (FOV) and the x-ray energy [2]. The breast is one of the radiosensitive organs, and its protection is recommended during radiography procedures. The tissue weighting factor for

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breast is higher for females than for males and higher for younger females than for older ones, further justifying the need for shielding from scatters, especially in the feminine gender [5]. Scatters are generally mitigated by hardware and software modifications [6], anti-scatter grids [2], appropriate beam collimation [7] and dose optimization [1].

Despite these strategies, medical imaging continues to witness scatters in daily practice [6], due to increasing demand for investigations involving ionizing radiation-producing modalities [8]. Head x-ray [1] and head CT investigations are anatomical regions with a high throughput in medical imaging. Due to high anatomical density, multiple surrounding structures and higher exposure settings to generate optimum image, the tendency to induce scattered radiation is high during examinations involving the head [6]. To mitigate the impact of these undesirable radiation from this contiguous anatomy to the breast, apparel shielding of the torso is now being recommended and practised [6, 9, 10].

These evidence-based recommendations are, however, not yet implemented in our facility, a regional referral hospital. Due to the strong influence wielded by this facility, implementing a policy change is likely to have a bandwagon effect on numerous feeder facilities who emulate her practice standards, and perhaps, in contiguous geopolitical zones, whose personnel often visited for update courses. This work is an attempt to add to the body of knowledge on the subject matter in the country generally and to specifically present empirical evidence to policy makers in our facility for a paradigm shift in practice.

Methods

Ethical considerations

This was a hospital-based, dual-modality, prospective and cross-sectional work undertaken between November and December 2019 at the radiology department of a foremost regional teaching hospital. It involved affixing portable, radioluscent thermoluminescent dosimeters (TLD) on the breasts of adult female patients during x-ray and CT examinations of the head to quantify the amount of scattered radiation reaching the breasts. Ethical approval for the CT component was obtained from the institutional Research Ethics Committee, while approval for the x-ray component was obtained from a neighbouring university ethical subcommittee. Hospital patients were enlisted for the work and they gave informed, signed consent. To guarantee confidentiality, only initials of their name was written in data collection sheet. The TLDs were also numbered and did not indicate name of subjects.

Equipment

The radiology department had two similar static x-ray machines which were engaged in the work. The machine was General Electrics (GE), silhouette VR, high frequency, 3-phase, static x-ray machines with maximum rating of 140 kVp (tube potential), 600 mA (tube current) and 2.7 mm Al (total filtration). It was manufactured in 2003 and installed in 2012. Within that time frame, it underwent several preventive and restorative maintenance, as well as re-calibrations. The machine had under-couch and erect potter-bucky detector trays incorporated with it [1]. It had full functionality as at the time of the work and had quarterly quality control checks from two dedicated hospital-based engineers. Other equipment and accessories were a computed radiography digitizer (model CR 12-x) (by Agfa healthcare Belgium) produced in December 2013. Detectors were a 25 cm × 30 cm (10″ × 12″) and 35 cm × 43 cm (14″ × 17″) standard photostimulable phosphor imaging plates (model CR MD4.0T General) also manufactured by Agfa Healthcare Germany.

The CT scanner used was also a GE product. It was GE Brightspeed, 4 slice scanner manufactured in 2007 and installed in the centre in 2012. Maximum technical imaging parameters were 140 kVp (tube potential), 350 (tube current), 4 s (gantry rotation time) and 85 cm (gantry aperture diameter). It had capabilities for axial and helical scan modes while cine mode was deactivated for the sake of minimizing dose. Calibration was done daily by radiographers using installed calibration software, while engineers carried out quarterly preventive maintenance and quality control.

Scattered radiation was quantified with thermoluminescent dosimeter chips (TLD-100 LiF: Mg, Ti) which had multidirectional energy response. They were acquired, calibrated, annealed and transported from one of the two regional dosimetric centres in the country. Due to cost, only two hundred of those chips were used. To shield them from background radiation, they were enclosed in small, black radiolucent polythene sachets. They were used with that additional enclosure during the procedure.

Subject selection

Subjects qualified for inclusion if they were ambulant, not on drip infusion or oxygen mask, not gravid as read from request cards and confirmed by them, no evidence of mastectomy, were aged ≥ 18 years, fell within a weight range of 60–90 kg in order to filter off outliers like asthenic and hypersthenic body shapes, had a visible neck that separated head from thoracic region, non-drooping breasts and signed a consent form. Although adult gynaecomastic cases were qualified for inclusion, none was encountered within the study period. Furthermore, patients were either for x-ray or CT and not both. So, investigations were carried out in separate diagnostic suites within the department and within the same period. For each modality, only fifty patients were enlisted.

Procedure

Anthropometric parameters were first obtained. Age was adopted from request cards that came from referring physicians. Gender that was not indicated on request cards was assumed from appearance since culturally, there were gender-specific appearances in the locality. Weight (kg) and height (m) were measured with balanced beam scale with an incorporated adjustable height rule. Both weight and height were read to the nearest 0.5 kg and 0.01 m (1 cm), respectively. Body mass index (kg/m^2) was calculated as weight divided by height. Information about x-ray machine and CT scanners was obtained from labels on the machines themselves, while imaging protocols were obtained from control consoles during procedures.

For CT scan of the head, some aspects of the method of Sidi et al. [6] were adopted. Each breast had a TLD chip affixed at its mid-craniocaudal point and held in place by transparent adhesive tapes. In addition, a 30×30 cm gonad shield with 0.35 mm lead equivalent was used to shield the left TLD cum breast all through the investigations. This was with a view to compare scatters to both breasts. Computed tomography procedure was carried out by radiographers at the centre according to standard protocols. Subjects were positioned for the CT examination supine, with canthomeatal line (CML) at 90° to headrest and with an imputed azimuth of 90° and 180° for lateral and postero-anterior (PA) scout images. Axial (x-axis) centring beam on CT gantry intersected both meatuses, diverged slightly and emerged at infra-orbital margin. The TLDs needed stationary tubes for maximum quantum detection efficiency. Therefore, only scout images in PA and lateral projections with stationary tubes were involved. Popular CT protocol is one in which scout images are generated with the least exposure parameters. In keeping with that ideal, subjects were scanned with 80 kVp, 10 mA, but with tissue range of 140–250 mm depending on clinical indication.

For computed radiography of the head, subjects were examined either erect or supine according to standard radiographic procedure. This involved using a potter-bucky detector tray or a detector with a stationary grid manually attached. Subjects were positioned for postero-anterior (PA) and lateral views, with canthomeatal line (CML) being perpendicular (PA projection) or parallel (lateral projection) to the horizontal line of the detector tray, respectively. Upper limbs were extended from field of view (FOV) of radiation and employed for stability as well. Exposure parameters were 90–100 cm focus-detector-distance (FDD), variable tube current (mA/mAs) and tube potential (kVp) depending on body habitus. The TLD chips were affixed similar to the method used in CT. After scout projections in CT, and PA and lateral projections in CR, the TLD chips were carefully retrieved, packed and then sent for reading at the centre where they were initially acquired.

Data analysis

Data were analysed with statistical packages for social sciences, version 20.0 (SPSS Incorporated, Chicago, Illinois, USA). Descriptive statistical tools of frequency, mean and mode were employed to give a summary of machine and subjects' parameters and dose outputs. Inferential statistical tools were also employed for analysis. A paired-sample t test was used to test for statistically significant difference in mean absorbed dose by both breasts while Pearson correlation analysis was used to test the strength of relationship between dose and biometric parameters. In the T test, difference found justified the necessity for torso shielding during radiographic examinations of contiguous anatomical regions. Level of significance was set at $p \leq 0.05$.

Results

A comparative barchart of exposure parameters between CR and CT is shown in Fig. 1. Computed radiography had higher values all through except in tube potential (kVp). Machine technical parameters are displayed in Table 1. General Electrics (GE) modalities which were manufactured and installed between 2003 and 2012 were used. Range of exposure parameters available for imaging are also displayed. As shown in Table 2, subjects were aged 19–54 (CR) and 23–55 (CT) and were fairly obese (CR: 34.02 ± 10.04 kg/m^2; CT

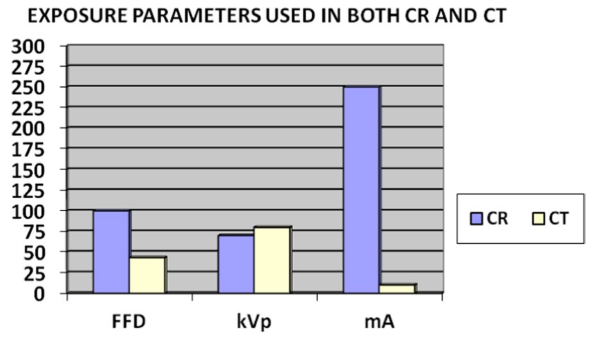

Fig. 1 Exposure parameters for CR and CT

Table 1 X-ray machine and CT scanner properties

Parameters	CR	CT
Model	GE silhouette VR	GE Brightspeed, 4 slice
Size	Static/floor mounted	Bulky/fixed
Manufactured	2003	2007
Installation	2012	2012
Tube current (mA), range	10–600	10–350
Tube potential (kVp), range	40–150	80, 100, 120, 140
Exposure time in CR (s) and gantry rotation time in CT (s), range	0.001–6.3	0.75–4
Minimum beam filter thickness	2.7 mmAl	Not known
Collimation	Available/perimeter	Available/slice thickness
Gantry aperture diameter (cm)	Not applicable	85
Detectors	Detachable/PSP plates	Inherent
Image viewing	On-screen and film	On-screen and film
Quality control	Restorative maintenance	Preventive maintenance

Table 2 Descriptive statistics of anthropotechnical parameters

S/No.	X-Ray (CR)				X-Ray (CT)			
	Variable ($n = 50$)	Range	Mode	Mean ± SD	Variable ($n = 50$)	Range	Mode	Mean ± SD
1.	Age (years)	19–54	32	34.30 ± 8.02	Age (years)	23–55	35	37.18 ± 7.10
2.	Weight (kg)	60–90	72	84.13 ± 22.02	Weight (kg)	60–90	70	82.32 ± 14.00
3.	Height (m)	1.54–1.82	1.68	1.65 ± 0.30	Height (m)	1.56–1.78	1.65	1.64 ± 0.45
4.	BMI (kg/m^2)	19.6–55.2	28.30	34.02 ± 10.04	BMI (kg/m^2)	18.8–52.2	26.40	30.60 ± 8.20
5.	kVp PA	75–80	70		kVp PA	80	80	
6.	kVp Lat	70–75	70		kVp Lat	80	80	
7.	mA PA	250–300	250		mA PA	10	10	
8.	mA Lat	250–300	250		mA Lat	10	10	
9.	mAs PA	15–35	18		mAs PA	NS	NS	
10.	mAs Lat	35–80	15		mAs Lat	NS	NS	

NS not shown (on monitor)

30.60 ± 8.20 kg/m^2). A summary of scattered radiation to the breasts is given in Table 3. The range and mean dose were CR: 1.02–3.61/1.94 ± 0.63 mGy and CT: 2.20–8.50/3.74 ± 2.28 mGy. Both breasts had huge dose difference in CR (72.3%) and CT (51.4%). There was enormous reduction in dose between unshielded and shielded breasts in CT (113%) and CR (32.2%), and these were statistically significant ($p < 0.05$). Correlation of dose with anthropometric parameters gave weak results.

Discussion

Contiguous radiosensitive organs receive low-dose irradiation often referred to as scattered radiation during radiographic examinations. This irradiation tends to increase the risk to cancer in exposed persons and gene mutation in descendants of exposed persons [1, 6]. To reduce or prevent scatter to the breasts, apparel shielding has been recommended [1, 6, 11]. This work was an attempt to provide further evidence to consolidate the recommendations in order to have a paradigm shift in current practice at our facility where apparel shielding for patients is not yet being implemented. The questions the work attempted to answer were whether scattered radiation from the head still reached the breasts despite anti-scatter strategies by radiographers. In addition, the work sought to know the quantity of scattered radiation that may reach the breast. It was equally desirable to investigate the influence of a one-sided breast shielding on the scattered radiation dose. All these were investigated in both computed radiography (CR) and computed tomography (CT) which were the most common x-ray-producing modalities in medical imaging at the facility.

Findings revealed that scattered radiation indeed reached the breast from both CR and CT. Left (shielded) and right (unshielded) breasts received a

Table 3 Dose characteristics in the population

X-Ray (CR); Absorbed dose (*n* = 50)				**X-Ray (CT); Absorbed dose (*n* = 50)**			
Absorbed dose (*n* = 50) Parameter	**Range**	**Mean ± SD**	**Mode**	**Absorbed dose (*n* = 50) Parameter**	**Range**	**Mean ± SD**	**Mode**
Right breast/unshielded (mGy)	1.15–3.61	2.42 ± 0.58	1.75	Right breast/unshielded (mGy)	3.65–8.50	5.38 ± 2.11	4.48
Left breast/shielded (mGy)	1.02–2.40	1.35 ± 0.33	1.23	Left breast/shielded (mGy)	2.20–4.13	2.02 ± 0.30	1.82
Dose difference	2.61 (72.3%)			Dose difference	4.37 (51.4%)		
Both breasts	1.02–3.61	1.94 ± 0.63	1.75	Both breasts	2.20–8.50	3.74 ± 2.28	4.48
Variables	***T*-statistics**	***p* value**	**Inference**	**Variables**	***T*-statistics**	***p* value**	**Inference**
Paired-sample *T* test							
Right and left breast dose	10.593	0.001	Significant relationship exists	Right and left breast dose	12.522	0.001	Significant relationship exists
Variables	***r***	***p* value**	**Inference**	**Variables**	***r***	***p* value**	**Inference**
Pearson correlation of dose (*n* = 50) and biometric parameters to test for nature of relationship							
Left versus right breasts	0.313	0.015	*r* = mild *p* = significant	Left versus right breasts	0.202	0.025	*r* = mild *p* = significant
Dose versus age	0.072	0.586	Weak	Age	0.110	0.344	Weak
Dose versus weight	− 0.012	0.927	Weak	Weight	0.052	0.840	Weak
Dose versus height	− 0.034	0.796	Weak	Height	− 0.020	0.690	Weak
Dose versus BMI	− 0.021	0.872	Weak	BMI	− 0.102	0.912	Weak

mean dose of 1.35 ± 0.33/2.42 ± 0.58 mGy (CR) and 2.02 ± 0.30/5.38 ± 2.11 mGy (CT). Subsequent analysis using a paired-sample *T* test revealed a statistically significant difference ($p = 0.001$) between the mean of shielded and unshielded breasts. That is an indication that shielding was practically useful. A further attempt at correlation returned weak relationship between dose and anthropometric parameters. The implication is that there are no evidence to suggest that body habitus influenced the emission of scattered radiation. That further necessitates the fact that shielding is important in addressing scatter irrespective of the size of the patient.

A closely similar and recent work from our country by Sidi et al. [6] corroborates our findings. They observed that scattered radiation from lumbosacral x-ray as well as head CT got to the breasts. In lumbosacral x-ray, they got a mean dose of 1.74 ± 0.40/2.30 ± 0.50 mGy for left (shielded) and right (unshielded) breast, respectively. The value was 3.00 ± 0.60/6.40 ± 3.45 mGy for CT. Also with *T* test, they found a significant difference between the mean of both breasts. In another work with lumbosacral x-ray carried out in Slovenia, Mekis et al. [5] observed as much as 80% reduction in breast dose when a 0.5 mm lead equivalent shielding material was used. A reduction of about 99% was reported in a work in United Arab Emirates [11]. Statistically significant dose reductions of 42% was also reported in a work published in America [12]. In CT of the head, post-shielding dose reduction of about 62% was equally noted [10]. These strong and consistent evidences place a moral obligation on radiographers, especially in Africa, to adapt their practices to current imperatives.

Although some writers had a strong bias for dose optimization in preference to shielding and other dose reduction strategies [13, 14], we are of the opinion that it is of greater advantage if every known strategy is combined with shielding. Cancer, especially that of the breast, remains a scourge to sub-Saharan African women, and every effort that has some modicum of effectiveness in containing a carcinogen is important.

The major limitation of the work was the enormous distance between the dosimetric laboratory and our facility. That compelled the authors to send the TLDs for reading through courier. It was therefore difficult to determine if the courier company accorded our dosimeters the same extreme caution as we did. It would have been relieving to have a closer dosimetric laboratory where TLDs could be submitted ourselves without fear of extraneous or confounding variables. Notwithstanding, since our findings are in tandem with a large number of similar works, we are of the opinion that whatever error crept into our result is too small to negatively influence the results significantly.

Conclusion

In conclusion, machine and radiographer-specific strategies were unable to stop scatters from getting to the breast from head x-ray and CT procedures. Also, breast shielding was found to significantly reduce dose from scatters. Adoption of shielding practice forthwith is strongly recommended.

Abbreviations

ALARA: As low as reasonably achievable; CML: Canthomeatal line; CT: Computed tomography; CR: Computed radiography; kVp: Kilovolt peak; mA: Milliampere; MRI: Magnetic resonance imaging; PA: Postero-anterior; TLD: Thermoluminescent dosimeter.

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Authors' contributions

All authors read and approved the final manuscript.

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Availability of data and materials

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approvals were obtained from Research Ethics Committee of Nnamdi Azikiwe University Teaching Hospital, Nnewi, Nigeria (NAUTH/CS/66/VOL8/84/ and Radiography Department Ethics subcommittee of Gregory University, Uturu, Nigeria (GUU/RAD/EC/VOL3/002.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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