EVALUATION OF THE RADIATION DOSE FOR MAMMOGRAPHY IN KING HUSSEIN CANCER CENTER, JORDAN

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by

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LIST OF SYMBOLS

C	The correction factor for breast formation
S	An X-ray spectrum correction factor
G	A conversion factor that describes the "K" fraction that is absorbed by the glandular tissue in the breast
K	The incident air kerma

LIST OF ABBREVIATIONS

AEC	Automatic exposure control
ACR	American college of Radiology
Al	Aluminum
BI-RADS	The Breast Imaging Reporting and Data System
CBT	Compression Breast Thickness
CC	Cranio Caudal
CF	Compression Force
DBT	Digital Breast Tomosynthesis
DRL	Diagnostic Reference Level
ESE	Entrance Skin Exposure
FFDM	Full Field Digital Mammography
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
JBCP	Jordan Breast Cancer Program
KHCC	King Hussein Cancer Center
kVp	kilovoltage peak
mAs	Milliampere-seconds
MBD	Mammographic breast density
MGD	Mean Glandular Dose
mGy	Milligray
MLO	Mediolateral Oblique
mm	Millimeter
Mo	Molybdenum
PACS	Picture Archiving and Communication System
Rh	Rhodium
R^2	R-square
W	Tungsten

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PENILAIAN DOS SINARAN UNTUK MAMMOGRAFI DI PUSAT KANSER KING HUSSEIN, JORDAN

ABSTRAK

Kanser payudara adalah jenis kanser yang paling tipikal di kalangan wanita. Sementara itu, mamografi ialah kaedah diagnostik yang paling banyak digunakan dan berkesan untuk pengesanan awal kanser payudara. Oleh kerana tisu payudara amat sensitif kepada sinaran, dos kelenjar min (MGD) ditentukan dengan menggunakan beberapa kriteria dos sinaran pendedahan khusus pemeriksaan payudara. Pesakit boleh menerima sekurang-kurangnya jumlah radiasi yang mungkin dengan kualiti imej yang membolehkan keterlihatan penemuan patologi. Hasilnya, Tahap Rujukan Diagnostik (DRL) telah diwujudkan untuk menyediakan parameter pendedahan optimum untuk menilai dan mengurangkan dos sinaran pesakit. Memandangkan tiada data tentang dos sinaran mamografi wujud di Jordan, kajian ini memberi tumpuan kepada penyediaan set data awal dengan menganalisis dos pesakit, purata dos kelenjar dan DRL dalam sembilan unit mamogram. Kajian itu terdiri daripada 3600 data untuk pesakit berumur 21 hingga 80 tahun dengan Ketebalan Payudara Mampat (CBT) 16.9 mm hingga 156 mm. Akhirnya, data dos sinaran pesakit dibandingkan dengan kajian lain yang diterbitkan dalam kajian litaratur. DRL untuk keseluruhan sampel dikira menggunakan persentil ke-75 dan ke-95 pembolehubah MGD. Nilai DRL di Jordan pada persentil ke-75 dan ke-95 ialah masing-masing 2.03 mGy dan 2.93 mGy. Seterusnya, nilai DRL untuk empat unjuran berbeza (pandangan kraniokaudal kanan (RCC), pandangan kraniokaudal kiri (LCC), pandangan serong mediolateral kanan (RMLO) dan pandangan serong mediolateral kiri (LMLO)) diwujudkan dalam kajian ini. Unjuran LMLO

mempunyai nilai DRL terbesar pada persentil ke-75 dan ke-95 MGD, iaitu 2.19 mGy dan 3.03 mGy. Begitu juga, nilai DRL untuk RMLO ialah 2.18 mGy dan 3.02 mGy pada persentil yang sama, iaitu lebih rendah sedikit daripada DRL untuk LMLO. Sementara itu, DRL untuk persentil yang sama untuk unjuran LCC dan RCC ialah 1.83 mGy dan 2.77 mGy dan 1.81 mGy dan 2.69 mGy dalam susunan tersebut. Nilai DRL di Jordan yang diperolehi dalam kajian ini adalah lebih rendah daripada DRL yang yang dinasihatkan oleh piawaian antarabangsa iaitu 3 mGy. Apabila keputusan daripada kajian ini dibandingkan dengan nilai DRL kajian lain, nilai persentil ke-95 didapati lebih tinggi sedikit, dan nilai persentil ke-75 didapati lebih besar di sesetengah negara manakala di negara lain kekal sama. Jadi, ia ternyata bahawa prestasi mamografi perlu dipertingkatkan. Akibatnya, pengoptimuman dos perlu diambil kira dalam praktis mamografi Jordan. Kesimpulannya, nilai purata MGD di Jordan ialah 1.6 mGy dan terdapat korelasi positif antara MGD dan CBT.

EVALUATION OF THE RADIATION DOSE FOR MAMMOGRAPHY IN KING HUSSEIN CANCER CENTER, JORDAN

ABSTRACT

Breast cancer is the most typical kind of cancer among women. Meanwhile, mammography is the most widely used and effective diagnostic technique for early detection of breast cancer. Since breast tissue is particularly sensitive to radiation, the mean glandular dose (MGD) is determined by utilizing several of the breast screening-specific exposure radiation dose criteria. The patient can receive the least amount of radiation possible with an image quality that allows for the visibility of pathological findings. As a result, the Diagnostic Reference Level (DRL) was established in order to provide optimum exposure parameters for assessing and reducing patient radiation doses. Since no data on mammography radiation doses exists in Jordan, this study focuses on preparing a preliminary set of data by analysing patient dose, average glandular dose, and DRL within nine mammogram units. The study comprised of 3600 data for patients aged 21 to 80 years old with a Compressed Breast Thickness (CBT) of 16.9 mm to 156 mm. Finally, patient radiation dose data was compared to other published studies in the literature. The DRLs for the entire sample were calculated using the 75th and 95th percentiles of the MGD variable. The DRL values in Jordan at the 75th and 95th percentiles are 2.03 mGy and 2.93 mGy, respectively. Following that, the DRLs values for four different projections ((right craniocaudal (RCC) view, left craniocaudal (LCC) view, right mediolateral oblique (RMLO) view, and left mediolateral oblique (LMLO) view) are established in this study. The LMLO projection has the greatest DRL values at the 75th and 95th percentiles of MGD, which are 2.19 mGy and 3.03 mGy.

Similarly, the DRL values for RMLO are 2.18 mGy and 3.02 mGy at similar percentiles, which are slightly lower than the DRL for LMLO. Meanwhile, the DRLs for the same percentiles for LCC and RCC projections are 1.83 mGy and 2.77 mGy and 1.81 mGy and 2.69 mGy in that order. The DRL values obtained for Jordan in this study are lower than the DRL that is advised by international standards 3 mGy. When the results from this study are compared with the DRL values of other studies, the 95th percentile value is found to be slightly higher, and the 75th percentile value is found to be greater in some countries while remaining the same in others. As a result, dosage optimization must be taken into account in Jordanian mammography practice. In conclusion, the mean MGD in Jordan is 1.6 mGy, and MGD and CBT have a positive correlation.

CHAPTER 1

INTRODUCTION

1.1 Background of study

Breast cancer is the most common type of cancer in female patients. It is the primary cause of cancer mortality among females (Bray *et al.,* 2018). Therefore, early detection of breast cancer is essential to enhance the chances of successful treatment. There is a variety of screening programs available to facilitate early detection. Mammography is the most reliable radiological test in screening programs to detect breast cancer (Suleiman *et al*., 2015). Early detection combined with proper treatment has been shown to reduce mortality by approximately 30% (Tabár *et al*., 2011). However, mortality due to breast cancer remains high, with a significant socio-economic and ethnic disparity (Harper *et al*., 2009).

X-ray mammographic techniques remain crucial to diagnostic procedures for both symptomatic and asymptomatic patients, especially for women over 50 years old, who comprise approximately 80% of breast cancer cases (Mello-Thoms *et al*., 2001). X-ray images can aid the differentiation between malignant tumors and benign conditions such as fibroadenoma, cysts, and mastitis (Chinyama, 2014). This ensures that suspicious features, including spiculated masses, microcalcifications, and architectural distortion, are distinctly confirmed and observed in mammography with high-quality images (Hakim, 2012).

However, X-ray imaging of the breast is faced with two key challenges. The first challenge is that significant biological changes within the breast that indicate cancer is frequently very subtle, and vital appearances such as microcalcifications require spatial and contrast resolution within the image that is generally higher than any other radiologic investigation. In order to maximize diagnostic efficacy, procedure and technical parameters must be carefully selected and applied. The second challenge is the radiosensitivity of the breast. Some of the most sensitive body cells are irradiated during the X-ray imaging procedure, often several times in a woman's lifetime. Hence, the International Commission on Radiological Protection (ICRP) introduced diagnostic reference levels (DRLs) as a parameter for quality control, dose-comparison, optimization, and limiting dose differences within diagnostic imaging centers (International Commission on Radiological Protection, 2, 2011). The procedures by which the DRLs are created have become essential for international comparisons as regards radiation dose measurements (Australian Radiation Protection and Nuclear Safety Agency, 2008a, 2014). The principle of maximum quality at the lowest risk to the patient is thus paramount in mammography.

Therefore, developing diagnostic reference thresholds is necessary for minimizing radiation doses. DRLs are tools for dose audits that generally provide medical physicists with the average dose delivered to the patients in each X-ray unit. Due to the differences in facilities and population features, the ICRP has recommended that DRLs be established at national, regional, and local levels to present orientations for dose optimization at each level. This prompts mammography centers whose mean doses surpass the recommended DRLs to consider optimization methods. Thus, DRLs are not maximum radiation doses that should not be exceeded but are aimed at providing a criterion for dose optimization across mammography facilities (Järvinen *et al.*, 2017). Nonetheless, adherence to best radiographic practices will ensure that radiation exposure values for individual X-ray tests of average-sized patients are not routinely exceeded. The standard way of establishing DRL data is through measuring radiation dose levels delivered for specific examinations in numerous hospitals in an individual country (Hart *et al*., 2002; National Radiological Protection Board, 1992). Using these data, examination-specific DRLs can be determined for that country, which represent the 75th percentile of the distribution of radiation dose limits or dose constraints to the medical exposure of patients (Vañó *et al*., 2017). Since different countries have different processes and facilities, each country should generate its DRL data rather than adopt data from other jurisdictions.

In addition, dose evaluation for mammography uses means glandular dose (MGD) because mammary glands have a relatively higher sensitivity to some adverse effects of radiation than skin and fatty tissues. There is a small risk of radiation-induced carcinogenesis related to the mammographic procedure, which has estimated the absorbed dose to the breast gland tissue as a vital aspect of quality control in the examination (Du *et al*., 2017). Mean glandular dose (MGD) is the recommended metric used by many authorities, such as the ICRP, the United States National Council on Radiation Protection and Measurements, the British Institute of Physics and Engineering in Medicine (IPEM), the European Council Protocol and the International Atomic Energy Agency (IAEA) (International Atomic Energy Agency, 2007). The International Atomic Energy Agency (IAEA) suggests a mean glandular dose (MGD) value of less than 3.0 mGy for a 42mm compressed breast composed of 50% glandular and 50% adipose tissues (Choi *et al*., 2010).

Breast cancer is the most frequent cancer among women and the most common cancer in general. In 2020, more than 2.26 million new instances of breast cancer were diagnosed in women, and there were 685,000 global deaths, breast cancer have been diagnosed in 7.8 million live women in the last five years and by the end of 2020 the most common cancer globally (World Cancer Research Fund International, 2021). Breast cancer is the most prevalent cancer in Jordan and the third leading cause of cancer mortality after lung and colorectal cancers, with the numbers steadily increasing (Ministry of Jordan, Jordan Cancer Registry, 2017). The Jordan Breast Cancer Program (JBCP) was established in 2007 and is supported by the King Hussein Cancer Foundation and Center and the Ministry of Health to facilitate regular mammography screening for average-risk women from the age of forty (Ministry of Jordan, 2017). At the program's onset, over 70% of breast cancer cases in Jordan were detected at advanced stages of the disease (stages III and IV), whereby survival rates are low, and treatment costs are much higher (JBCP, 2021). Interestingly, Jordan has one of the most developed healthcare systems in the Arab world, garnering patients from several surrounding countries for treatment (Abdel-Razeq *et al.*, 2020).

Several researchers have explored the risk factors associated with mammography screening in Jordan. For instance, Ammar & Alsater (2018) reported that first-degree family history of breast cancer is a strong predictor of breast cancer screening at the King Hussein Cancer Foundation and Center (KHCC) early detection clinic. Qatamish & Nusairat (2018) noted that increasing awareness among the community on breast cancer screening and early detection is pertinent to initiate a cycle of reducing the mortality and morbidity rate. However, DRLs do not exist in Jordan. In the absence of DRLs, large dose variations will occur, which is unacceptable for a radiosensitive organ such as the breast. Similarly, the MGD diagnostic parameter has not been entirely explored for Jordan. Hence, this study intends to evaluate the radiation dose for screening mammography in Jordan.

1.2 Problem statement

The risk and benefits of screening are constantly under scrutiny leading to worldwide debates regarding the eventual practicalities of screening programs, triggered by cost-economic considerations (Hendrick, 2010). Despite the growing number of breast cancer cases in Jordan, i.e., 13899 cases between 1996 and 2014, breast cancer research in Jordan has been relatively limited. This is imperative as breast cancer comprised 39.4% of cancer cases in females and 20.8% of all cancer cases among both genders (JBCP, 2021). A search from PubMed yielded 105 publications between 1985 and 2019, with only three papers published between 1985 and 1999 and 82 papers between 2010 and 2019 (Abdel-Razeq *et al.*, 2020). Until recently, no study had evaluated the radiation dose received in mammography examination in terms of DRLs in Jordan. Hence, there are currently no Jordanian DRLs as well as MGD values for mammography examination. Although DRLs have been reported in a variety of legislative documents in Australia and Europe and have been applied for general breast examinations in Europe and United States, DRL values are scarcely documented in the rest of the world (Australian Radiation Protection and Nuclear Safety Agency, 2008b; European Commission, 1997).

This absence of information on radiation doses in mammography in Jordan has thus prompted the need to evaluate the MGD and DRLs for dose assessment during mammography examination in Jordan, which will then be compared with international values. Moreover, the relationship between compressed breast thickness (CBT) and MGD has not been investigated in Jordan. This is vital as CBT can influence the MGD through several pathways representing diverse mechanisms. The measured DRLs and MGD will aid the optimization of radiation dose parameters for medical imaging facilities, thus ensuring that patients are protected from the risk of a high radiation dose, allowing for the safe and early detection of breast cancer. Thus, this research seeks to evaluate radiation doses and establish a DRL in Jordan to improve radiation doses to patients and ensure that they stay within reasonable limits for image quality and patient safety. This research evaluates radiation doses and establishes a DRL in Jordan. This research also provides a reference point that health institutions and other researchers in Jordan can refer to and update doses periodically as stipulated in international guidelines.

1.3 Objectives

This study develops the following research objectives:

(a) To establish of diagnostic reference levels (DRLs) for screening mammography in Jordan compared to international standard value of 3.0 mGy.

(b) To evaluate the correlation between mammography parameters and estimated the radiation dose for screening mammography in Jordan.

(c) To determine the average MGD value and investigate the relationship between MGD and compressed breast thickness (CBT) using full-field digital mammography (FFDM).

1.4 Scope of study

In this study, the safe radiation dose for screening mammography in Jordan will be evaluated based on DRLs and compared with international guidelines and published research in different countries. Data will be collected from the King Hussein Cancer Center, considered the most advanced center in the field of breast cancer care and mammography in Jordan. The mammography radiation dose will be analyzed based on the international guidelines for radiation dose in Jordan. The parameters that influence the radiation dose for screening mammography will be assessed. The study will also focus on determining the mean MGD for screening mammography in Jordan. Full-filed digital mammography (FFDM) will be used to investigate the relationship between compressed breast thickness (CBT) and MGD.

1.5 Thesis outline

This thesis comprises five (5) chapters. Chapter 1 entails a concise introduction to the thesis, comprising the study background, problem statement, significance of the research, objectives, and scope of the study, and a thesis outline. Chapter 2 reviews relevant literature as regards radiation dose for screening mammography, diagnostic reference levels (DRLs), and mean glandular dose (MGD). Chapter 3 entails the methodology developed to explore the objectives of the research. Chapter 4 comprises results and discussion from the evaluation of parameters that affect radiation dose for screening mammography in Jordan; the determination of DRL and MGD values and their comparison with different countries; and the relationship between compressed breast thickness (CBT) and MGD. Chapter 5 outlines the main conclusions and recommendations deduced from the results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides detailed knowledge of the anatomy of the breast, breast changes, mammographic breast density (MBD), radiation risk and benefit, mammography systems, mammography projections (RCC, LCC, RMLO, and MLO), patient position, compression force (CF), compressed breast thickness (CBT), tube voltage (kVp), tube current and exposure time product (mAs), the filters, entrance skin exposure (ESE), mean glandular dose (MGD), diagnostic reference levels (DRLs), automatic exposure control (AEC), image quality, and breast cancer in Jordan. It also discussed some similar scientific research that has been done.

2.2 Anatomy of the breast

Breasts are a pair of subcutaneous organs on the anterior thoracic that is entirely encased by the superficial pectoral fascia in an adult female. The breast is in front of the second to sixth ribs in the mid-clavicular line. The pectoralis major muscle connects the breast to the abdominal muscles serratus anterior and external oblique (Koshi, 2017). The glands that build up the female breast are supported by fat and fibrous tissue. Lobules refer to both the milk-secreting component of the gland and the tissues that support it. Clusters of lobules form the breast lobes. The lobes are separated by fibrous tissue sheets that go from the chest wall muscles to the skin. A single duct drains each of the lobes. The ducts link to openings on the top of the nipple. The nipple has 15–20 ducts that enter it. The lactiferous sinus, located just deep into the areola, is a dilated portion of each duct that receives milk during lactation. The alveoli that enter the smallest branches are also included in the smallest lobules. Genetic, ethnic, and nutritional factors and an individual's age, parity, and menopausal status all influence shape and size of the breast. Hemispherical, conical, piriform, or narrow and flattened breasts are all possible shapes (Bistoni & Farhadi, 2015). Figure 2.1 shows the anatomy of a female's breast.

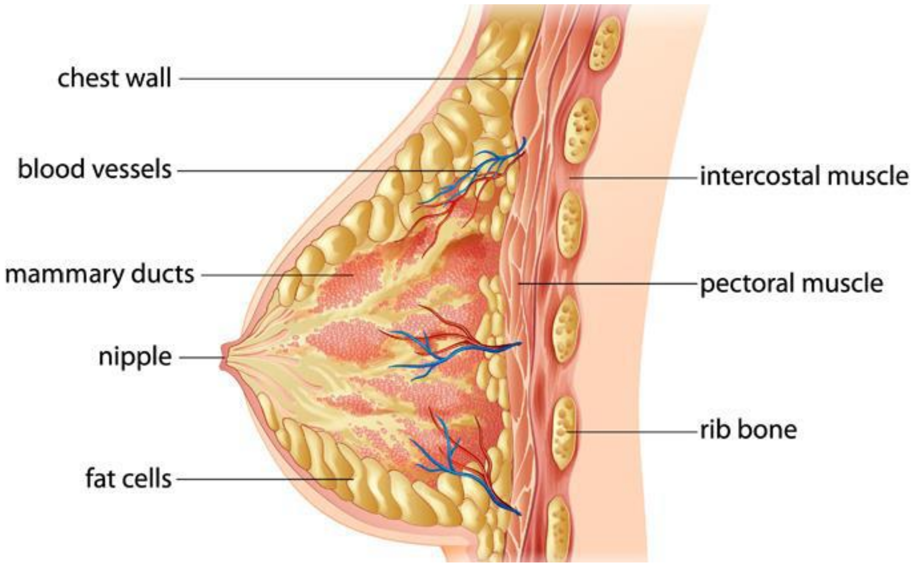

Figure 2.1 Anatomy of a female's breast (Moore, 2018).

2.3 Breast changes

In most females, breast consists of glandular and adipose tissues while adipose tissue gradually replaces glandular tissue from youth through maturity (Boyd *et al.*, 2007). Because of glandular development and fat deposition, female breasts get larger after menopause, as do the nipples and areolas. Breast size and structure are influenced by various genetic, cultural, and dietary variables (Gray, 2000; Moore, 2015).

The breast is a complex soft-tissue organ whose contents fluctuate over time, especially after menopause, throughout the menstrual cycle, during pregnancy, and as one gets older. On the other hand, menopause is followed by a natural and rapid decline in the body's oestrogen and progesterone production. The lack of hormonal stimulation causes a progressive decrease in glandular tissue and an increase in fatty tissue in the breast. Breast tissue is more receptive to diagnostic testing since it has a lower tissue density. As a result, tumor detection by mammography is more accessible in menopausal or premenopausal women than in young women (Ellis *et al.*, 2013). Menopause generally affects a woman in her late forties or early fifties, followed by a slew of symptoms related to oestrogen and progesterone depletion (Bistoni *et al.*, 2015).

Benign breast changes are more common in women of childbearing age, peaking between the ages of 30 and 50, whereas breast cancer is more common after menopause. Clinical, radiographic, and, if necessary, histological diagnostic studies to rule out malignancy, palliation of symptoms, and counseling and monitoring patients at elevated risk of breast cancer are all part of treating benign breast changes. Pain, a palpable mass, and nipple discharge are common presenting symptoms that require focused diagnostic imaging in addition to a thorough history and clinical examination (Walthers *et al.*, 2016).

The Breast Imaging Reporting and Data System (BI-RADS) was developed by the American College of Radiology (ACR) to standardize the terminology used to describe mammographic results and provide radiologists with a unified reporting process vocabulary, thereby reducing confusion and providing data for risk assessment and a standardized description of radiological results. BI-RADS is an extensively utilized and well-recognized system, as demonstrated in Table 2.1 (Tabár *et al.*, 2011).

Table 2.1 Adapted from the BI-RADS assessment categories for the characterization of radiological findings in the breast and the resulting management recommendations (Tabár et al., 2011).

BI-RADS category	BI-RADS code	Recommendation
Assessment incomplete	0	Comparison with previous images or further diagnostic investigations may be necessary
Negative	1	Refer for breast cancer screening
Benign	2	Refer for breast cancer screening
Probably benign	3	Shortened-interval follow-up (in 6 months)
Suspect	4	Histological study recommended
Highly suggestive of malignancy	5	Histological diagnostic confirmation and initiation of therapy required

2.4 Mammographic breast density (MBD)

Mammographic breast density (MBD) measures the amount of fibroglandular tissue in the breast relative to fat. It has been correlated to screening sensitivity and specificity and is recognized as an independent risk factor for breast cancer. Mammography, the initial breast cancer screening method, is a simple and quick means to determine breast density. In X-ray imaging, fibroglandular tissue (fibroblasts, epithelial cells and connective tissues) appears radiopaque (white), whereas fatty tissue appears radiolucent (black) (Bistoni *et al.*, 2015). Because it absorbs less X-rays, fat tissue appears black or radiolucent, while epithelial and stromal components show up white or radiopaque because they filter X-rays well and absorb more energy.

Mammographic breast density (MBD) is a subjective measurement of the absolute amount of dense tissue in the breast (absolute density) or a proportion of the mammogram that is composed of dense tissue. According to radiologist it is defined as, the ratio of the area of dense (white) tissue divided by the total area of the tissue (percent density). Breast tumors are also shown as radiodensity areas since they have the same X-ray attenuation coefficient as fibroglandular tissue. Regarding the relationship between MBD, age, and breast cancer, younger women should have higher cancer rates because their MBD is also higher. However, breast density on a mammogram represents the percentage of fibroglandular tissue. Breast density is one of the major contributors to false-negative screening mammography results as well as the primary reason for screening mammography's poor performance in younger women. Moreover, false-positive results have been associated to breast density. Breast density is a strong, independent predictor of breast cancer risk (Rhodes et al, 2015). The MBD measures the proportion of dense fibroglandular tissue to adipose tissue in the breast. For women with elevated MBD, the sensitivity of mammography is decreased because radiopaque fibroglandular tissue can conceal tumours. The MBD therefore captured the masking risk associated with heterogeneously dense and extremely dense breast tissue and provided some indication of the likelihood that tumours may be obscured (Destounis et al, 2017). Younger women therefore have a larger risk of acquiring concealed cancer since their breasts are denser than those of older women. Other factors that may influence breast cancer risk include geographic location, age at menarche, menopausal age, hormone replacement therapy, family history of breast cancer, body mass index (BMI), number of menstrual cycles, and socioeconomic status (Goh et al., 2021). Breast composition becomes less dense with a decrease in connective tissue volume due to physiological changes in the breast's glandular tissue with age, signaling reproductive maturation (Eklund et al., 2000). Mammographic breast density was divided into four categories: (a) nearly entirely fatty; (b) dispersed regions of fibroglandular density; (c) heterogeneously dense; and (d) very dense (Figure 2.2). Table 2.2 displays the glandular tissue percentiles for each breast (Ghieh et al., 2021).

The MDB term helps to describe circumstances in which dense breast tissue conceals tiny, underlying breast lesions with mammographic attenuation resembling fibroglandular tissue. Due to the lack of contrast, it might be difficult to interpret thick breast tissue on a mammogram, making it possible to miss tiny, noncalcified breast cancers that could otherwise grow into bigger tumors with lymph node involvement and lower survival rates, as shown in Figure 2.2 (d), which is extremely dense. MBD reduction enhances the sensitivity of mammography and promotes an earlier diagnosis by decreasing the chance of undetected small cancer in more dense breast tissue (Lester et al, 2022). Cancer is 4-6 times more likely to develop in women with breast density in category d (Figure 2.2 (d)) than in women with breast density in category a (Figure 2.2 (a)). The biological mechanisms by which MBD contributes to increased breast cancer are not known (Sherratt et al., 2016).

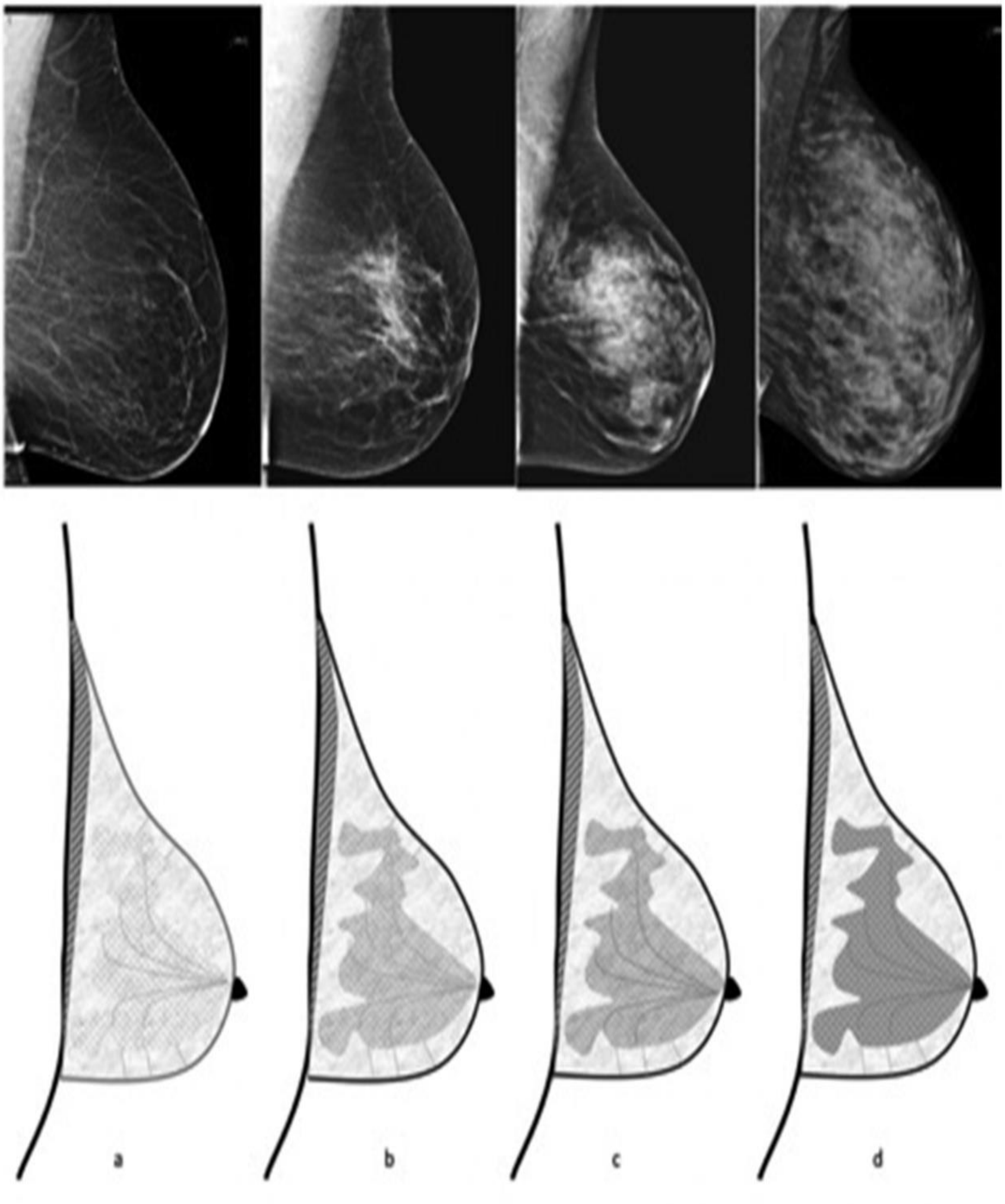

Figure 2.2 Breast composition densities on a mammogram with corresponding illustrations (a) mostly fat, (b) scattered fibro-glandular tissue, (c) heterogeneously dense, and (d) extremely dense (Ghieh *et al.*, 2021).

Table 2.2 Description of the breast density that differentiated breast fibroglandular tissue from fatty tissue.

Breast composition densities	**Description of breast density**
Type (a)	The breasts are almost entirely fatty (0%–25% dense tissues).
Type (b)	There are scattered areas of fibroglandular density (26%–50% dense tissues).
Type (c)	The breasts are heterogeneously dense, which may obscure small masses (51%–75% dense tissues, and many areas of fibrous and glandular tissue that are evenly distributed).
Type (d)	The breasts are extremely dense, which lowers the sensitivity of mammography (over 75% dense tissues, and breasts have a lot of fibrous and glandular tissue, which makes it hard to see a cancer because it can blend in with the normal tissue).

2.5 Radiation risk and benefit

Ionization is defined as the loss of one of an atom's orbital electrons. Two charged particles are produced when one electron is released: (i) the electrically negative free electron and (ii) the positively charged rest of the atom. These are referred to as ion pairs. Ionizing radiation has enough energy to damage cells by causing chemical changes. Certain cells can die or become abnormal for a short time or the rest of their lives. Radiation can cause harm to the cells of the body by damaging the genetic material (DNA). The amount and length of exposure and the exposure itself determine the severity of cell damage. In general, the amount and duration of radiation exposure influence the degree or type of health effect (Hendrick, 2010).

The risk of radiation-induced breast cancer is minimal in contrast to the benefits of early breast cancer detection (Yaffe *et al.*, 2011). Radiation fear is a common concern among women in the screening age group, and it is commonly cited as a reason why screening mammograms are not obtained. As women become more self-aware of their breast density, they may become less motivated to do a screening test that could potentially increase their risk of radiation-induced breast cancer if the test is of less help to them personally due to dense breast tissue (Nguyen *et al.*, 2018). Today's mammography X-ray equipment exposes the breast to significantly less radiation than previous models. The X-rays do not penetrate tissue as easily as those used in the normal chest, arm, or leg X-rays, which improves image quality (American Cancer Society, 2014). Beginning at the age of 40, yearly mammography has a lifetime risk of 1.3 to 1.7 fatal cancer cases per 100,000 women (Hendrick, 2010). Age at menarche and menopause, age at first pregnancy, family history, prior benign breast illness, and radiation are all risk factors for breast cancer (Dixon, 2006).

2.6 Mammography

Mammography is regarded as the most effective technique for the early detection of mammary cancer. The benefits of screening mammography have been well documented, and it has been proven to reduce breast cancer mortality by approximately 25% (Vainio & Bianchini, 2002). The use of digital mammography as a screening tool to find breast cancer at an early stage has enhanced the benefits and risks of this method of patient radiation protection, as well as the requirement to look at the dose of radiation received during screening mammography and the risk associated with it. However, the radiosensitivity refers to how sensitive cells or tissues are to ionizing radiation. Certain patients might be more radiation sensitive. Sensitivity is brought on by the radiotherapy's harmful side effects, which cause lesions in the patient's healthy tissues. Depending on when they first appear, these effects could be immediate or delayed (Borrego-Soto *et al*, 2015). Mammograms are currently one of the most widely accepted screening techniques and are widely regarded to have an essential role in breast cancer detection (Guo *et al.*, 2009). A mammography unit is an ideal device for a woman's breast examination. The mammography unit's components are the generator, the X-ray tube, the breast support, the compression paddle, and the receptor with its holder. Mammography is the most effective method for women with no breast cancer symptoms. There is also ultrasound and Magnetic Resonance Imaging as alternatives (MRI).

In today's clinical practice, radiologists must examine each patient's mammography for any abnormality, and doctors can use biopsy testing to establish if a tumor is benign or malignant. A diagnostic mammogram is often performed on a woman who has a breast issue, such as a tumor, skin changes, redness, nipple discharge, or an abnormal sign found on a screening mammogram. Women who have never had a breast issue but have had a breast mastectomy and have previously been treated for breast cancer are frequently screened with diagnostic mammography. Extra images can be taken if needed to look more closely at an area of concern or to analyze any changes detected between one year's mammography and the next, or for the symptomatic patient who may require further magnification, additional views, and/or breast ultrasound during a diagnostic mammogram because a radiologist evaluates the images. To make a significant region of concern simpler to examine, specific images such as exaggerated craniocaudal views (XCCL), axillary views, cleavage views, spot views, or magnification views are sometimes employed (American Cancer Society, 2014). During mammographic imaging, the radiographer prepares the patient, performs proper positioning, and applies compression force to lower breast thickness and spread breast tissue. In addition to the traditional imaging approach, there is the option of using a different imaging procedure.

2.7 Mammography projections

A routine mammographic screening examination requires a minimum of two exposures per breast. All exams should include imaging in two planes for the right (R) and left (L) breast: (i) CC view (Figure 2.3) and (ii) MLO view (Figure 2.4). Mammograms are performed by trained technicians and radiologists who perform them regularly. Mammography projections are used for assessing the size and position of the tissue being evaluated on the mammogram plate. The angle between these images shows how much tissue has been captured on each view, which helps to diagnose whether there are any abnormalities in the breasts.

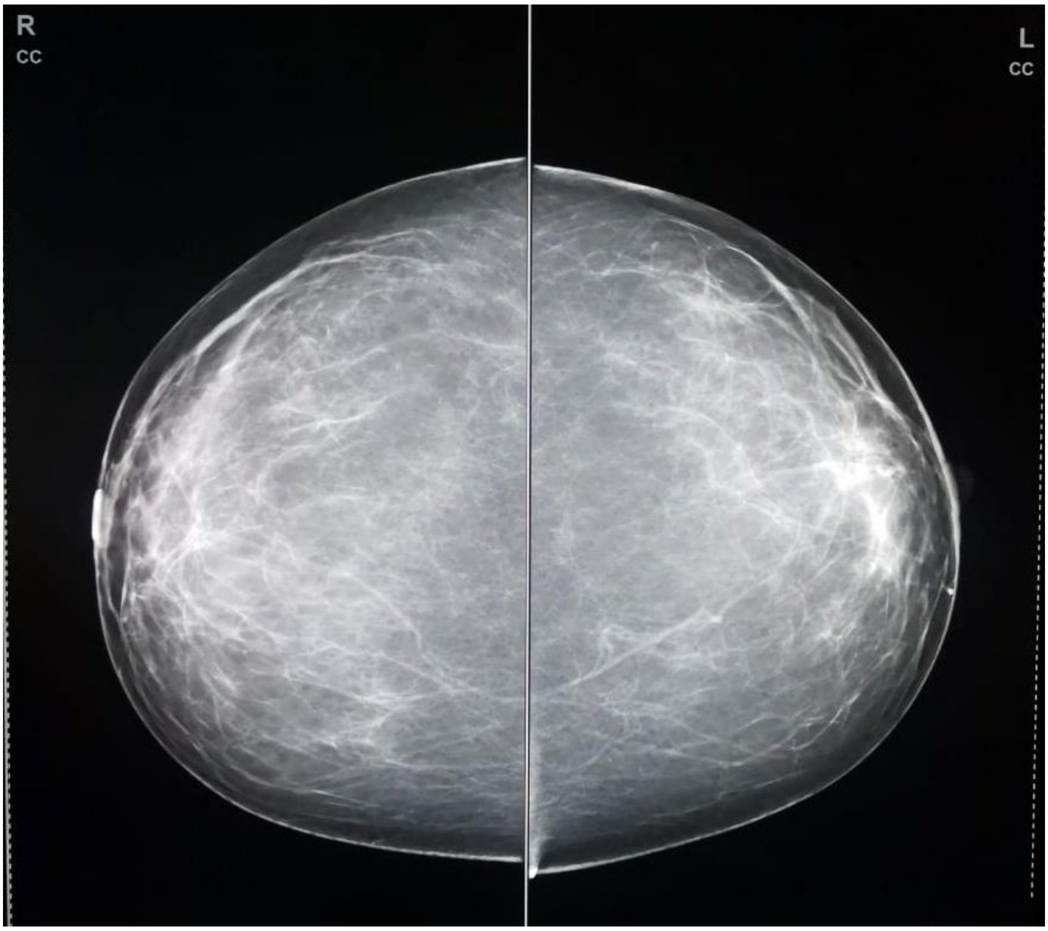

Figure 2.3 Right and left craniocaudal views (RCC & LCC) (KHCC, 2021).

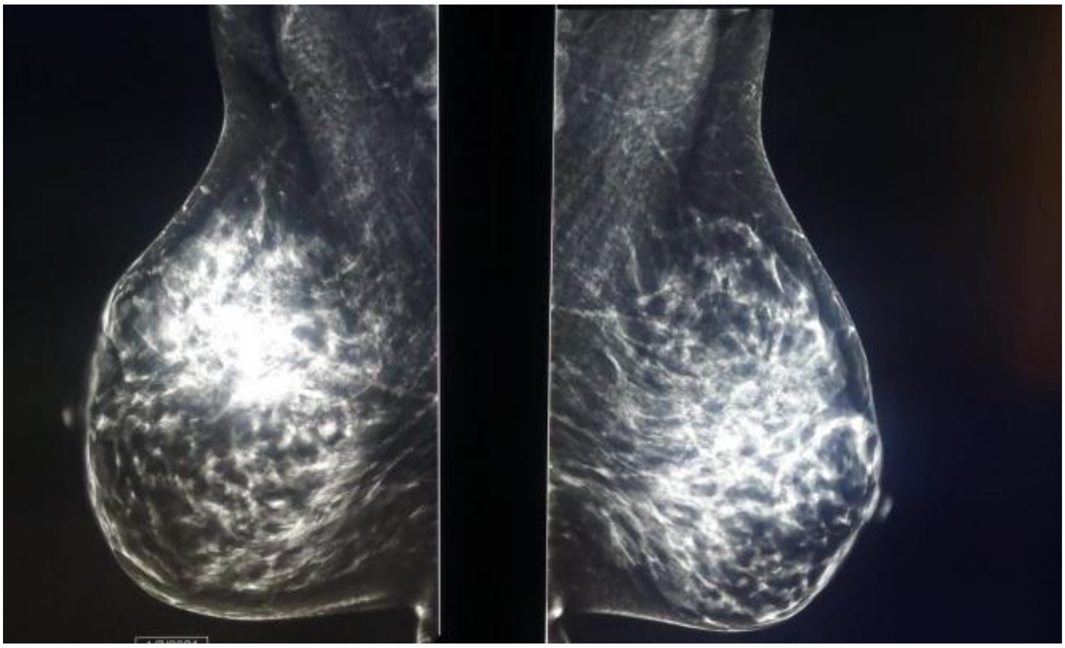

Figure 2.4 Right and left mediolateral oblique (RMLO & LMLO) (KHCC, 2021).

A CC image of the breast should ideally show maximal tissue on the medial and lateral sides, the retromammary space, and some pectoral muscle. On the CC view, the following points were examined: In (i), the nipple should be in profile; (ii) the nipple should point straight and not lateral or medial (Figure 2.4). The MLO projection is done at a 30° to 70° tilt from vertical, allowing for clear and good visualization of the entire breast and pectoral muscles. From this perspective, the majority of carcinomas may be detected. The MLO view is augmented by the CC view, which provides a complete view of the mammary glands. The x-ray tube is straight overhead in a CC perspective, with the beam moving from superior to inferior. All techniques need tissue compression. In the standard view, the compression paddle must match the image receptor's size, and full-field collimation is utilized to image the whole breast. Additional views should be used only when standard views are inconclusive. The axilla, axillary tail, inframammary fold, and all of the breast tissue should be seen in an MLO image. In an ideal MLO view, (i) the breast should be drawn out with the nipple in profile; (ii) the pectorals muscle margin should be visible; and (iii) the pectorals muscle margin should be well visible.

There is a link between the two points of view. In general, if a lump can be seen in one view, it can be seen in both. A radiologist or a computer-aided diagnostic system generally reads mammography pictures. If the doctor notices a worrisome lesion area in one of the images, he will compare it to the comparable region in the other view. Due to the superposition of breast glands, if the two regions are not identical, it is likely to be a false positive area (Li *et al.*, 2020).

2.8 Patient position

Breast position is essential in mammography and the clinical imaging of the breast that results since the ideal position increases the amount of breast tissue seen in the image (Watanabe *et al*, 2022). The breast is put in a natural anatomical position in mammography, with the nipple perpendicular to the chest wall, and this is applied to all testing techniques. Careful attention can be performed during the patient's placement to avoid artificial movement of breast tissues and periodic breathing movements to maximize imaging of tissues and avoid overlapping structures(Georgsson, 2003). The patient's breast was positioned on the support paddle with compression. Most mammographic artifacts may be eliminated, and mammography performance can be improved with careful patient position. The quantity of breast tissue in the image is maximized with optimal positioning. It is important to remember that when situating the patient, the entire body, not only the patient's breast, must be considered. Each patient's bodily habitus is distinct. For maximal tissue visibility, it must be analyzed and then corrections are made. It is critical to tilt the patient's head properly for CC view and raise the arm for the MLO view (Eklund, 2000).

The machine utilizes automatic exposure control, which means it automatically selects the exposure variables, such as kVp, mAs, and anode/filter combination, according to the granularity and thickness of the breast. Prior to exposure, the equipment also offers compressed breast thickness. After prepping the patient and deciding on a comfortable position, the examination was carried out. The breast was put on the pressure platform and squeezed to an appropriate thickness. A top-to-bottom view of CC and MLO from the middle of the chest to the side of the body using the X-ray tube at an angle are routine observations.

2.9 Compression force (CF)

The mechanical compression was achieved by moving the compression paddle toward the breast support until the desired breast thickness was reached. This value was equivalent to the compressed breast thickness recorded in the image header of the CC or MLO view image of the corresponding breast. The compression was performed in the craniocaudal direction to mimic the CC acquisition. In contrast, in the case of MLO acquisition, the breast was compressed at a 45° angle to the CC compression. Breast laterality was accounted for by flipping the breast to have the correct orientation during the compression (Garc´ıa *et al.*, 2020).

To maximize the amount of breast tissue that is included in the image, compression provides a clamping action that reduces anatomical motion during the exposure, thereby reducing this source of image un-sharpness. It is important that the breast is compressed as uniformly as possible and that the edge of the compression plate at the chest wall be straight and aligned with both the focal spot and image receptor. Because the mechanical characteristics of the breast are non-linear beyond a certain thickness reduction, applying more pressure does not affect picture quality and adds to patient pain. Several manufacturers have devised specialized mechanisms in an attempt to provide greater compression while reducing the risk of excessive compression (Dance, 2014).

Breast compression is performed by placing the breast on a support above the detector and using a thin, transparent compression paddle to keep it in position. By changing the natural curve of the breast to establish a constant thickness, a homogenous signal is generated throughout the imaging. Image quality is improved due to reduced tissue superimposition and x-ray dispersion a lower average glandular dose (AGD) to the breast tissue, and less geometric blurring/motion unsharpness (Branderhorst *et al.*, 2015). A proper application of compression force is one of the criteria for producing high picture quality in mammography. Compression force is generally measured in Newton (N).

2.10 Compressed Breast Thickness (CBT)

The relative risk associated with breast density is substantially larger than the relative risk associated with a family history of breast cancer or any menstrual and reproductive risk factors (Green *et al.*, 2016). Extensive mammographic density may also make breast cancer more difficult to detect by mammography and thus increases the risk of the development of cancer between mammographic screening tests (Boyd *et al.*, 2007). In a mammogram, a tumor appears similar to dense tissue, which may make it difficult to detect a tumor directly. Several studies have indicated a significant correlation between breast density and the development of breast cancer, women with a dense breast being six times more likely to develop cancer. Dense breasts usually contain more glandular and fibrous tissue (Rampun *et al.*, 2020). Breast density has a wide variation across the population, including among women of the same age. It has been shown to influence the risk of breast cancer in whites, African Americans, Asian Americans, and Asians (Ursin *et al.*, 2003).

The compression of breast tissues helps minimize the blurring of motion, separates structures within the breast, and reduces the thickness of the breast tissue. This decreases the radiation required and scattered that reaches the image receptor. For high-quality mammography, an adequate compression of breast tissues is critical. Compression decreases the thickness of tissue that radiation must penetrate, thus decreasing scattered radiation and increasing contrast while reducing the breast tissues exposed to radiation. Compression also makes the breast thickness more uniform, leading to more uniform image densities and thus may be easier to interpret. The compressed breast thickness displayed is often used to select the technique variables, so it is important to achieve this level of accuracy (International Atomic Energy Agency, 2007). Compressed breast thickness is generally measured in millimeters mm.

2.11 X-ray peak tube potential (kVp) and X-ray tube current - exposure time product (mAs)

The difference in potential delivered to the X-ray tube is known as kVp. The average energy of the X-ray spectrum generated is referred to as X-ray quality and is directly proportional to kVp. In an acquisition, kVp is used to modify the amount of penetration and exposure. The quantity of photons reaching the image receptor to distinguish between structures is known as penetrance. Radiation dose, exposure, and contrast are all affected by changes in kVp. In addition, when kVp increases, the dose also increases correspondingly. Exposure doubles in intensity for every 15% increase in kVp, but contrast decreases as kVp increases (Sy *et al.*, 2020). A mammography machine is intended to produce a beam of radiation between 35 and 40 kVp, which is appropriate for imaging soft tissue. Anodes made of molybdenum (Mo) and tungsten (W) are used to generate a low-energy X-ray beam. Rhodium (Rh), aluminum (Al), and Mo are frequently utilized as filters to exclude undesirable energy beams to get a specific range of beam energy. Previous research has found that using W and Rh as anode and filter (W/Rh) in conjunction with low tube kVp values produces the highest image quality in mammography (Alkhalifah *et al.*, 2017; Varjonen *et al.*, 2008). The Mo filter, which can be utilised in combination with a Mo target (Mo/Mo), is one of