Technical Note

Quality Assurance and Average Glandular dose Measurement in Mammography Units

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Abstract

To ensure the safe operation of mammography units, acceptance tests and quality assurance (QA) protocols have been developed by the American Association of Physicists in Medicine (AAPM), Engineers Registration Board, and International Atomic Energy Agency. Eight mammography units manufactured by five different manufacturers located in hospitals in our region were investigated following the AAPM and Atomic Energy Regulatory Board (AERB) protocols using a solid-state dosimeter-based PTW-NOMEX Multimeter and a metal-oxide-semiconductor field-effect transistor. This study evaluated different operating parameters through mechanical test, accelerating voltage (kVp) accuracy test, machine output measurement, half-value layer measurement, calibration of compression device, image quality assessment, measurement of leakage radiation, radiation survey, and average glandular dose (AGD) measurements using stereotactic needle biopsy phantom. The results show that out of eight mammography units, only a single mammography unit (U-1) passed all QA tests and 2 units passed 7 tests, 2 units passed 6 tests, and 3 units passed 5 tests out of 8 QA tests. In unit 5, the AGD value was 4 and 1.93 mGy before and after service, respectively. QA programs as recommended by AAPM and AERB should be carried out periodically to ensure safety in breast cancer screening. This work points to the importance of the regulation and effective compliance and also help in both improving the QA and reduce the glandular dose received by the patients.

Keywords: Average glandular dose measurement, image quality, mammography, quality assurance

Received on: 11-07-2016 **Review completed on: 04-08-2017** **Accepted on: 04-08-2017**

Introduction

Breast cancer is the most common disease among middle-aged women worldwide.[1] In India, breast cancer is the second most common malignancy after cervical cancer. GLOBOCAN project report (2011–2014) shows that there are 145 incidence rates per 100,000 female population and 70 mortality rates per 100,000 female population in India.[2] The incidence is increasing in most countries at the rate of 1%–2% annually and soon nearly one million women will be suffering from this disease every year throughout the world. Imaging of the breast aims at early diagnosis of breast lesions, differentiation of benign from malignant lesions, and the detection of tiny cancers before they are symptomatic or palpable.[3]

X-ray mammography is an important examination widely used for female breast screening and also used in male breast for the examination of symptomatic patients.[4-6] The dose delivered to the breast depends on the X-ray spectrum for target/filter (T/F) combination, breast thickness, X-ray tube current with exposure time in milliampere-second (mAs), and the peak kilo voltage (kVp) values.[7] Even though the mammography unit operates in the low tube voltage range typically about 25–35 kVp when compared to other radiography units, a little variation in its operating parameters can lead to the delivery of higher doses which can be detrimental since the breast is a radiosensitive organ. It is, therefore, necessary to ensure the performance of the machine operating parameters are to specifications and maintained.

This work examined eight mammography units from five manufacturers following the American Association of Physicists in Medicine (AAPM) and Atomic Energy Regulatory Board (AERB) protocols which include test for accelerating

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Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.JMP_69_16

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How to cite this article: Selvan CS, Sureka CS. Quality assurance and average glandular dose measurement in mammography units. J Med Phys 2017;42:181-90.

voltage (kVp), mAs accuracy and its corresponding dose, half-value layer (HVL) measurement, machine output using NOMEX multimeter, compression paddle calibration, image quality check using both mammography accreditation phantom and single exposure high-resolution phantom, leakage radiation measurements, and radiation survey using pressurized ion chamber-based survey meter.[4,8-10] In addition, entrance skin air kerma was measured using Metal Oxide Field Effect Transistor (MOSFET) dosimeter and stereotactic needle biopsy phantom in one of the mammography units to analyze the average glandular dose (AGD).

Materials and Methods

Machine details

The quality assurance (QA) tests were carried out on eight mammography units, of which 7 units have molybdenum (Mo) filter and the unit 1 (Siemens - Mammomat Inspiration) has beryllium (Be) filter. The technical details of the units manufactured by different manufacturers are summarized in Table 1. These machines were installed during the past 15 years in various hospitals located in residential as well as commercial areas.

Acceptance test/quality assurance

The following tests were carried out in all the mammography machines as a part of QA.

1. Mechanical test
2. Accelerating voltage (kVp) accuracy test
3. Machine output measurement
4. HVL measurement
5. Calibration of compression device
6. Image quality assessment
7. Measurement of leakage radiation
8. Radiation survey.

The tests 1–6 were performed using a solid-state dosimeter-based PTW-NOMEX Multimeter (PTW-FREIBURG, Physikalisch-Technische-Werkstätten, DE-79115, FREIBURG, serial no. T11049). The software, NOMEX multimeter version S030008 was connected through a USB cable to an external computer (laptop) that controls the mode of the radio diagnosis equipment and then data were recorded.[11] In all the measurements, the computed radiography (CR) cassette was placed in the bucky without CR imaging plate and film in order to extend the life time of the CR imaging plate and to avoid the wastage of film respectively.

Mechanical tests

The following mechanical tests such as mechanical characteristics, indicators, and tube housing were carried out in all mammography units as shown in Table 2.

Accelerating voltage (kVp) accuracy test

This study was performed to verify whether the measured kVp matches with the set kVp. In general, X-ray tubes which are designed for film-screen mammography have Mo target, a thin beryllium window, and a Mo filter of about 0.03–0.4 mm thicknesses as given in Table 1. These tubes operate in the voltage range of 22–49 kVp and commonly have a rotating anode to achieve tube current in the range of 100–200 mA.[12] The kVp accuracy was evaluated manually for different settings by gradually increasing its value from 25 to 35 kVp at constant mAs and T/F combination at the focus to detector distance (FDD) of 65 cm by placing the NOMEX multimeter on the breast support.[13] Further, the percentage of error was calculated using the equation 1. The results are shown in Table 3.

$$PE = \frac{\text{Measured kVp} - \text{Set kVp}}{\text{Set kVp}} \quad (1)$$

where,

PE - Percentage of error

Measured kVp - X-ray tube operating voltage measured in the dosimeter

Set kVp - Reading noted from X-ray tube control panel.

Machine output measurement

The machine output was measured to understand the performance of the X-ray generator, tube, and filtration which allows one to determine whether the unit can produce images with acceptable short exposure time. The output was

Table 1: Technical details of the mammography units

Unit	Manufacturer	Model	AERB type approval certificate number	Maximum operating parameters				Total filtration	Year of manufacture	Year of installation	Type of detector
				kVp	mA	S	mAs				
1	Siemens Pvt. Ltd.	Mammomat Inspiration	AERB/02/1426	35	-	6	630	0.5 mm Be	2013	2013	CR
2	Siemens Pvt. Ltd.	Mammomat 3000 Nova	AERB/02/779	35	150	4	600	0.03 mm Mo	2004	2008	CR
3	GE Healthcare Pvt. Ltd.	Alpha ST	AERB/28/908	35	100	3	300	0.33mm Mo	2003	2005	CR
4	Planmed Oy	Sophie Classic	AERB/46/1146	35	110	9.9	500	0.3 mm Mo	2001	2002	FR
5	GE Healthcare Pvt. Ltd.	Senographe DMR+	AERB/04A/776	49	100	20	-	0.4 mm Mo	2000	2002	FR
6	Hologic Inc.	M-IV Series	AERB/46/1329	39	100	-	400	0.4 mm Mo	1998	2000	CR
7	Metaltronica	FLAT III	-	35	90	9	-	0.3 mm Mo	2006	2007	FR
8	Metaltronica	Lilyum	AERB/48/03	35	100	-	640	0.35 mm Mo	2008	2010	CR

AERB: Atomic Energy Regulatory Board, Be: Beryllium, Mo: Molybdenum, CR: Computed radiography, FR: Film-screen radiograph

also measured by the compression device placed at a height of 4.5 cm from the patient's breast being imaged. Then, the multimeter was placed into the lower surface of the compression device. With the compression device in place, the radiation output was measured at various kVp ranging from 25 to 35 kVp by keeping 5 and 10 mAs. The average of mR/mAs (mGy/mAs) was calculated (X) and its consistency at each kVp station was checked by evaluating the coefficient of variation (COV) using the equation 2. The results are shown in Table 4.

$$\text{Coefficient of variation} = \frac{\left[\sum (Xi - X)^2 / n - 1\right]^{1/2}}{X} \quad (2)$$

where,

X - Mean value

Xi - Individual X values

n - Total number of samples.

Half-value layer measurement

Multimeter was placed on the center of the bucky at 65 cm FDD, and operating parameters were selected ranging from 25 to 35 kVp at constant 5 and 10 mAs setting in Mo/Mo (T/F) combination.[14] In each exposure, the HVL value was noted and compared with its corresponding HVL range, which is calculated using the formula provided by the American College of Radiology (ACR) as given in equation 3.[15,16] The results are shown in Table 5.

$$\left[\left(\frac{\text{kVp}}{100}\right) + 0.03\right] \leq \text{HVL} < \left[\left(\frac{\text{kVp}}{100}\right) + C\right] \quad (3)$$

where C = 0.12 mm Al for Mo/Mo.

Table 2: Details of mechanical tests

	Provision available in number of units
Mechanical characteristics	
Locking facility adequacy for immobilizing the X-ray tube	All 8
Accuracy of tube orientation indication	All 8
Movement of field limiting diaphragm	All 8
Alignment of compression device	All 8
Locking facility of the compression device	5
Indicators in control panel	
Power "ON" display	8
Tube current display	8
Tube potential display	8
Exposure time selection (mAs/s)	8
Tube housing	
Material and thickness of inherent filtration indicated	5
Material and thickness of added filtration indicated	6
Total filtration indicated	3
Focal spot location indicated	8

Calibration of compression device

The compression paddle is used to vary the breast thickness and in turn to reduce the breast dose.[17] Hence, it is necessary to check the compression pattern of the device to avoid discomfort to the patient. To do so, a flat conventional weighing scale was placed on the bucky and the X-ray tube was fixed at a craniocaudal view (beam enters at the head side end of the part being examined and exits at the legend). Then, the compression paddle was pushed at a maximum level toward the bucky (loaded with cassette). At that time, the magnitude of weight in kilogram (kg) was noted in each mammography unit which was then converted into newtons (N) using the relationship 1 kg = 9.8066 newtons.

Image quality assessment

The phantoms standardized by ACR for mammography image assessment are mammography accreditation phantom (CIRS Model 015 - Computerized Imaging Reference Systems, Inc., Norfolk, VA, USA) and single exposure high contrast resolution phantom (CIRS Model 016A, USA). These phantoms were used to assess the quality of mammography image.[18] The mammography accreditation phantom resembles a 4.5 cm compressed breast of average glandular/adipose composition. It is made up of 7 mm wax insert on the surface, a 3.4 cm thick acrylic base, and a 3 mm thick cover. The wax insert consists of many objects such as nylon fibers, speck groups, and masses of different size and thickness which is used to assess image quality to detect fiber-like structures, microcalcifications, and tumors, respectively. The schematic representation of the wax insert in the mammography accreditation phantom is shown in Figure 1 and the sizes of objects in the wax insert are given in Table 6. To take measurements, the phantom was centered laterally on the image receptor so that the chest wall edge of the phantom can be aligned with the chest wall edge of the image receptor as shown in Figure 2 and all the steps prescribed in the manual were followed as given below.

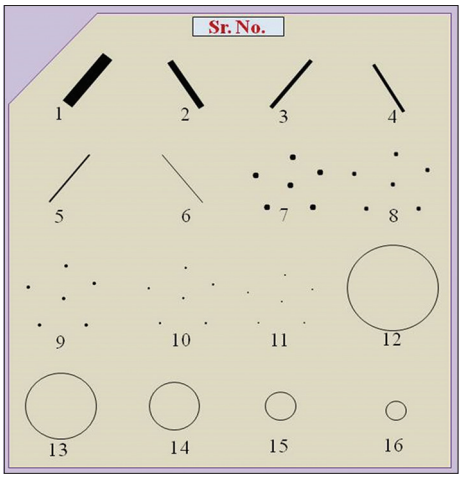

Figure 1: Schematic representation of the wax insert in the accreditation phantom image (6 fibers, 5 speck groups, and 5 masses)

Table 3: Percentage of variation in kVp accuracy

Mammography units	Operated tube voltage (kVp)																				
	Selected tube current 5 mAs											Selected tube current 10 mAs									
	25	26	27	28	29	30	31	32	33	34	35	25	26	27	28	29	30	31	32	33	34	35
U-1																						
Maximum	8.8	9.2	9.2	8.9	8.2	7.6	8	8.4	7.5	8.5	7.7	11.2	10.38	13.3	16	12.4	9.3	8.7	8.4	8.1	8.8	8.2
Mean	7.2	8.4	7.7	7.5	7.5	7.6	7.4	7.5	7.2	7.9	7.7	5.6	8.8	12.2	15.3	11	7.3	8	7.5	8.1	8.5	8.5
U-1 (after service)																						
Maximum	3.11	2.28	1.92	0.83	1.11	1.62	0.69	1.28	0.37	1.2	0.92	2.8	2.71	1.15	1.84	0.71	0.34	0.69	0.35	1.23	0.62	0.61
Mean	2.02	1.19	0.79	0.41	0.4	0.37	0.7	0.69	0.36	0.62	0.35	1.22	1.93	0.42	0.75	0.39	0.4	0	0.37	1	0.33	0.34
U-2																						
Maximum	0	0.76	0.37	0	0.34	0.66	0.64	0.93	0.91	0.29	0.57	2	2.69	2.96	3.57	3.79	4.33	4.51	5	5.45	6.17	7.14
Mean	0.8	1.15	1.48	1.78	2.06	2.66	2.9	3.12	2.42	1.47	2	2.4	2.69	2.96	3.21	3.44	4.33	4.19	4.37	5.15	5	5.42
U-3																						
Maximum	2.8	1.92	2.22	1.78	1.72	1.66	1.61	1.56	0.91	1.17	1.14	2	1.92	1.48	1.78	1.72	1.33	1.61	1.25	1.51	0.88	1.14
Mean	1.6	1.53	1.48	1.42	1.03	1	0.96	1.25	0.6	0.58	0.57	1.2	1.15	1.11	1.07	1.03	1	0.96	1.25	0.9	0.58	0.57
U-4																						
Maximum	3.6	2.69	2.96	1.42	2.06	2	2.25	2.5	4.54	2.94	2.28	4.4	3.84	3.33	2.5	2.75	2.66	2.58	2.81	3.63	3.23	3.42
Mean	3.6	2.69	0.37	2.85	2.06	3	2.25	2.5	4.54	3.23	2.28	4.4	4.23	4.07	3.21	2.75	3	2.58	2.81	3.33	3.23	3.14
U-5																						
Maximum	9.2	9.61	7.77	10.7	8.27	8.66	6.77	7.81	7.87	5.88	6	10.4	9.61	7.77	6.42	7.24	8.33	6.77	7.81	7.87	7.94	9.14
Mean	7.6	6.92	7.77	7.85	7.93	7.33	8.06	6.56	6.06	5.58	5.14	9.6	9.61	8.51	7.5	6.89	7	7.41	6.87	6.36	7.05	7.14
U-6																						
Maximum	7.6	6.92	6.66	6.42	5.86	5.66	4.83	4.37	4.54	3.82	3.14	8.4	7.69	7.03	6.78	5.51	5.66	5.16	5	4.54	4.41	3.71
Mean	7.2	6.15	5.92	5	4.82	5	4.83	4.37	3.63	3.52	3.42	8	6.92	5.92	5.35	5.17	5	4.51	4.06	3.93	3.52	2.85
U-7																						
Maximum	8.8	6.92	7.03	6.42	5.17	6	3.87	3.12	2.72	2.35	2.28	3.2	3.46	3.7	5.71	3.1	6	6.12	5.93	5.75	5.29	5.42
Mean	8	6.92	6.66	5.35	5.17	5.33	3.87	3.12	2.72	2.94	2.57	3.2	3.46	3.7	3.57	3.1	4.66	5.16	4.37	4.54	4.11	4.28
U-8																						
Maximum	9.6	8.84	7.77	7.14	8.27	7	7.09	6.56	7.27	6.17	5.42	11.2	9.61	8.88	8.92	7.58	9	9.03	9.68	7.57	6.17	5.14
Mean	6.4	5.76	5.18	5.35	5.17	4.66	4.51	4.06	4.54	4.11	4.28	10.4	9.23	9.25	8.21	8.27	8	8.06	8.43	7.27	7.35	6.57

Table 4: Calculated coefficient of variation of output

Unit	mAs settings	Operating tube voltage (kVp)										
		25	26	27	28	29	30	31	32	33	34	35
U-1	5	0.006	0.007	0.001	0.004	0.002	0.002	0.002	0.001	0.003	0.002	0.003
	10	0.010	0.007	0.006	0.050	0.050	0.042	0.039	0.045	0.013	0.008	0.005
U-2	5	0.058	0.042	0.067	0.055	0.017	0.043	0.043	0.048	0.030	0.036	0.022
	10	0.045	0.059	0.038	0.039	0.026	0.037	0.018	0.027	0.025	0.026	0.038
U-3	5	0.057	0.038	0.039	0.053	0.023	0.038	0.033	0.028	0.024	0.017	0.023
	10	0.064	0.045	0.047	0.022	0.051	0.030	0.035	0.030	0.029	0.029	0.025
U-4	5	0.041	0.053	0.034	0.048	0.051	0.022	0.021	0.019	0.026	0.031	0.031
	10	0.016	0.060	0.020	0.043	0.045	0.039	0.031	0.044	0.031	0.010	0.020
U-5	5	0.068	0.078	0.052	0.077	0.044	0.049	0.072	0.039	0.037	0.048	0.044
	10	0.079	0.059	0.024	0.048	0.059	0.054	0.040	0.038	0.037	0.041	0.037
U-6	5	0.054	0.041	0.055	0.044	0.032	0.045	0.042	0.033	0.026	0.025	0.025
	10	0.035	0.044	0.021	0.016	0.052	0.036	0.031	0.034	0.025	0.036	0.027
U-7	5	0.030	0.020	0.032	0.028	0.022	0.019	0.021	0.036	0.050	0.008	0.020
	10	0.057	0.030	0.030	0.025	0.035	0.035	0.030	0.035	0.027	0.019	0.023
U-8	5	0.054	0.037	0.037	0.040	0.034	0.040	0.032	0.026	0.031	0.027	0.023
	10	0.065	0.057	0.043	0.037	0.032	0.043	0.044	0.033	0.021	0.019	0.047

- The acrylic disk was placed on the phantom by assuring that the disk does not cover any test object locations
- Preliminary images of the phantom without the dosimeter were taken to ensure correct positioning of the phantom
- The film was placed inside the cassette
- The operating parameters such as AEC mode, 28 kVp,

Table 5: Comparison of measured and American College of Radiology recommended half-value layer values

Operating voltage (kVp)	Operating current (mAs)	ACR recommended HVL value (mmAl)	Measured HVL values (mmAl)							
			U-1	U-2	U-3	U-4	U-5	U-6	U-7	U-8
25	5	0.28-0.37	0.304	0.296	0.291	0.295	0.308	0.339	0.297	0.307
	10		0.308	0.294	0.290	0.291	0.304	0.336	0.295	0.305
26	5	0.29-0.38	0.315	0.308	0.304	0.311	0.315	0.351	0.309	0.320
	10		0.316	0.307	0.303	0.308	0.312	0.348	0.308	0.318
27	5	0.30-0.39	0.322	0.318	0.315	0.318	0.329	0.363	0.320	0.329
	10		0.327	0.319	0.316	0.315	0.324	0.361	0.320	0.327
28	5	0.31-0.40	0.338	0.328	0.328	0.329	0.331	0.375	0.330	0.337
	10		0.336	0.332	0.327	0.328	0.338	0.372	0.331	0.340
29	5	0.32-0.41	0.348	0.338	0.337	0.338	0.344	0.382	0.340	0.348
	10		0.341	0.341	0.337	0.339	0.344	0.381	0.340	0.346
30	5	0.33-0.42	0.357	0.347	0.346	0.342	0.357	0.391	0.348	0.355
	10		0.356	0.351	0.346	0.348	0.351	0.388	0.347	0.358
31	5	0.34-0.43	0.364	0.355	0.354	0.351	0.362	0.397	0.355	0.363
	10		0.364	0.359	0.354	0.356	0.359	0.394	0.355	0.367
32	5	0.35-0.44	0.373	0.364	0.363	0.363	0.371	0.401	0.362	0.372
	10		0.373	0.368	0.362	0.366	0.368	0.400	0.363	0.375
33	5	0.36-0.45	0.385	0.372	0.370	0.371	0.384	0.405	0.369	0.380
	10		0.385	0.381	0.370	0.373	0.376	0.408	0.369	0.385
34	5	0.37-0.46	0.397	0.385	0.374	0.380	0.391	0.414	0.375	0.391
	10		0.395	0.392	0.374	0.380	0.381	0.415	0.374	0.394
35	5	0.38-0.47	0.408	0.391	0.382	0.385	0.397	0.419	0.381	0.398
	10		0.407	0.403	0.382	0.386	0.392	0.420	0.381	0.402

ACR: American College of Radiology, HVL: Half-value layer

Table 6: Different size of objects in the wax insert

Nylon fibers (1-6)	Al_2O_3 specks (7-11)	Masses (thickness) (12-16)
1.56 mm	0.45 mm	2.00 mm
1.12 mm	0.40 mm	1.00 mm
0.89 mm	0.32 mm	0.75 mm
0.75 mm	0.16 mm	0.50 mm
0.54 mm	0.16 mm	0.25 mm
0.40 mm	-	-

30 mAs, and Mo/Mo combination suitable for a 4.2 cm compressed breast of average density was chosen for exposure

- The film was developed and analyzed to assess image quality.

The single exposure high contrast resolution phantom which incorporates two 17.5 μ thick gold-nickel alloy bar patterns as shown in Figure 2 was used to analyze the resolution of the image. These bar patterns are positioned at 90° to allow the assessment of resolution perpendicular and parallel to anode–cathode axis in just one exposure. The targets have 17 segments from 5 line pairs/millimeter (lp/mm) to 20 lp/mm and are equivalent to 25 μ of lead or 2.6 mm of aluminum at 20 keV. The patterns are permanently embedded in a thin acrylic sheet. It enables consistent, reproducible positioning at 4.5 cm above the breast support plate and 1 cm from the chest wall, centered laterally

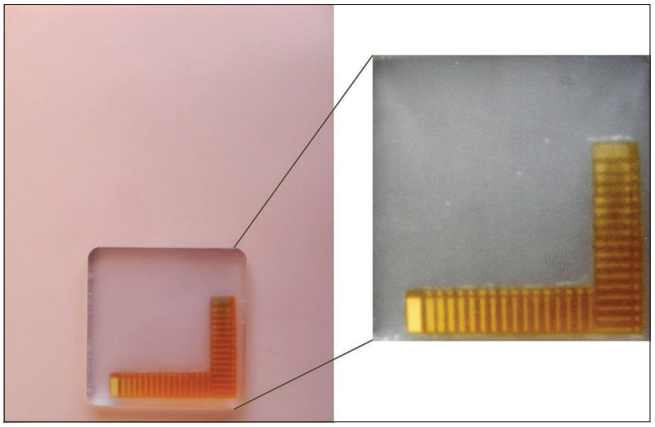

Figure 2: Photograph of the single exposure high contrast resolution phantom

as recommended by the ACR. The phantom was placed at the desired height on the bucky and in such a way to keep the pattern within 1 cm of the chest wall edge of the image receptor. Then, the operating parameters were set as same as mammography accreditation phantom procedure, and the film was exposed.

Measurement of leakage radiation

It is mandatory to measure leakage radiation around the medical diagnostic X-ray equipment tube housing to assure safety in accordance with the AERB safety code on diagnostic X-ray equipment and installations.[10] X-ray tube housing shall be so

constructed that leakage radiation averaged over an area of 10 cm^2, with no linear dimension >5 cm and located at 5 cm from any point on the external surface of X-ray tube housing, shall not exceed 0.02 mGy in 1 h. Based on this protocol, the leakage radiation in different direction of the X-ray tube such as anode side, cathode side, front, back, and top at 20 cm distance from the focal spot which corresponds to 5 cm from X-ray tube housing for a heavy exposure of 30 kVp and 100 mAs were measured using a pressurized μR ion chamber survey meter (451P-RYR, Fluke Biomedical).[10]

Radiation survey

Radiation survey was conducted using the same pressurized μR ion chamber survey meter in different locations around the mammography room as given below when a 5 cm × 5 cm × 5 cm water phantom was placed on the bucky to achieve a full scatter condition, and it was exposed to 35 kVp and 100 mAs.

a. Entrance door (ED)
b. Wall A (behind the mammography unit stand)
c. Wall B (right side of the X-ray tube)
d. Wall C (front wall)
e. Wall D (left side of the X-ray tube)
f. Waiting area (WA) (patient WA)
g. Dressing room (DR) (patient DR)
h. Control console (CC).

In unit 1, the ED, Wall A, Wall B, Wall C, Wall D, WA, DR, and CC were located at 2.50, 1.87, 2.00, 2.13, 1.80, 1.90, 1.72, and 0.87 meters (m), respectively, from the X-ray tube. Similarly, in unit 2, these points of measurement are located at 2.38, 1.85, 1.80, 2.51, 1.80, 2.25, 1.80, and 0.93 m, respectively, in unit 3, 1.52, 0.80, 1.93, 1.20, 1.47, 2.00, 1.34, and 0.69 m, respectively, in unit 4, 1.72, 0.78, 1.45, 2.52, 1.55, 1.95, 1.13, and 0.87 m, respectively, in unit 5, 2.50, 1.20, 2.30, 2.18, 2.00, 3.25, 1.87, and 1.20 m, respectively, in unit 6, 1.62, 2.21, 1.83, 1.55, 2.50, 2.67, 1.80, and 1.35 m, respectively, in unit 7, 2.12, 2.37, 2.30, 3.15, 1.87, 2.50, 2.00, and 1.30 m, respectively, and in unit 8, 2.82, 1.25, 1.00, 2.75, 1.38, 3.00, 1.30, and 1.12 m, respectively.

Work load

In the mammography unit, X-ray tube usage is important for the shielding design. The workload is a measure of the operational time or the amount of use of the X-ray equipment. A workload distribution indicates the workload across a range of operating voltages.[19] Further, the work load was calculated using the equation 4.

$$\text{Work load} = \left(\frac{\text{Number of patients}}{\text{Day}}\right) \times \left(\frac{\text{Number of days}}{\text{Week}}\right) \times \frac{\left(\frac{\text{Number of film}}{\text{Patient}}\right) \times \left(\frac{\text{mAs}}{\text{Film}}\right)}{60} \text{mA} - \text{min / week} \quad (4)$$

Average glandular dose measurements in stereotactic needle biopsy phantom

The stereotactic needle biopsy phantom (Model No. L-013) of thickness 4.5 cm was placed on the cassette holder and a portable MOSFET dosimeter (TN-RD-91, Best Medical Canada, Canada) S1 (TN-502RD-H) probe were placed on the phantom at various locations.[20] The probe S1 was placed on the top of the phantom to measure the entrance surface air kerma (ESAK) as shown in Figure 3a. Likewise, measurements were taken thrice at various points as shown in Figure 3b for 28 kVp tube voltage and 90 mAs current.

The unit 5 was selected for the AGD measurement study as it showed maximum output at low tube voltage out of 8 units as shown in Table 4. The AGD was measured using a Model No L-013 type stereotactic needle biopsy phantom in unit 5 by measuring the ESAK in 11 positions as shown in Figure 3b and also by knowing the ESAK to AGD conversion factor value of 0.187 at 28 kVp for Mo/Mo combination using the following equation 5.[21]

$$D_g = D_{gN} \times X_{ESAK} \quad (5)$$

where,

D_g - Average glandular dose

D_{gN} - Air kerma to AGD conversion factor

X_{ESAK} - Entrance skin air kerma in mGy.

Results

Acceptance test/quality assurance

Mechanical tests

As given in Table 2, the possible mechanical tests were carried out and it was found that all the mammography machines satisfied the basic requirements such as mechanical characteristics, working conditions of indicators in control panel, and tube housing indicators. From this, it was known that all the chosen machines were suitable for further QA. If

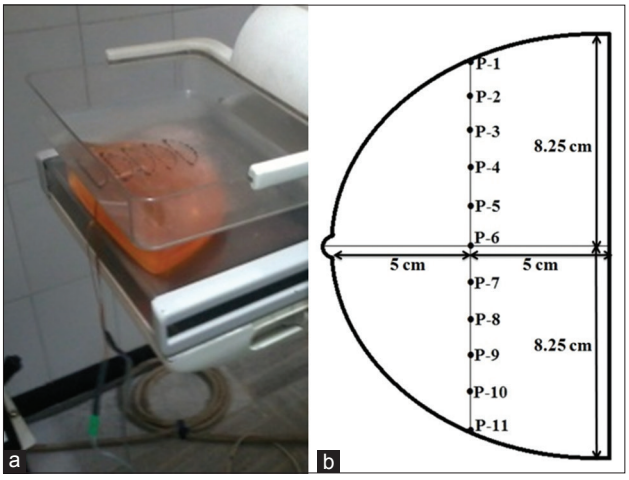

Figure 3: (a) Experimental setup to measure the entrance dose. (b) Schematic representation of S1 probe position on the top

otherwise, the unsatisfied machines need to be serviced instead of proceeding further.

Accelerating voltage (kVp) accuracy test

The percentage of variations in kVp accuracy calculated using the equation 1 for those eight mammography units at various kVp at 5 and 10 mAs are given in Table 3. From Table 3, it is observed that the deviation in measured kVp reaches maximum value of 13.3%, 7.14%, 2.8%, 4.54%, 10.7%, 8.4%, 8.8%, and 11.2% for unit 1–8, respectively. As per AAPM guidelines, the acceptable limit of the percentage of variation in kVp accuracy is ± 5% and hence only the units 3 and 4 passed the kVp accuracy test. However, the percentage of variation in kVp accuracy is beyond the limit in units 1, 5, and 8 at all kVp and mAs settings. In unit 2, the percentage of deviation was within the limits at all kVp at 5 mAs, but it increased gradually and went beyond the limits at higher kVp at 10 mAs. In unit 6, the percentage of variation decreased gradually as the kVp increased at both 5 and 10 mAs settings. In unit 7, the percentage of variation decreased gradually as the kVp increased at 5 mAs settings, but it was reversed at 10 mAs. This variation may be due to the problem in the power supply connected to the X-ray tube housing and also rely on the switches on the control panel. Out of eight mammography units, unit 1 showed the maximum deviation in kVp accuracy. This problem was solved immediately with the assistance of service engineer and radiological safety officer.

Machine output measurement

The COV in output measurements calculated using equation 2 for those eight mammography units at various kVp at 5 and 10 mAs are given in Table 4. As per the AAPM protocol, the acceptable limit of the COV in output should be <0.05. The failing percentages in the eight machines were 0%, 18.2%, 18.2%, 13.6%, 40.9%, 13.6%, 4.5%, and 13.6% respectively. Other than the U-2, U-3 and U-5, all other units had failing percentages <15%. Nearly 96.3% of the failing COV is happening below the 30 kVp with more failing percentage in the low kVp. All COV for >30 kVp were passing except for the unit 5 at 31 kVp. Based on these data, it is observed that the COV tolerance higher at low tube voltage irrespective of tube current in most of the units.

Half-value layer measurement

The HVL of the machine was measured using NOMEX multimeter at various kVp and mAs which is shown in Table 5 and it is compared with ACR recommendation. From Table 5, it is observed that the HVL values of all the mammography machines are within the acceptable limits. The data are also in good agreement with the data published by Gaurav Agarwal, *et al.*, Boone, and J. G. Coletti for Mo/Mo combination.[12,22]

Calibration of compression device

The mammography compression paddle was calibrated in the eight mammography units and the results are shown in Figure 4. From the figure, it is noted that the measured forces in units 1–8 are 107.87, 132.39, 176.52, 117.68, 166.71, 112.77, 147.1, and 117.68 N, respectively, which satisfies the AERB and AAPM recommended tolerance limit of 111–200 newtons. It is observed that the measured force is not the same in all the mammography units. If the measured force is less, the machine requires lesser force to compress the breast. Hence, the units 1, 4, 6, and 8 required lesser force to compress the breast, but units 3, 5, and 7 required more force for the same.

Image quality assessment

Image quality assessment using mammography accreditation phantom

To perform image quality assessment, the film was exposed in the presence of the mammography accreditation phantom at operating parameter 26 kVp and 50 mAs for Mo/Mo combination which is shown in Figure 5. The corresponding visibility details and scores obtained for various mammography units are given in Table 7. In accordance with the ACR guidelines, each mammography unit should show at least ten objects such as four in fiber, three in specks, and three in mass to pass the image quality when the AGD is 3 mGy or less. From Table 7, it can be observed that units 2 and 4 were not satisfying ACR requirement of fiber visibility; other than these two units, the remaining units can give good quality images as they show 10–15 objects. Out of these 8 units, unit 3 gave the best image as it showed 15 objects out of 16.[23]

Image quality assessment using single exposure high contrast resolution phantom

To measure the spatial resolution of the image, the film was exposed in the presence of the high contrast resolution pattern at the same operating parameter 26 kVp and 50 mAs for Mo/Mo combination in a plane 4.5 cm above the image receptor, and the same exposed film of unit 3 is shown in Figure 6. From Figure 6, it is possible to clearly visualize 15 lp/mm for bars parallel to the anode–cathode direction and 13 lp/mm for bars perpendicular to the anode–cathode direction. The ACR recommended that the limiting resolution (for a high-contrast pattern) in a plane 4.5 cm above the image receptor, due to geometric factors, should not be <13 lp/mm for bars parallel to the anode–cathode axis of the X-ray tube and 11 lp/mm in the perpendicular direction.[21] Hence, these results satisfied the ACR guidelines as well.

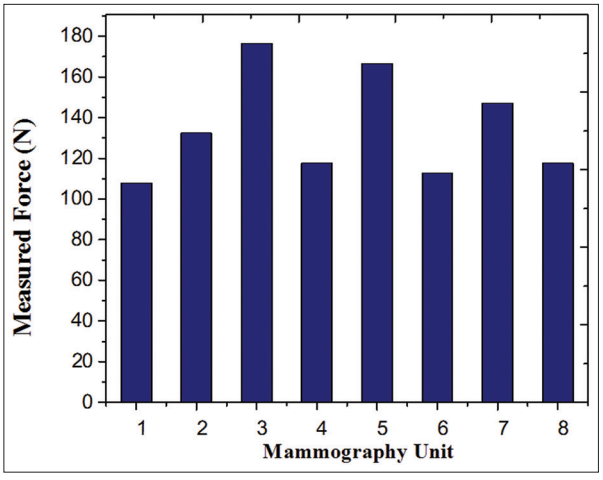

Figure 4: Calibration of mammography compression paddle

Measurement of leakage radiation

The leakage radiation dose was measured as per the AERB protocol[10] around the X-ray tube housing in all mammography units at different directions such as top, back, front, right, and left side of the X-ray tube at a distance of 20 cm from the focal spot which corresponds to 5 cm from external surface of X-ray tube housing. From Figure 7, it can be observed that unit 5 and 7 have higher leakage radiation beyond the AERB prescribed limit of 0.02 mGy in any 1 h.[10] This was due to improper maintenance of X-ray tube shield and also failure in conducting QA program periodically. The dose reached a maximum value of 0.0211 mGy at the right side of the X-ray tube in unit 5. Similarly, in unit 7, maximum doses were measured as 0.0218 (U-7), 0.0201 (U-7), and 0.0207 mGy (U-7) at left, front, and top sides, respectively. In units 1–4, 6, and 8, the maximum doses observed were 0.0022 (U-1), 0.0031 (U-2), 0.0055 (U-3), 0.0069 (U-4), 0.0092 (U-6), and 0.0055 mGy (U-8) at right, left, right, right, right, and back sides, respectively, which is within the acceptable level. It was also observed that a minimal dose was obtained at the front side (Wall C direction) of the X-ray tube in all mammography units except U-7 due to the presence of a lead glass which is attached to the gantry near the collimator.

Table 7: Visibility details and scores obtained in accreditation phantom for various mammography units

Phantom	Object	U-1	U-2	U-3	U-4	U-5	U-6	U-7	U-8
CIRS 015	Fiber (*n*=6)	4	3	6	3	4	4	4	4
	Specks (*n*=5)	3	3	4	3	3	3	3	3
	Mass (*n*=5)	4	4	5	4	2	4	4	4
Total object (*n*=16)		11	10	15	10	9	11	11	11

CIRS: Computerized Imaging Reference System

Radiation survey

The radiation survey was conducted in eight mammography units, and the variation in dose at different locations such as ED, Wall A, Wall B, Wall C, Wall D, WA, DR, and CC of the mammography unit layout is plotted in Figure 8. From Figure 8, it is observed that the dose reached a maximum of 186 μR/h at ED in unit 3. This leakage was the result of a small crack in the ED which is at closer distance when compared to other units. In the CC, the maximum dose of 157 μR/h was measured in unit 1. Similarly, the maximum dose of 83 (U-4), 74 (U-8), 65 (U-8), 71 (U-4), 85 (U-1), and 143 μR/h (U-4) were measured in wall A, Wall B, Wall C, Wall D, WA, and DR, respectively. The doses measured from all these eight units at various locations were well within the recommended dose limits meant for any radiation worker concerned even though all the layouts are different in size.[24]

Work load

Work load data were obtained from eight mammography units; the results are 120 (U-1), 49.2 (U-2), 250 (U-3), 88.8 (U-4), 13.3 (U-5), 12.4 (U-6), 226.6 (U-7), and 35 mA min/week (U-8). From these results, we can see unit 3 and 7 have higher workloads out of the eight included in the study.

The data of calculated workload values are presented in this paper. It will be useful for clinical radiologists, radiographers, and medical physicists in shielding calculation for better radiation protection.

Average glandular dose measurements using stereotactic needle biopsy phantom

The compressed stereotactic needle biopsy phantom was exposed at 28 kVp and 90 mAs and the corresponding entrance dose measurements were carried out at various locations of the phantom using MOSFET. The captured image with the biopsy

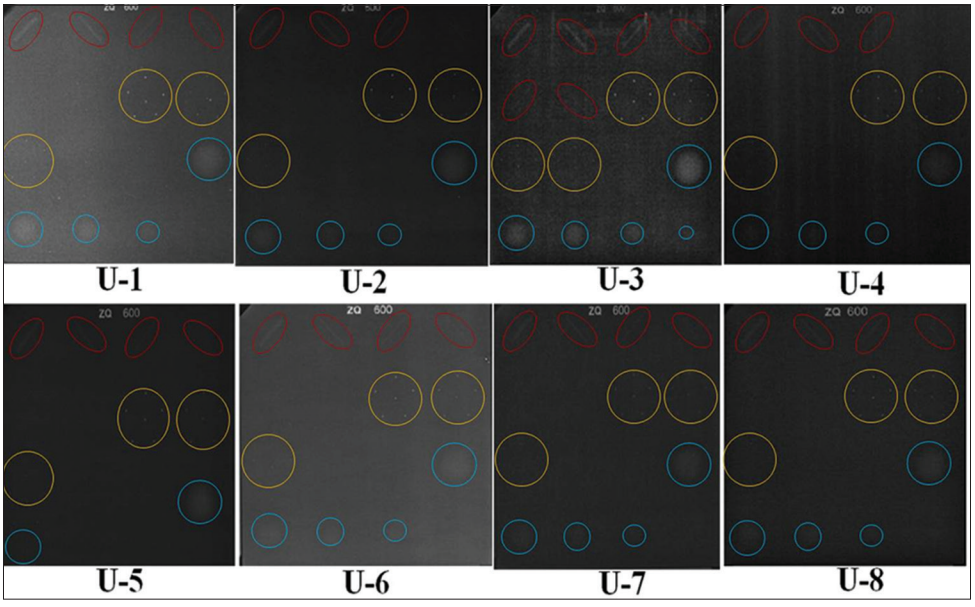

Figure 5: Visibility details and objects of the wax insert seen on the exposed film

phantom is shown in Figure 9, and the average value of ESAK measurements is given in Table 8.

From Table 8, it can be observed that the ESAK before service is in the range of 12.6–31.3 mGy with an average value of 21.3 mGy and the corresponding calculated AGD is in the range of 2.35–5.85 mGy with an average value of 4 mGy thus exceeding the European protocol tolerance value of 2.5 mGy for compressed breast and ACR protocol tolerance value of <3 mGy. However, after proper services in the same machine, the ESAK was measured in the range of 9.39–11.20 mGy with an average value of 10.36 mGy and the corresponding calculated AGD was in the range of 1.75–2.09 mGy with an average value of 1.93 mGy which is well within the European and ACR protocol acceptable limit in all the positions.

Discussion

This work had been borne out as a clinical project to understand the quality of the mammography units which are widely used for routine breast screening. The focus has been in the hospitals around our region to examine whether the units are maintained to meet the vendor specifications or the international stands. Our work revealed that the current QA programs followed by the clinics were inadequate to ensure safe use of the mammography units. It is clear that the medical care for women has been compromised which should be addressed immediately. We hypothesize that such inadequacies may not be just limited to our region only, but also all across the country. Even though this is a clinical project, our work had identified the inadequacies in these hospitals involved and immediately rectified them, bringing their QA program to international standards. Realizing the high expenses of QA instruments, our work also serves as a demonstration of providing clinical services to nearby hospitals.

Conclusion

Rigorous implementation of QA for mammography units is essential. Current QA practices that are followed in clinics are inadequate and they do not comply with the international standards. Our clinical project has brought hospitals in our region to international standard by addressing the

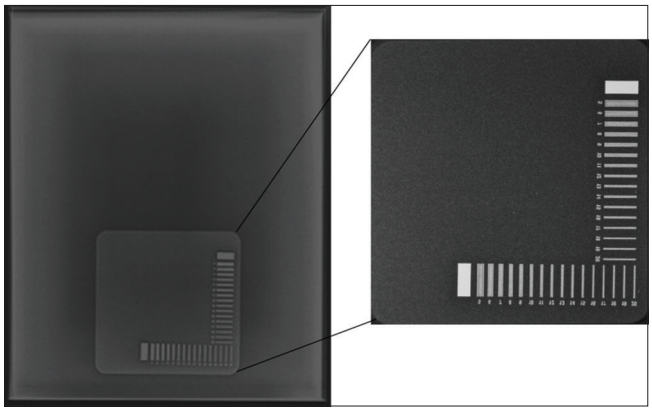

Figure 6: Visualization of countable bar pattern images on the exposed film

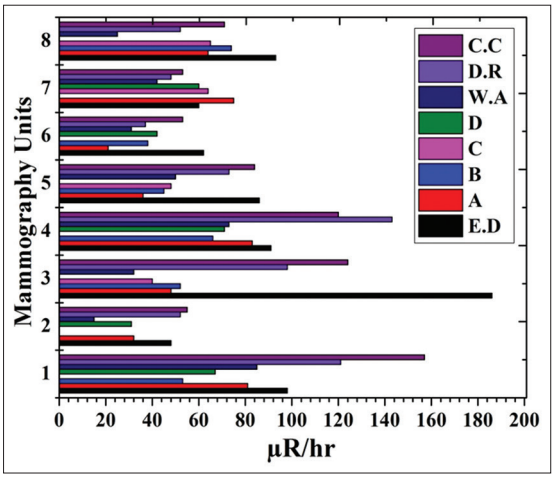

Figure 7: Measurement of radiation survey at various locations

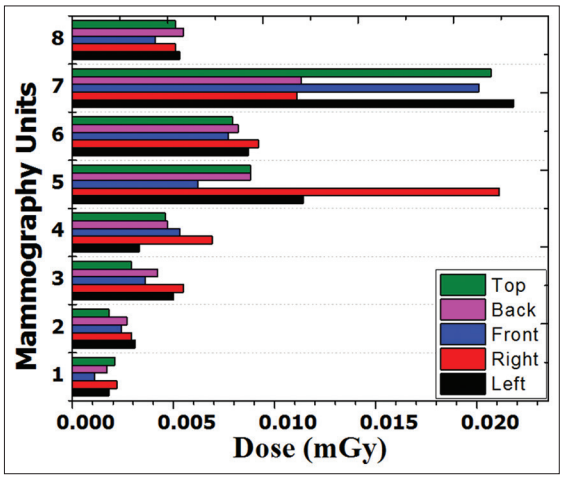

Figure 8: Measurement of leakage radiation dose at various directions

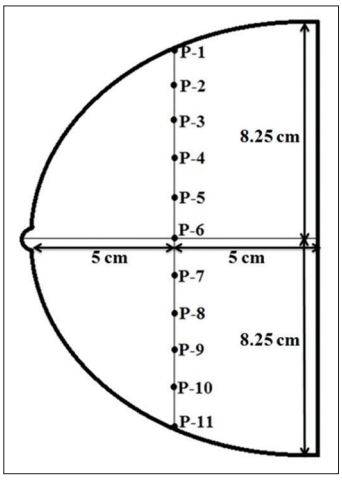

Figure 9: Image of the exposed film with biopsy phantom

Table 8: Measured entrance surface air kerma and calculated average glandular doses in unit 5

Number of positions	Measured ESAK (mGy)		Calculated average glandular dose (mGy)	
	Before service	After service	Before service	After service
1	12.6	9.44	2.35	1.76
2	15.1	9.39	2.82	1.75
3	20	10.24	3.74	1.91
4	18.9	10.26	3.53	1.91
5	25.3	10.89	4.73	2.03
6	31.3	11.20	5.85	2.09
7	26.5	11.18	4.95	2.09
8	24.3	10.64	4.54	1.99
9	27.1	10.46	5.06	1.95
10	20.4	10.26	3.81	1.91
11	13.8	10.04	2.58	1.87
Average	21.3	10.36	4.00	1.93

ESAK: Entrance surface air kerma

inadequacies in accordance to the AAPM and AERB protocols. This project also demonstrated a feasibility of shared cost of the expensive QA instruments if performed by a trusted entity for a small fee to bring the mammography units to international standards.

Acknowledgment

We thank Dr. Ganesan Ramanathan, Mr. P. Venkatraman, and Ms. S. Sangeetha, for their support to improve the manuscript. The authors would like to acknowledge Science and Engineering Research Board, Department of Science and Technology, New Delhi, for providing financial support (Project Ref. No: SR/FTP/PS-171/2011) and all the hospitals/institutions in South India who supported this study.

Financial support and sponsorship

The authors would like to acknowledge Science and Engineering Research Board, Department of Science and Technology, New Delhi, for providing financial support (Project Ref. No: SR/FTP/PS-171/2011) and all the hospitals/institutions in South India who supported this study.

Conflicts of interest

There are no conflicts of interest.

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