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Evaluation of scatter radiation dose to eye lens and thyroid gland from digital mammography

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ABSTRACT

Background: Digital mammography is a well-established screening examination for breast cancer due to its high sensitivity and specificity. However, digital mammography uses X-ray which is an ionizing radiation that can cause injury to all types of cells. In the patient positioning for mammography, the radiosensitive organs such as eye lens and thyroid gland are close to the radiation beam. Therefore, it is necessary to measure the scattered radiation dose to monitor and control the exposure within the standard limit.

Objectives: To study the scatter radiation dose of eye lens and thyroid gland and absorbed doses of breasts in patients undergoing digital mammography at Vajira Hospital, Bangkok, Thailand.

Materials and methods: Optically Stimulated Luminescent (OSL) dosimeters were taped to the patient's skin over the right and left lateral canthal angles, right and left thyroid lobes of 60 women (age range, 40–70 years) to measure the scattered radiation dose at each location in two routine mammographic projections; the cranial–caudal and the mediolateral oblique projections. The accumulated OSL dosimeters from patients were analyzed on a dosimeter reader. Breast compression thickness, compression force, average entrance skin dose, and glandular dose displayed on the mammography unit were recorded for each projection.

Results: The average scatter radiation dose to the skin overlying the right and left lateral canthal angles were 0.082 and 0.076 mGy, the right and left thyroid lobes were 0.929 and 0.883 mGy respectively. We found that the average scatter radiation doses were not exceed the radiation protection standards. On average, patients receive a glandular dose (AGD) of about 2.64 mGy. AGD was not exceed the dose limit recommended by the ACR where AGD of an ACR accreditation phantom shall not exceed 3 mGy. The average absorbed dose of breasts in digital mammography at Vajira Hospital was within the standard level. Meanwhile, the mean entrance skin dose was 9.96 mGy closer to the limit set by the IAEA, which was specified not to exceed 10 mGy for breasts of thickness between 4 and 6 cm.

Conclusion: The scatter radiation dose and absorbed doses determined through our study were within the standard level. Maximum visibility, especially for the signs of pathology, was achieved by imaging protocols that optimize the procedure and balance the quality requirements with the radiation dose to the patient. Monitoring of radiation dose in mammography reduces the risk of ionizing radiation and promotes the quality of public health services.

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Introduction

Breast cancer is the most common cancer in women worldwide. Since 2000, cancer has been the leading cause of death in Thailand.[1] In women, breast cancer is rapidly increasing with over 19,452 new cases expected in 2025.[1] The American Cancer Society recommends that women undergo regular screening mammography for early detection and to reduce the number of deaths from breast cancer. Digital mammography is a well-established screening examination for breast cancer due to its high sensitivity (67.8%) and specificity (70%).[2] Although, breast cancer screening with mammography alone is not perfect, but it has been one of the worldwide health strategies to reduce breast cancer mortality.[3] The goal of routine mammographic positioning is to screen the entire breast adequately. In most cases, the two standard mammographic projections, cranial-caudal (CC) view and mediolateral oblique (MLO) view, provide the best coverage of the breast tissue.[4] In addition, 3D Digital Breast Tomosynthesis (DBT) can be examined by taking images of the breast tissue as thin slices, one slice at a time, where each slice is 1 mm thick. At an angle of 15-50 degrees in tomosynthesis, approximately 50 slices of images are produced each time, where images were taken for a total of 4 times (2 times per side). Therefore, 200 images, each with 1 mm apart, will be obtained in the examination. This enables the observation of breast tissue that was previously stacked more clearly, despite the breast being dense, which includes patients with breast augmentation. Thus, lesions and abnormalities can be accurately identified, resulting in less images to be taken. The advantages of DBT have been confirmed by various studies[5-7] which includes faster detection of primary cancers and better visualization that enhances the observation of abnormalities in the breast.

However, both conventional and tomosynthesis modes of mammography are performed using X-ray which is an ionizing radiation that can cause injury to all types of cells. This adverse effect depends on the amount and energy of the exposed X-ray along with type and age of the cells. Excessive doses of X-ray can cause both short- and long-term cell damage and injury, where the risk of radiation exposure does not only depend on the energy, amount and type of radiation, but also on the organ being examined, size of the patient, as well as the examination techniques. In the posture adjustment of the patient for breast X-ray, it was found that the organs close to the radiation beam were the eye lens and thyroid gland.[8] Radiation exposure measurement to monitor and control within the limit requires a personal dose measuring device such as the Optically Stimulated Luminescence (OSL) dosimeter which can also be used to measure low-dose radiation from diagnostic radiology.[9] As OSL dosimeter can be molded into various aspects, making it small, easy to use with high sensitivity to radiation, can reanalyze the radiation dose, and is radiolucent which does not affect imaging diagnosis of diseases. For instance, the use of a nanoDot™ OSL dosimeter that has a wide range of radiation energy response (approximately 5 keV – 20 MeV) in diagnostic radiology can be employed to measure the amount of scattered and absorbed radiation on the skin near the organ of interest[10] or radiation sensitive areas such as eye lens and thyroid gland.

This study aims to determine the average glandular dose and entrance skin dose and use nanoDot™ OSL dosimeters to measure the scatter radiation dose received at anatomical locations like eyes and thyroid gland from digital mammography in representative patient population in order to monitor and control the radiation dose within the prescribed radiation safety standard.

Materials and methods

The study was approved by the Research Ethics Committee of the Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok, Thailand (COA 160/2563). Informed written consent was sought and documented. The subjects in this study consisted of 60 women (age range of 40–70 years) who received screening mammography were invited to participate in the study. The inclusion criteria is women aged 40–70 years have a screening mammogram as recommended by U.S. Preventive Services Task Force (USPSTF) and the American College of Obstetricians and Gynecologists (ACOG) recommendations.[11] However, we excluded the women age younger than 40 years old or older than 70 years old, pregnant women, women with breast implantation or augmentation, women with breast abnormalities, women with mastectomy or history of breast cancer.

The characteristic of nanoDot™ OSL dosimeter is shown in Table 1. These dosimeters are well appropriated for scatter radiation measurements because minimal angular dependence and sensitive to energies from 5 keV to 20 MeV. The accuracy is ±10% according to the manufacturer's specifications. The lower limit of detection (LLD) of the OSL dosimetry system was 0.0335 mGy, as stated on the manufacturer's calibration certificate. Front of nanoDot™ carried alphanumeric sensitivity code with serial number, for instance, the alphanumeric sensitivity code is DN082 refers to the sensitivity of 0.82. Each OSL dosimeter has different sensitivity which will be included in an algorithm of OSL reader software to calculate the radiation dose.

In this study, the correction factor for the 80 kVp to 44 kVp was not included for the calculation. We do concern for this factor, however, the value of conversion factor is very small.[12, 13] We expected that it would not have much impact on the results.

Table 1 Characteristic of nanoDot™ OSL dosimeter.

Type of radiation measured	X and gamma rays, beta
Useful energy range	From 5 keV to 20 MeV
Detector	nanoDot™ OSL (Optically Stimulated Luminescence)
Technology	Aluminium oxide doped with carbon, Al_2O_3:C
Dot	10 mm x 10 mm
Thickness	2 mm
Angular dependence	Minimal angular or energy dependence: Ideal for measuring skin dose at a point of interest

Note: Results expressed in absorbed dose

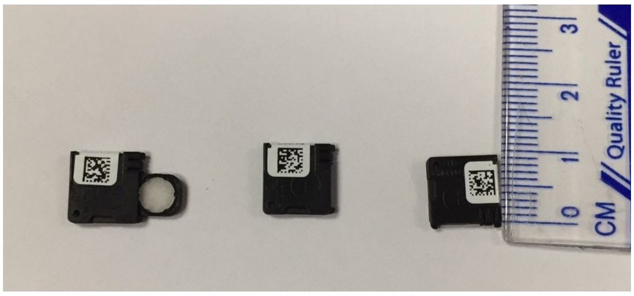

Figure 1*. Photograph showing Optically Stimulated Luminescence dosimeter (nanoDot*™*), which is 1 × 1 cm noninvasive radiation detector.*

Before the mammographic examination, four nanoDot™ OSL dosimeters (Figure 1) were taped to the patient's skin over the right and left lateral canthal angles of eyes, right thyroid lobe and left thyroid lobe (Figure 2). During mammography, the nanoDot™ OSL dosimeters measured the skin entrance scattered radiation doses at each location in two routine mammography projections, the conventional cranial-caudal (CC) view and both conventional and tomosynthesis mediolateral oblique (MLO) projections following the routine protocol of Vajira Hospital. Each nanoDot™ OSL dosimeter was read and erased before using with the next patient.

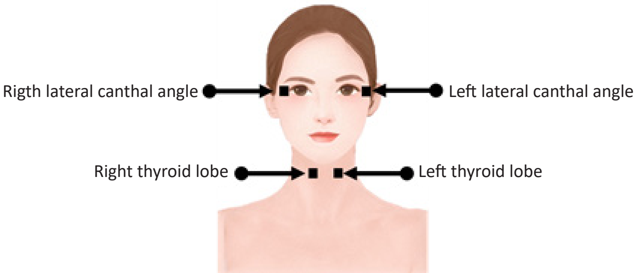

Figure 2*. Placement of nanoDot*™ *OSL dosimeters.*

All mammograms were obtained with the same mammography unit (MAMMOMAT Revelation; Siemens Medical Solutions Inc., Erlangen, Germany) installed in the year 2020 at Vajira Hospital, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok, Thailand (Figure 3). The mammographic unit was checked and certificated by Department of Medical Sciences Ministry of Public Health, Thailand according to quality standards of medical diagnostic X-ray machines. Mammography unit operated in standard automatic exposure control mode. Tube potential (peak kilovoltage) and tube current–time product (milliampere seconds), target-filter combination (W/Rh), and patient age were recorded. For each mammographic projection, breast compression thickness, compression force, average entrance skin dose, and glandular dose displayed on the mammography unit were recorded. Image quality of all mammograms was verified by radiological technologists and accepted by radiologist.

nanoDot™ OSL dosimeters were removed and stored with a control dosimeter until readout. The accumulated nanoDot™ OSL dosimeters from patients were analyzed on a dosimeter reader (MicroStar Dosimetry Reader, Landauer) (Figure 4). The exposed dosimeters were readout the next day after irradiation to prevent signal loss and addition of background radiations. Each nanoDot™ OSL was repeatedly read three times. The average readings were calculated. Results were also adjusted for background radiation based on control dosimeter readings. These nanoDot™ OSL dosimeters results represented dose at the skin external to the eye lens and thyroid gland.

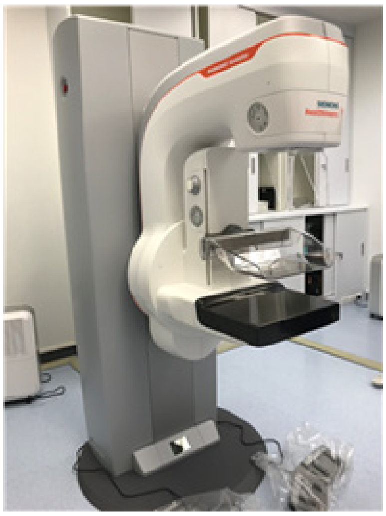

Figure 3*. A digital mammographic unit (MAMMOMAT Revelation; Siemens Medical Solutions Inc., Erlangen, Germany) installed in the year 2020 at Vajira Hospital, has been used to perform 2D conventional mammography and 3D breast tomosynthesis.*

Figure 4*. Photographs show MicroStar dosimetry reader for reading OSL dosimeters with MicroStar reader software for interpreting results.*

Results

The average age of subjects in this study was 56 years (range of 40-70 years). The average tube potential in this study was 43.95 kVp. The average tube current–time product was 220.23 mAs, and the mean compression force was 64.4 N (Table 2).

Scatter radiation dose measurements

The average scatter radiation dose, maximum dose, and minimum dose to the skin overlying the thyroid gland and lateral canthal angles of eyes are shown in Table 2. Distribution of each value from each location is shown in Figure 5.

Table 2 Scatter radiation dose of skin near organs of interest.

Organ	Average dose (mGy)	Maximum dose (mGy)	Minimum dose (mGy)	SD (mGy)
Right eye	0.082	0.323	<0.0335	0.063
Left eye	0.076	0.207	<0.0335	0.046
Right thyroid	0.929	2.276	0.188	0.497
Left thyroid	0.883	2.050	0.276	0.428

Right and left eyes

nanoDot™ OSL dosimeters placed near the right and left lateral canthal angles were used to estimate scatter radiation received by the eye lens. One measurement for the right and left eyes from one patient was below the LLD of the dosimeters. Other individual entrance skin measurements for the eye lens were above LLD of the dosimeters. The average scatter radiation dose to the skin at the right and left lateral canthal angles were 0.082 and 0.076 mGy respectively.

Thyroid gland

nanoDot™ OSL dosimeters taped above both thyroid lobes were used to estimate exposure of the thyroid gland. All individual skin measurements for the thyroid glands were over LLD of the dosimeters. The average scatter radiation doses to the skin above the right and left thyroid lobes were 0.929 and 0.883 mGy respectively.

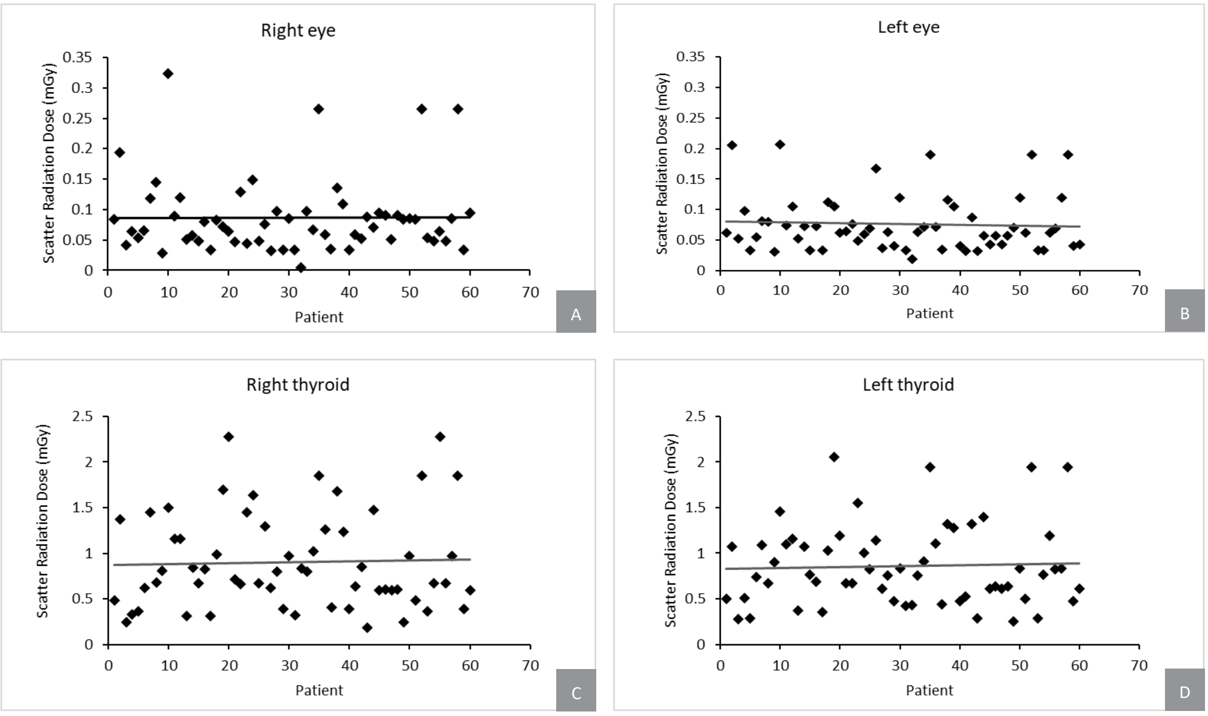

Figure 5. *Scatterplots show entrance skin doses for right (A) and left (B) lateral canthal angles, right (C) and left lobes of thyroid gland (D).*

Average Glandular dose and Entrance skin dose

Regarding the absorbed doses and correlated parameters in sixty mammographic examination participants in our study at Vajira Hospital, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, it was found that the average glandular dose, which is a system-displayed average value was 1.33 mGy and 1.46 mGy for right cranial–caudal (RCC) and left cranial–caudal (LCC), and 4.08 mGy and 3.70 mGy for right mediolateral oblique (RMLO) and left mediolateral oblique (LMLO), respectively. The average glandular dose which is a system-displayed average value for all mammographic views was 2.64 mGy. The average glandular dose in the craniocaudal view was less than that in the mediolateral oblique view. The mean entrance skin dose was 5.06 mGy and 4.7 mGy for RCC and LCC, and 14.87 mGy and 15.2 mGy for RMLO and LMLO, respectively. The mean entrance skin dose which is a system-displayed average value for all mammographic views was 9.96 mGy. The mean entrance skin dose in the craniocaudal view was less than that in the mediolateral oblique view (Table 3).

Breast Compression Thickness

The average breast compression thickness was 55.47 mm and 54.09 mm for RCC and LCC, and 58.79 mm and 58.53 mm for RMLO and LMLO, respectively. The average breast compression thickness in our study was 56.72 mm for all views (Table 3). Average glandular dose increased with increasing breast compression thickness. Figure 6 shows the average glandular doses as a function of breast compression thickness for RCC (A), LCC (B) views in conventional mode and RMLO (C), LMLO (D) views in conventional and tomosynthesis mode (Figure 6).

Table 3 Parameters measured for each mammographic view.

Projection	kVp	mA	Compression Thickness (mm)	Compression Force (N)	Average Glandular dose (mGy)	Average Entrance skin dose (mGy)
Right craniocaudal (RCC)	29.11 (26, 32)	116.92 (50.4, 279.1)	55.47 (28, 84)	56.64 (28, 111)	1.33 (0.65, 3.6)	5.06 (0.91, 14.6)
Left craniocaudal (LCC)	28.98 (26, 32)	109.85 (47.1, 222.6)	54.09 (24, 79)	53.89 (29, 95)	1.46 (0.6, 10.4)	4.70 (0.82, 12.4)
Right mediolateral oblique (RMLO)	58.79 (54, 64)	332.53 (163.8, 740)	58.79 (33, 85)	74.15 (34, 131)	4.08 (2.12, 18.16)	14.87 (2.25,42.3)
Left mediolateral oblique (LMLO)	58.91 (54, 64)	321.64 (161.3, 621.2)	58.53 (34, 85)	72.92 (31,127)	3.70 (1.92, 10)	15.20 (2.45,32.4)

Note: Values are averages with minimum and maximum, MLO projections consist of conventional and tomosynthesis modes.

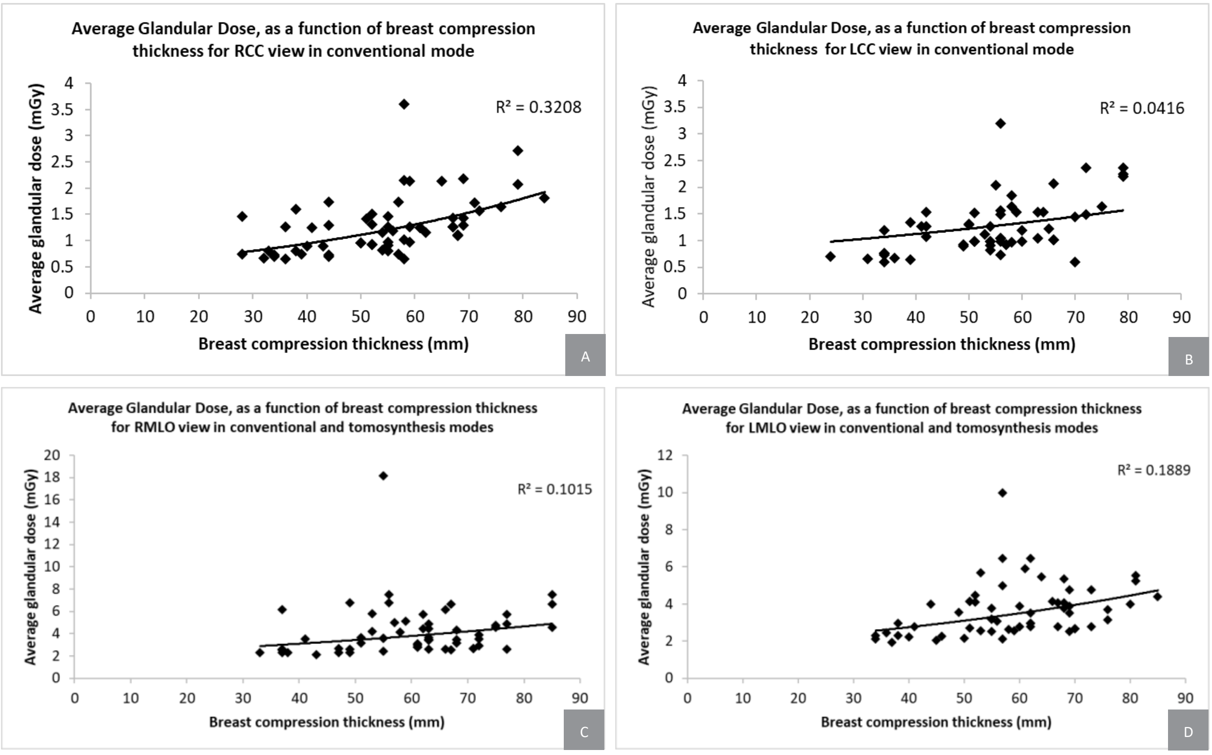

Figure 6. *Average glandular doses, as a function of breast compression thickness for RCC (A), LCC (B) views in conventional mode and RMLO (C), LMLO (D) views in conventional and tomosynthesis modes.*

Discussion

In this study, we measured the scatter radiation dose by using nanoDot™ OSL dosimeters placed on the skin of a representative population of women. We focused on tissues that have greater susceptibility to radiation effects, including the eye lens and thyroid gland.[14, 15] During positioning, a relaxed posture allows the breasts to naturally fall forward and loosen the skin and muscles of the chest.[4] Chest wall is brought closer to the image receptor by turning the patient's head to the contralateral side, and bringing it forward around the face shield. This results in visualization of more medial, superior, and posterior tissue of the breast. Just turning the head to the side is contrary to the positioning process.[4]

In this study, we placed nanoDot™ OSL dosimeters on the skin overlying the lateral canthal angles of the eyes which turned the patient's head to the contralateral side. The placement of this research is consistent with the suggestion of Chusin T *et al*. that eyes close to the imaged side received a higher dose whereas the contralateral eye received a negligible dose, implying that nanoDot™ OSL dosimeters should be pasted on eyes that are close to imaged tissue for improving accuracy of measurement.[16] The positions of nanoDot™ OSL dosimeters at thyroid gland in the study by Chetlen *et al*. are comparable to those employed by us.[8]

Sixty female patients were studied using a digital mammography facility at Vajira Hospital, Faculty of Medicine Vajira Hospital. Chetlen *et al*. reported that the average scatter radiation dose to the skin overlying the eye lens and thyroid gland from digital screening mammography in 207 female subjects were 0.025 and 0.245 mGy respectively.[8] In this study, we found that the average scatter radiation dose to the skin overlying the lateral canthal angles of eyes were 0.082 and 0.076 mGy, the right and left thyroid lobes were 0.929 and 0.883 mGy, respectively. The average scatter radiation dose of eyes and thyroid gland in our study was higher than Chetlen *et al*.'s study because we performed MLO projections with both conventional and tomosynthesis modes according to routine protocol of Vajira Hospital while Chetlen *et al*. performed MLO projections with only conventional mode. Nonetheless, the average scatter radiation doses of eyes were not higher than the ocular-radiation protection standards formulated by the National Council on Radiation Protection and Measurements (NCRP) and the International Commission Radiological Protection (ICRP). It was all predicated on the assumption that radiation cataracts are deterministic and only appear when a threshold dose is exceeded. For detectable opacities, this value is currently 0.5–2 Gy for acute exposures and 5 Gy for chronic exposures.[17] Although, average scatter radiation doses of thyroid gland measured in our study was relatively high, Yuan *et al*. reported that patients who had been exposed to radiation from mammography did not have significantly higher risk of development of thyroid and hematologic cancers.[18] Further, the thyroid gland is considered less radiosensitive compared to the eye lens.

On average, patients receive a glandular dose (Mean AGD) of about 1.39 mGy in cranio-caudal view and 3.89 mGy in mediolateral oblique view. The AGD of 1.39 mGy for cranio-caudal view in our study was similar to those reported by Chetlen *et al*. and Theerakul K and Krisanachinda A as 1.36 mGy and 1.65 mGy respectively.[8, 19] The AGD of 3.89 mGy for mediolateral oblique view in our study was similar to Raed M K M Ali *et al*.'s study reported as 3.6 mGy.[20] Moreover, we found that when breast compression thickness increases, increasing the average glandular dose preformed with both conventional and tomosynthesis modes in all views comparable to other studies.[8, 19]

Mean AGD of cranio-caudal view was not exceed the dose limit recommended by the American College of Radiology (ACR) that AGD delivered during a single cranio-caudal view of an FDA-accepted phantom simulating a standard breast shall not exceed 3.0 mGy (0.3 rad) per exposure. Dose from a mode that combines a 2D view with a DBT view is not subject to the 3.0 mGy performance criteria. Each view within the mode should be compared separately against the performance criteria.[21] The average absorbed dose of breasts in digital mammography at Vajira Hospital was within the standard level. Meanwhile, the mean entrance skin dose displayed on the mammography unit was 9.96 mGy closer to the limit set by the International Atomic Energy Agency (IAEA) which specified not to exceed 10 mGy for breasts of thickness between 4 and 6 cm.[22] The mean entrance skin dose in our study was close to 10 mGy because the average breast compression thickness in our study was close to 6 cm. Radiation protection as low as reasonably achievable principle can be applied to patients to prevent any radiation incident.

Conclusion

Scatter radiation dose and absorbed doses determined through our study were within the standard level. Selection of a proper technique (technique factors, image processing, etc.) is what makes mammography the examination that requires the highest image quality for diagnosis. Maximum visibility, especially of the signs of pathology, is achieved by using state-of-the-art equipment and imaging protocols that optimize the procedure and balance the quality requirements with the radiation dose to the patient. Monitoring of radiation dose in mammography reduces the risk of ionizing radiation and promotes the quality of public health services. As a result, the hospital uses a quality mammography unit by maintaining the image quality that can be diagnosed following the standard for the patients effectively.

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