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Estimation of cancer risks during mammography procedure in Saudi Arabia

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ABSTRACT

The aims of the present work were to quantify radiation doses arises from patients' exposure in mammographic X-ray imaging procedures and to estimate the radiation induced cancer risk. Sixty patients were evaluated using a calibrated digital mammography unit at King Khaled Hospital and Prince Sultan Center, Alkharj, Saudi Arabia. The average patient age (years) was 44.4 ± 10 (26–69). The average and range of exposure parameters were 29.1 ± 1.9 (24.0–33.0) and 78.4 ± 17.5 (28.0–173.0) for X-ray tube potential (kVp) and current multiplied by the exposure time (s) (mAs), respectively. The MGD (mGy) per single projection for craniocaudal (CC), Medio lateral oblique (MLO) and lateromedial (LM) was 1.02 ± 0.2 (0.4–1.8), 1.1 ± 0.3 (0.5–1.8), 1.1 ± 0.3 (0.5–1.9) per procedure, in that order. The average cancer risk per projection is 177 per million procedures. The cancer risk is significant during multiple image acquisition. The study revealed that 80% of the procedures with normal findings. However, precise justification is required especially for young patients.

1. Introduction

Female breast malignancy is the prominent tumour and contributes 25% of cancer incidences in females in the Saudi Arabia and around 8000 cases are diagnosed annually (Bazarbashi et al., 2017). In Saudi Arabia, breast cancer occurs in women around the age of 52 and 50–60% of patients are diagnosed at a late stage. In contrast, breast malignancy contributes 55.2% of cancer incidences in women and half of the cases arise in females above 65 years old in western countries (Saggu et al., 2015; El-Bcheraoui et al., 2015). The incidence of breast malignant tumors will rise in the kingdom in the near future because of the residents aging, lifestyles and the population growth. Two-thirds of patients with breast cancer were pre-menopausal and the median age was 45 years (El-Bcheraoui et al., 2015). The common risk factors include: null parity or pregnancy at late age, menstrual history, obesity and genetic factors (family history) (Saggu et al., 2015). A considerable number of individuals were unwilling to seek medical advice out of fear of cancer and shyness in Saudi Arabia (Saggu et al., 2015). Mammography, is the imaging procedure of choice (gold standard) to detect and diagnose breast cancer since its development in the late 1920s and is also recommended for breast malignant tumors screening every 2 years (minimum) for females in the age range 50 to 74 years (van Steen and van Tiggelen, 2007). In screened women, mammographic imaging procedures reduced the mortality of breast cancer patients up to 30% compared with a control patients with diagnostic accuracy up to 79% (Sree et al., 2011; Kerlikowske et al., 1995). The radiation dose from a mammogram is around 3.0 mSv, which may upturn the probability of mammary gland radiation inducing malignant tumors (Yaffe and Mainprize, 2011) because the breast tissue of young women is highly radiosensitive in a human body (Carmichael et al., 2011). Previous studies showed that patients are subjected to several X-ray exposures from radiodiagnostic exposures for therapeutic or diagnostic purposes may significantly increase the radiogenic risk to certain sensitive tissues or organs (Alkhorayef et al., 2017;

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Carmichael et al., 2011; Yilmaz et al., 2007; ICRP, 2007). It has been reported that the delivery of 10.0 mGy to a female below the age of fifty-five years old can substantially upturn the probability of lifetime risk of breast malignant tumor induction by up to 13.6% (Yilmaz et al., 2007). Since some breast cancers are difficult to detect, radiologists usually require a comparison of the image for both breasts because normal breasts can appear differently for each woman. Therefore, it is vital to limit the radiation exposure in mammography procedures to its minimal achievable value consistent with diagnostic information. Therefore, reasonable evaluation of radiographic image quality is mandatory to balance against patient radiation exposure to X radiation. In the updated publication of the international. commission on radiological. Protection. (ICRP), it was stated that the weighting factor according to organ radio sensitivity was increased from 0.05 to 0.12 from the breast (ICRP, 2007). This is due to the research finding revealed the augmented radio sensitivity of mammary gland tissues and the fact that breast malignant tumors is almost one-quarter of the total cancer incidence in women (Siegel et al., 2018). The association between radiation induced breast malignant tumors and radiation dose is a product of several factors such as age at exposure, latent period (time after exposure) and hormone level etc. The age at exposure is the most important factor, with young girls being at higher risk than women around menopausal age. The reason is a need for oestrogen stimulation and tissue proliferation in order for radiation damage to occur in breast tissue. The breast tissue is increasingly radiosensitive during pregnancy due to increased hormone levels. The latent period for radiation induced breast to occur is approximately 5–10 years (Noone, 2018). The latent period is longest in younger women and shortest for older women. Furthermore, the latent period for young children can be even longer to about 35–40 years (Siegel et al., 2018; Noone, 2018; Ries et al., 2018). It is well documented that the mammographic procedure is very helpful in providing useful data which can help the radiologist in generating a precise diagnosis, and afterward a successful patient management and treatment. However, to diminish the risk of radiation induced malignant tumors, precise patient dose estimation and optimization are required to bring down the probability of breast cancer to its minimal value (EC, 1996). In the literature, the mean glandular dose (MGD) ranged between 2.0 and 3.7 mGy per procedure (Warrenet al., 2016; Pasicz et al., 2016; Fartaria et al., 2016; Ślusarczyk-Kacprzyk et al., 2016; Soliman and Bakkari, 2015; Hauge et al., 2014; Al-Kafi et al., 2009). Although, evaluation of patients' ionizing radiation exposures from radiodiagnostic examinations is recommended for dose optimization and benefit/risk evaluation, few studies have been published regarding patient doses during mammography in Saudi Arabia (Soliman and Bakkari, 2015; Al-Kafi et al., 2009). The purposes of the present work were to (i) evaluate the patients' MGD in mammographic X-ray procedures and (ii) to quantify the breast cancer probability due to image acquisition with X radiation.

2. Materials and methods

The examined patients sample consists of 60 patients who were examined at the radiology department of King Khaled Hospital, Alkharj, Saudi Arabia. The ethics and review council approved this research and knowledgeable permission was attained from all the patients before collection the data. All patients were undergoing the procedure due to medically justified clinical conditions. Patients' demographic data (age (years), breast thickness (mm) and radiographic exposure factors), X-ray tube voltage (kVp), product of time and tube current (mAs), exposure time and X-ray projection were recorded for all patients. Each patient underwent six projections in total: three projections for each female breastcranioi-caudal (CC), medio-laterall oblique (MLO) projections and: latero-medial (LM).

2.1. X-ray unit

The mammographic X ray examinations were conducted using a digital mammography system (Giotto mammography image, Internazionale Medico Scientifica (IMS), Bologna, Italy). The X-ray machine was equipped with a-Selenium (Se) direct conversion flat panel detector with modulation transfer function (MTF) at 2.0 lp/mm $\geq$ 90%, spatial resolution: 6.0 lp/mm and Mo-Rh filter materials (Table 1). The mammography unit is equipped with automatic exposure control (AEC).

2.2. Patient position

In mammography, vigilant breast positioning is necessary to avoid motion artefact and tissue superimposition. The breast was placed in anatomical position with the nipple perpendicular to the thoracic cage and compressed gently with a paddle with tissue equivalent material. Sixty-five cm source to skin distance (SSD) was used as a standard distance for all procedures. Exposure parameters were selected according to the breast thickness.

2.3. Entrance Surface Air Kerma (ESAK, mGy) calculation

ESAK (mGy) is the practical unit of choice in mammographic imaging dose measurement and the quantity of choice to quantify the breast tissue doses resulting from ionizing radiation exposure in mammography. The ESAK (mGy) (free-in-air, no backscatter) is the most frequently used quantity for patient dosimetry in mammographic imaging. This enables a comparison between different previous studies in addition to the effective dose. The ESAK (mGy) was quantified per projection for each procedure.

2.4. Mean Glandular Dose (MGD) calculations

The MGD, which is defined as average amount of radiation to breast glandular tissues, is the dosimetry quantity generally recommended for risk assessment (ICRP, 2007). The MGD is estimated indirectly from the ESAK and half value layer (HVL). The MGD is based on some standard breast parameters. Therefore, MGD is extrapolated using the ESAK and conversion coefficient is based on Monte Carlo calculations for standard breast projections (50% for each tissue: adipose (fatty) and glandular). The mammary gland tissues composed of glandular, fatty and fibrous tissues and the exact composition is age dependent. Breast density and fibrous

Table 1
Mammographic X ray unit features.

Model	Frequency (kHz)	Power (kW)	X-ray-tube potential (kVp)	Source detector distance (cm)	Operation power (kW)	Detector type	Target material
E-40MGHF	40	5	22–35	68	3.5	a-Se direct conversion	Mo/Rh

Table 2
Image aquision parameters and patients doses during mammography.

Variables	Mean	Std. deviation	Minimum	Median	1st quartiles	3rd quartiles	Maximum
Age (Year)	44.44	10.21	26.00	44.00	37.00	49.00	69.00
Tube voltage (kVp)	29.1	1.86	24.00	28.00	28.00	31.00	33.00
Tube current time product (mAs)	78.3	17.47	28.00	70.00	70.00	90.00	173.00
Time (ms)	571.0	116.56	446.00	496.00	496.00	638.00	1226.00
Breast thichness (mm)	48.1	11.32	23.00	46.00	39.00	57.00	76.00
ESAK	4.4	1.1	1.7	4.6	3.8	5.0	7.9
MGD	1.1	0.26	0.40	1.10	0.90	1.20	1.90

Table 3
Image aquision factors per projection.

Projection	Tube voltage (kVp)	Tube current (mA)	Time (ms)	Dose (mGy)	Breast Thickness (mm)	Compression force (daN)
Cranio-caudal (CC)	28.5 ± 1.8	73.9 ± 14	534 ± 75	1.02 ± 0.2	42.3 ± 9	17.9 ± 2
	(24.0–31.0)	(28.0–173)	(446–938)	(0.4–1.8)	(23.0–64.0)	(11.0–20.0)
Mediolateral Oblique (MLO)	29.6 ± 1.8	81.9 ± 21	600 ± 152	1.1 ± 0.3	52.0 ± 12	17.1 ± 3
	(24.0–33.0)	(31.0–140)	(450–1226)	(0.5–1.8)	(28.0–76.0)	(7.0–20.0)
Lateromedical (LM)	29.4 ± 1.7	79.1 ± 17	579 ± 111	1.1 ± 0.3	50.0 ± 10	17.1 ± 3
	(24.0–33.0)	(31.0–146)	(450–1226)	(0.5–1.9)	(26.0–70.0)	(9.0–20.0)
Overall mean and range	29.1	78.3	571	1.1	48.1	17.4
	(24.0–33.0)	(28.0–173)	(446–1226)	(0.4–1.9)	(23.0–76.0)	(7.0–20.0)

tissue decrease with age while adipose tissue increases with age. In this study, the MGD was extrapolated using the conversion coefficient from Dance et al. (2009). The coefficient value depends on the breast thickness and composition and exposure parameters (filtration, tube voltage (kVp) and target material. The mean value was presented in this study according to Eq. (1).

$$MGD = ESAK \cdot g \cdot s \cdot c \qquad (1)$$

where g is the absorbed radiation energy in the glandular tissue of the breast, calculated using Monte Carlo simulation related to HVL. Thus g is ESAK (k factor) conversion factor to MGD with 50% granularity

c-factor used for to adjust variation in breast composition,

s-is a correction factor X-ray spectrum variation,

g and c factors used in reference to half value layer, beam filter and the breast density (Lee et al., 2010; Dance et al., 2009).

2.5. Cancer risk estimation

Exposure to radiation from a mammographic procedure results in a heterogeneous dose to different tissues and organs. The probability of the cancer risk or severity of the tissue reaction depends on the dose value and tissue radio sensitivity (ICRP, 2007). In cancer/hereditary effects, any dose can cause effects (linear no-threshold (LNT)) model, regardless of its value and the probability is directly related to the dose (ICRP, 2007)). The effective radiation dose (*E*, mSv), is extrapolated dose using organ equivalent radiation doses (mSv) multiplied by tissue-weighting factors (W_t), is the quantity of choice to express the cancer probability. Hence, the risk of malignant tumor induction following a mammographic X-ray procedure was quantified using the mean organ equivalent dose and radiation risk factors product. The ICRP quantified the malignant tumor risk, which represents a 5.5% chance of developing cancer. The risk coefficient for breast cancer due to radiation is 116 x 10^{-4} Sv^{-1} and was used to estimate the probability of cancer per procedure (ICRP, 2007).

3. Results

A total of sixty mammographic procedures were performed in the present work. The foremost clinical indication for mammography was to detect suspicious lesions (lumps) for breast cancer. Patient characteristics (age and breast thickness), compression force (Dekanewton (daN)) mammographic exposure parameters (kVp, mA, s) and patient doses (mGy) are presented in Tables 2 and 3. The mean patient age is 44.4 ± 10 (26.0–69.0 years) for a mammogram. A considerable number of patients are young (Fig. 1), suggesting that they are more at risk compared to older patients (median age is 44.0 years). The mean tube voltage was comparable with previous studies and breast thickness (Baek et al., 2017; Warren et al., 2016; Hauge et al., 2014; Dance et al., 2009). The mean ESAK (mGy) and MDG (mGy) were 4.4 ± 1.1 and 1.1 ± 0.3, respectively. The radiation induced cancer due to mammography was estimated to be 177 × 10^{-6}. Table 4 presents a correlations matrix between variables of the mammography procedure. The table shows that there is a statistically significant linear relationship at the level of significance ($p < 0.01$) or less between the MGD and exposure parameters (kVp, mAs) and breast thickness.

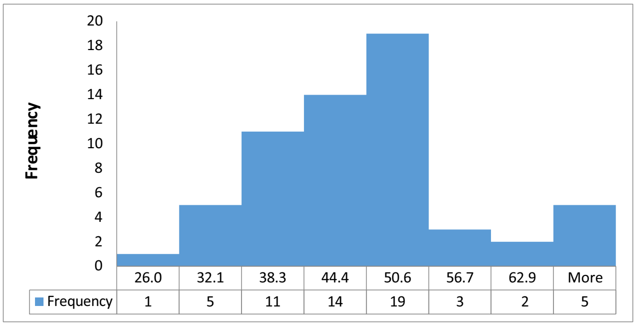

Fig. 1. Patients' age distribution.

4. Discussion

Radiation induced carcinogenesis risk to the breast is of concern hence, radiation dose evaluation and risk estimation is essential in establishing and evaluating the justification criteria of the procedure based on risk/benefit analysis. It also helps practitioners to optimize the quality of the radiographic images with the minimal achievable radiation exposure. Mammography is performed to detect breast cancer because it has the sensitivity for early

Table 4
Correlations matrix between variables.

Variables		Dose	Age	kVp	mAs	Time (ms)	Breast thickness
MGD (mGy)	Correlation	1.00					
	P-Value	0.00					
Age (year)	Correlation	−0.13	1.00				
	P-Value	0.08					
Tube voltage (kVp)	Correlation	0.82**	−0.15	1.00			
	P-Value	0.00	0.06				
Tube corrent-time product (mAs)	Correlation	0.81**	−0.03	0.81**	1.00		
	P-Value	0.00	0.39	0.00			
Time (ms)	Correlation	0.79**	0.01	0.81**	0.89**	1.00	
	P-Value	0.00	0.46	0.00	0.00		
Breast thickness (mm)	Correlation	0.45**	−0.07	0.84**	0.66**	0.73**	1.00
	P-Value	0.00	0.24	0.00	0.00	0.00	

** Means there are statistically significant relationship at the level of significance (0.01) or less.

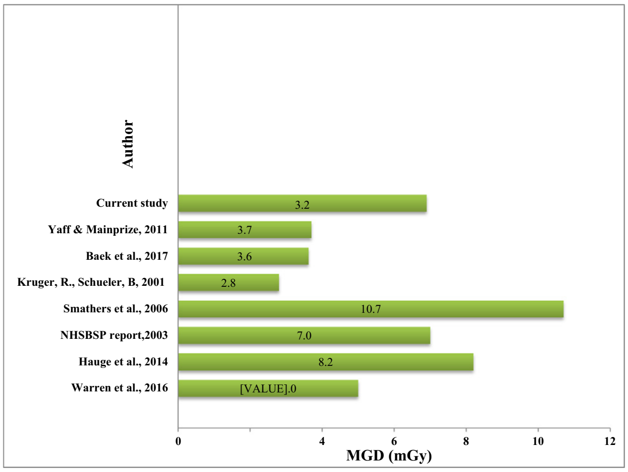

Fig. 2. Comparison of MGD dose (mGy) during 2 projections of mammography procedures.

Table 5
Breast organ equivalent doe from various imaging modalities (Isidoro et al., 2017; Sree et al., 2011; Hendrick, 2010; Mettler et al., 2008; Boone et al., 2001).

Modality	Breast dose (mGy)
Mammography (current study)	3.2
Positron emission mammography (PEM)	2.5
Mammography	4.7
Dedicated breast CT	5.4
Ventilation/Perfusion SPECT	0.8
Breast-specific gamma imaging (BSGI)	2.0
CT chest	5.7–19.1
CT coronary angiography	50–80

detection with low-cost and is a low radiation dose procedure. Lee et al. (2010) reported that high image quality reduced the breast cancer mortality by up to 30%. During screening programmes, CC and MLO are used as standard projection for each breast. However, in this study three projections were used for each breast according to the department routine protocol (CC, MLO and LM projections). This variation in projections is due to the fact that during screening mammograms patients have no symptoms while in this study mammography is used only after suspicious signs of breast cancer are present after physical examination. Therefore, diagnostic procedures may require additional radiographic projection. In the present work, The MGD (mGy) per single projection for CC, MLO and LM was 1.02 ± 0.2 (0.4–1.8), 1.1 ± 0.3 (0.5–1.8), 1.1 ± 0.3 (0.5–1.9). The overall MGD per single breast was 3.22 mGy (Table 3). Mammographic image quality and MGD depend on imaging technique and the radiographic system used. The patient radiation dose per mammographic examination is lower compared to the previous published researches (Warren et al., 2016; Pasicz et al., 2016; Fartaria et al., 2016; Ślusarczyk-Kacprzyk et al., 2016;Soliman and Bakkari, 2015; Hauge et al., 2014; Al-Kafi et al., 2009; Dance et al., 2009; Smathers et al., 2007; Kruger and Schueler, 2001) (Fig. 2). The mean age in this study is 44.4 (26.0–69.0) years. This illustrates that a significant number of patients are young (Fig. 1). Therefore, a restricted justification criterion is recommended since 80% of the cases are with normal findings. Radiation exposure during mammography is the main source of cancer risk; therefore radiologists and gynecologists should consider other alternatives such as ultrasound for the procedure and use it as a clearly justified risk versus benefit approach. Table 4 shows a correlation between patient characteristics (breast thickness), exposure parameters with the ESAK and MGD. In contrast Olgar et al. (2012) reported that no correlation between breast tissues compressed thickness patient radiation dose (MGD) in projection imaging while a significant correlation was reported with 3D imaging. In mammography, it is an essential requirement to balance between tube potential and tube current and radiation dose. Lower exposure parameters within the range of photoelectric absorption of the tissue will improve the image quality with higher doses to the breast during mammography. This is especially valid for conventional radiography. However, in digital systems, because the image quality depends mainly on signal-to-noise ratio, thus higher exposure parameters may still provide acceptable image quality. Patient doses showed some variation, even with the procedure performed at the same X-ray machine (Table 3). This variation is explained according to the differences in the breast tissue of patients. As previously mentioned (Saggu et al., 2015; Yaffe and Mainprize, 2011; van Steen and van Tiggelen, 2007), breast density and thickness depend on patient age. Furthermore, the MGD is also less than the maximum dose per projection stated by FDA (3.0 mGy per projection) (FDA, 2017). The breast size and density, which affected by ethnic origin, is one of the main sources of high radiation dose. Thinner and denser breasts are found in Asian countries compared to Europe and North America (Geeraertt et al., 2012). Since exposure factors are a function of breast thickness, hence a possible variation in radiation dose is expected because radiation beam attenuation depends on breast size and density. Warren et al., 2016 reported that MGD of 3.0 mGy and 5.0–10.0 mGy for small and larger breasts, respectively. In the literature, Warren et al. (2016) stated that reduction of breast malignant tumors mortality due to screening programmes is overshadowed by the expected deaths due to radiation induced cancer. The radiation induced cancer due to mammography was estimated to be 177×10^{-6} or 2 cancer cases per 10,000 procedures for each breast. This risk is considered low compared to the accurate diagnosis that mammography can provide. Table 5, illustrate breast equivalent dose compared to other breast imaging modalities used for breast cancer detection and evaluation. The first group is X ray transmission imaging modalities which include mammography (contrast-enhanced digital mammography (CEDM, digital tomosynthesis mammography and dictography) computed tomography (CT). the second group is radionuclides imaging which includes scintimammography (SMM), positron emission tomography (PET) and single photon emission computed tomography (SPECT), positron emission mammography (PEM), and hybrid imaging modalities such as PET/MRI and PET/CT. The third group include non- ionising radiation imaging modalities such US imaging, thermography, magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (MRS), optical imaging and electrical impedance based imaging. The breast dose in nuclear medicine procedures (PEM, SPECT and BSGI) is lower compared to X ray imaging procedures (mammography and dedicated breast CT). Table 5 also provides comparison with CT chest and CT coronary angiography, where the breast is not the organ of interest in these investigations, were ranged between 2 and 25 times compared to mammography. Thus precise justification is required for these investigations to avoid radiation induced cancer for the breast. Despite the radiation risk, mammography is still used for early breast cancer detection, which depends on the perceived image quality that the system capable to provide. In the USA, a substantial reduction in mortality rate of approximately one third from 1989 to 2012 was achieved due to the early diagnosis rate (American Cancer Society, 2017). In recent years, digital breast tomosynthesis was introduced offering better 3D imaging, which eliminates tissue superimposition from the 2D technique, which yielded an increase in cancer detection, up to 40%. MGD is used to estimate the individual patient's risk from the procedures. However, this estimation is subject to a considerable level of uncertainty. The uncertainty is based on the dosimetry and extrapolation of an effective dose system, size of the breast, patient characteristics and variation between patients.

5. Conclusions

There is a statistically significant relationship at the level of significance (0.01) or less between the MGD and tube current time product (mAs) and breast thickness (mm). The cancer risk from this procedure is extremely low; nevertheless, repeated exposures will increase the cancer risk to a significant level. Therefore, precise justification is required for young patients. Patient doses are comparable or lower compared to previous studies. Revision of justification criteria is mandatory along with imaging protocol to eliminate the amount of procedures of normal findings (80%) and to reduce the unnecessary radiation exposure. Establishment of a diagnostic reference level (DRL) in Saudi Arabia for mammography will minimize the malignancy risk due to ionizing radiation to its lowest possible value.

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