ASSESSMENT OF MEAN GLANDULAR DOSE TO PATIENTS FROM DIGITAL

MAMMOGRAPHY SYSTEMS

A THESIS PRESENTED TO THE

DEPARTMENT OF MEDICAL PHYSICS

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

UNIVERSITY OF GHANA

BY

CAROLINE KACHANA PWAMANG

ID: 10507467

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF A

MASTER OF PHILOSOPHY DEGREE IN MEDICAL PHYSICS

JULY, 2016

DECLARATION

This thesis is the result of research work undertaken by CAROLINE KACHANA PWAMANG in the Department of Medical Physics, School of Nuclear and Allied Sciences, University of Ghana under the supervision of Dr. Mary Boadu, Prof. Cyril Schandorf, and Mr. Edem Sosu.

………………………………….. ……………………………..

CAROLINE KACHANA PWAMANG Date

(Student)

……………………………… ....

DR. MARY BOADU Date

(Principal Supervisor)

………………………… ……………………………..

PROF. CYRIL SCHANDORF Date

(Co-Supervisor)

………………………… ……………………………

MR. EDEM SOSU Date

(Co-Supervisor)

ABSTRACT

Mean glandular dose assessment of patients undergoing digital mammography examination has been done. A total of 297 patient data was used for the study. Basic Quality Control tests were done to ascertain the performance of the equipment used. The results of Quality Control tests indicated that the three Mammography units used for this study were functioning within the internationally acceptable performance criteria. Patients with a breast thickness of 30 mm within the two age groups of .40-49 yrs and 50-64 yrs received doses slightly higher than the acceptable dose levels. A patient in the category 40-49 yrs with breast thickness of 30 mm received 1.83 mGy as calculated Mean Glandular Dose, 2.10 mGy was the recorded dose and 1.58 mGy was recorded under the age group 50-64 yrs. These values have deviated by -22%, -40%, and -5.33% respectively from 1.5 mGy which is the recommended dose for a breast thickness of 30 mm. Also patients with breast thickness of 70 mm under the age group 40–49 yrs had a recorded dose of 6.58 mGy, which deviated by -1.21% from the recommended value of 6.5 mGy for that breast thickness. Aside these values, all the other values were within the recommended dose values. The percentage deviation between the recommended values and the calculated values was within ±25% which was a working limit that was set for this work. Doses delivered by the Full-field Digital mammography equipment were higher than doses delivered by the Computered Radiography equipment. The calculated Mean Glandular Doses for the three facilities were within recommended dose values.

DEDICATION

I dedicate this work to my Husband, Mr. Neumann Jampanah, my children, Ancilla Bendowe Jampanah and Archibald Neumann Asaliwe Jampanah Jnr, and my mother Madam Gertrude Latinga, for their love and support.

ACKNOWLEDGEMENTS

I am most grateful to my supervisors; Prof Cyril Schandoff, Dr. Mary Boadu, and Mr. Edem Sosu, for their directions, guidance and corrections made on this work. I acknowledge my husband for his immense contribution to the success of this work; my thanks also go to my mother, Madam Gertrude Latinga and my uncle, Justice Gabriel Pwamang for their support during my MPhil program. My appreciation goes to my mother in-law for her assistance, Dr. Francis Hasford from RAMSRI and Mr. Emmanuel Akrobortu from RPI for their assistance. My special thanks go to the staff of the mammography units at Korle-Bu Teaching Hospital, Trust Hospital, and Supreme Specialist Centre. Finally, am highly indebted to Prof. Augustine Kwame Kyere, the head of department for the Medical Physics Department, for his support during my MPhil program.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS

ACR	American College of Radiology
AEC	Automatic Exposure Control
ALARA	As Low As Reasonably Achievable
BI-RADS	Breast Imaging Reporting and Database System
CB	Compressed Breast
CBT	Compressed Breast Thickness
CC	Craniocaudal
COV	Coefficient of Variation
CR	Computed Radiography
DNA	Deoxyribonucleic Acid
DR	Digital Radiography
DRLs	Diagnostic Reference Levels
ENS	European Nuclear Society
EPA	Environmental Protection Agency
ESAK	Entrance Surface Air Kerma
ESE	Entrance Skin Exposure

FFDM	Full Field Digital Mammography
HVL	Half Value Layer
IAEA	International Atomic Energy Agency
IAK	Incident Air Kerma
ICABME	International Conference on Advances in Biomedical Engineering
KBTH	Korle-Bu Teaching Hospital
LCC	Left Craniocaudal
LMLO	Left Medio-Lateral Oblique
MGD	Mean Glandular Dose
MLO	Medio-Lateral Oblique
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NBCF	National Breast Cancer Foundation
OD	Optical Density
PMMA	Polymethylmethacrylate
PSP	Photostimulable Storage Phosphor
QA	Quality Assurance
QC	Quality Control
RCC	Right Craniocaudal
RMLO	Right Medio-Lateral Oblique
RPOP	Radiation Protection of Patients
SD	Standard Deviation
SID	Source-to- Image Distance
SSC	Supreme Specialist Centre
TH	Trust Hospital
USA	United States of America

WHO	World Health Organisation

CHAPTER ONE

1.0 Overview

This chapter provides a background to cancer in general and breast cancer in particular. It talks about the importance of early detection of breast cancer, the use of mammography for the early detection, and the risk of radiation dose to patients from digital mammography systems in general. It focuses on the statement of the problem and defines the objectives that should be achieved to fulfill the requirement of the study scope. Relevance and justification of the work is also developed in this chapter.

1.1Background

1.1.1 The female breast

The adult female breast (figure 1.1) sits atop the pectoralis muscle (the "pec" chest muscle), atop the ribcage (Argani et al). It extends from just below the collarbone (clavicle), to the armpit (axilla) and across to the breastbone (sternum). It is composed of glandular, fatty and connective tissue. It is made up of lobules (glands that produce milk), ducts (tubes that carry milk from the lobules to the nipple), fatty and connective tissue (surrounds and protects the ducts and lobules and gives shape to the breast), areola (the pink or brown, circular area around the nipple that contains small sweat glands, which secrete moisture as a lubricant during breast-feeding and nipple (the area at the centre of the areola where the milk comes out) (Marieb, 2006).

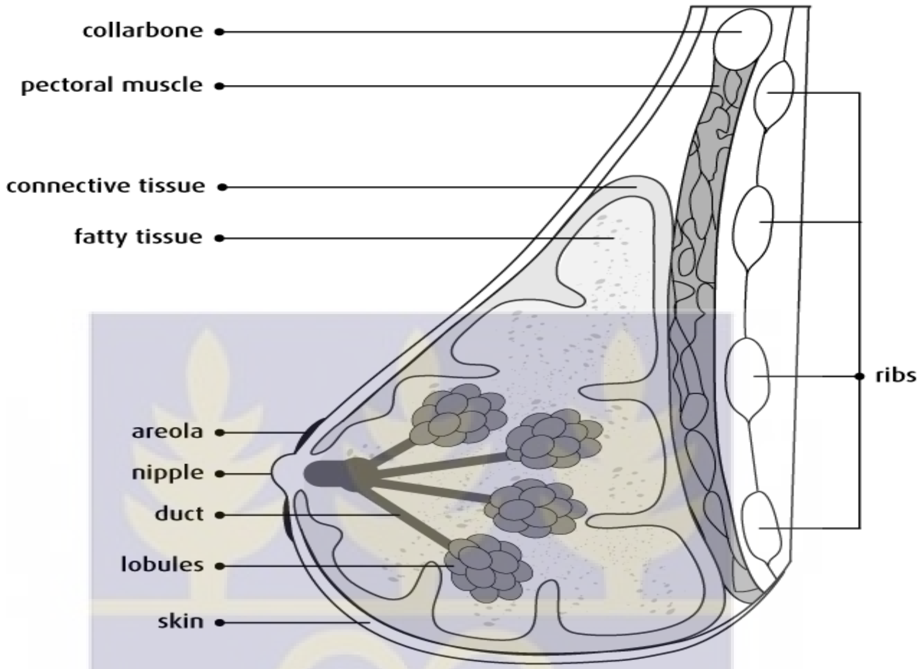

Figure 1. 1: Anatomy of the adult female breast

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter provides an overview of mammography and digital mammography dose assessment in particular, previous work done worldwide on conventional and digital systems.

2.1 Mammography Overview

Mammography is a radiological examination of the breast. The main purpose of mammography examination is for the early detection of breast cancer (Dellie et al., 2012). While it is used primarily for the detection and diagnosis of breast cancer, mammography also has value in pre-surgical localization of suspicious regions and in the guidance of biopsies. The X-rays used in mammography are produced from molybdenum, rhodium or tungsten or a combination of any two of them as anode or target material. Most mammography tubes use beryllium exit windows between the evacuated tube and the atmosphere. The X-ray beam is produced when relatively large amounts of electrical energy is transferred from the cathode and collide with the target or anode material. Only a small fraction (typically less than one percent) of the energy deposited in the tube is converted to X-rays producing bremsstrahlung and characteristic X-rays. The remaining ninety-nine percent of the energy is converted into heat. This excessive heat produced in the X-ray tube can damage it by melting anodes and rupturing tube housing. To avoid excessive heating of the anode material, most X-ray tubes are mounted on tube housing which provides mechanical support and also serve as a container to store oil or water used to cool the anode during operation. Metallic filters are used to provide selective removal of low X- ray energies from the beam before it is incident on the patient. In mammography, a molybdenum anode X- ray tube is commonly used with a molybdenum filter. This filter acts as an energy window providing greater attenuation of X- rays both at low energies and high energies, while allowing the molybdenum characteristic X- rays from the target and X- rays of similar energy produced by bremsstrahlung to pass through the filter with relatively high efficiency.

Mammography can either be for screening or diagnostic purposes (Dance et al., 2014).

2.1.1 Screening Mammography

Screening mammography is a radiological examination used to detect unsuspected breast cancer in asymptomatic women, i.e. women who do not show any signs or symptoms of breast cancer. The aim of a screening mammogram is to find breast cancer when it's still too small to be felt by a woman or her doctor, and to reduce the occurrence of far-advanced breast cancer in general. It is widely known that breast cancer can be induced by high doses of ionising radiation, such as X-rays, and the probability of induction is believed to be dependent on dose. Breast cancer induction decreases with increasing age at exposure, therefore it is advisable to set the age range for screening programs at an older age. The American College of Radiology (ACR) recommends a baseline mammogram by age 40, twice yearly examinations between ages 40 and 50, and once yearly examinations after age 50. For high risk factor women, screening mammography can be implemented at an earlier age. During screening mammography, two X-ray images (views) are taken, the cranio-caudal view and mediolateral oblique view, except in the case of women with large breasts where more views are taken to see as much breast tissue as possible (ACR, 2003).

2.1.2 Diagnostic Mammography

Diagnostic mammography is used after suspicious results on a screening mammogram or after some signs of breast cancer alert the physician to check the tissue. During a diagnostic mammography, more X-ray images are taken, providing views of the breast from different angles. Magnification mammography may be undertaken to zoom into a specific area of the breast where there is a suspicion of an abnormality. This gives a better image of the tissue for more accurate diagnosis (NBCF, 2015).

Screen-film/conventional mammography and digital mammography are the two main mammography systems most commonly used for the detection and diagnosis of breast cancer.

2.1.3 Screen-Film Mammography

Screen-film/Conventional mammography was invented in 1969. In screen-film mammography, a high resolution fluorescent intensifying screen is used to absorb the X-rays and converts the pattern of X-rays transmitted by the breast into an optical image. These screens are used in conjunction with single emulsion radiographic film, enclosed within a lightproof cassette. The formation of the X-ray image on the film process includes the X-ray beam emerging from the patient being converted into a pattern of visible light by the cassette's intensifying screen, and the visible image is then captured permanently on the film. Upon chemical development of the film with a processor, the emulsion that contains the latent X-ray image is converted into specks of metallic silver. The screen and film are arranged such that the X-rays pass through the cover of the cassette and the film to impinge upon the screen. Absorption is exponential, so that a larger fraction of the X-rays are absorbed and converted to light near the entrance surface of the screen. The screens are often constructed with rare earth phosphors such as gadolinium oxysulfide (Gd_2O_2S). X-rays that pass through the tissue are collected by the phosphor screens and converted to light. The film is positioned very close to the screen to capture the light photons; the image is then obtained by exposing the film. Films have significant disadvantages and limitations which include the lack of ability to detect small differences in contrast. The poorly exposed nature of images due to the film's stringent requirements for proper exposure which leads to repeated exposures and reduced visibility of microcalcifications. There is also an increase in the examination time due to the chemical processing of film, they require large storage space in patient health records, and must be transported physically to the physician for viewing (Haus and Yaffe, 2000).

2.1.4 Digital Mammography

Digital mammography which was introduced in early 2000 also uses X-rays to produce images of the breast, but unlike the screen-film system, there is a detector that converts the X-rays to digital images and they are stored directly in a computer. In digital mammography, image acquisition, processing, display and storage are performed independently, allowing optimization of each. Acquisition is performed with low noise X-ray detectors having a wide dynamic range. As the image is stored digitally, it can be displayed with contrast that is independent of the detector properties and defined by the requirements of the particular imaging task**.** There are currently two types of digital mammography systems: computed radiography (CR) which uses indirect digital detectors, and digital radiography (DR) which uses direct digital detectors. With a CR system, the X-rays transmitted through the breast are absorbed by the CR imaging plate, a Photostimulable storage phosphor (PSP). Absorbed X-ray energy corresponding to anatomical variations in the breast produces an electronic latent image on the PSP. The cassette is then removed from the mammography system and placed in a CR reader with a scanning laser beam that stimulates the release of light corresponding to the incident X-ray intensity. The light information is captured, converted to a digital signal, and displayed at the workstation. However, with the DR system, the X-ray signal is directly converted to a digital signal at the acquisition stand. No cassette is used. The image is displayed at the workstation shortly after it is acquired (Seibert, 2013).Digital mammography systems offer a number of practical advantages and patient conveniences over conventional systems. Digital images are immediately available, therefore reduces the waiting time. The quality of the images can be evaluated as they are being taken, digital systems are fast, so patients spend less time in uncomfortable positions.Contrastof the images can be adjusted and sections of an image can be magnified after the mammogram is complete making it easier to see subtle differences between tissues. Digital images can easily be stored and retrieved and their transmission from one physician to another is quick and easy, multiple copies can easily be printed with the digital system (Chevalier et al., 2012).

2.2 COMPONENTS OF MAMMOGRAPHY EQUIPMENT

The mammography equipment consists of an X- ray tube and an image receptor mounted on opposite sides of a mechanical assembly, a filter, breast compression plate, Automatic Exposure Control (AEC), source to image distance, grids and magnification. Because the breast will be imaged from different angles, the assembly can be rotated about a horizontal axis. Its elevation can also be adjusted to accommodate patients of various heights. The mammography system's geometry is arranged such that, a vertical line from the focal spot of the X-ray source grazes the chest wall of the patient. This is to ensure that most, if not all the tissue near the chest wall will be imaged.

2.2.1 X-ray Tube

In mammography, the X-ray tube is usually operated at a kilovoltage of 25 to 32 kVp with molybdenum and rhodium as target materials in the anode. Both molybdenum and rhodium are used as target materials in the anode because they produce characteristic X-ray radiation at optimal energy levels. The mammography X-ray beam consists of bremsstrahlung and characteristic X-rays. Molybdenum has characteristic x-rays of 17.9 and 19.5 keV, while rhodium has characteristic x-rays of 20.2 and 22.7 keV (Bick and Diekmann, 2010).The slightly higher energy x-rays from rhodium provide better penetration of thicker or denser breasts. To reduce exposure times, typical x-ray tube currents are usually high, between 80 and 100 milliamperes (mA). Exposure times are usually about 1 second, but may be as long as 4 seconds for dense, thick breasts. In mammography, the X-ray tube is arranged such that the cathode side of the tube is adjacent to the patient's chest wall (anode heel effect), this is because the highest intensity of X-rays is available at the cathode side and the attenuation of X-rays by the patient is generally greater near the chest wall (Dance et al., 2014).

2.2.2 Compression Plate

The breast compression plate is a stiff polymethyl methacrylate device that is usually positioned parallel to the surface of the image receptor. A good breast compression is an important factor in mammography imaging. A number of benefits are associated with good breast compression. Compression generally results in greater sharpness, less scatter, and reduced patient dose. Spot compression, or dual focus compression, may be used to achieve maximum compression in a limited region of interest. It reduces the thickness of the breast and allows low peak voltages to be used, thereby improving subject contrast, compression spreads the breast tissue out, making pathologic conditions easier to detect.

Compression reduces exposure times, thus minimizing patient motion blurs and film reciprocity law breakdowns associated with long exposure times. The only disadvantage of compression is patient discomfort (Dustler et al., 2012).

2.2.3 Filters

Filtration is the process of attenuating and hardening an X-ray beam. A filter is a material placed in the useful beam to absorb radiation based on energy level or to modify the spatial distribution of the beam. Filtration is required to absorb the lower-energy X-ray photons emitted by the tube before they reach the target. This is because low-energy X-rays cannot penetrate the object being examined to help produce the desired image, they may degrade the image by increasing scatter, and may increase the dose delivered. The use of filters produces a cleaner image by absorbing the lower energy x-ray photons that tend to scatter more (Yaffe et al., 2012).

2.2.4 Grids

Scattered radiation reduces contrast in all radiographic images. High contrast is especially important in mammography where cancerous tissue and normal tissue appear quite similar since the densities of the tissues are almost the same. In the imaging of dense or large breasts, image contrast can be reduced by scattered radiation from the breast. The scatter-to-primary ratio for a breast of average size and density can be 0.6 or greater (Gray and Princehorn, 2011). Reducing the effects of scattered radiation has been achieved through the use of scatter absorbing grids. To offset the reduction in X-rays caused by the grids, an increase in the mAs to about 2 to 2.5 times the value for non-grid techniques is required. The increase in mAs increases patient dose. The grid should have a high transmittance of primary radiation; this is to avoid excessive increase in patient dose. For this reason, carbon-fibre covers and fibre-interspace materials are often used.

Since low energies are used in mammography, it is essential that the covers be of uniform construction so that structural artifacts are not introduced. There are two types of grids: stationary and moving grids. Stationary grids are high strip density grids with extremely fine grid lines (approximately 80 grid lines/cm). In mammograms produced with stationary grids, grid lines are evident upon close inspection and may interfere with the perception of small, subtle microcalcifications. Moving grids are thinner and have carbon fibre interspace material. Moving grids may produce grid lines in cases where the exposure only takes place over a few oscillations of the grid, It is therefore important that the grid assembly be sufficiently rigid that grid motion is not impeded when the breast is under vigorous compression. Most modern mammographic X-ray units are designed with moving grids to blur the grid lines thereby reducing its presence in the image. Moving grids are essential because they produce good image quality despite the associated increase in patient dose. The increase in patient dose associated with the use of grids may be reduced by using higher tube voltage settings, using higher speed recording systems, and increasing the X-ray beam filtration (Assiamah, 2004).

2.2.5 Automatic Exposure Control (AEC)

AEC, also known as phototiming, is designed to automatically provide the radiation exposure needed to produce a mammogram with an acceptable and consistent optical density. It is an operation mode of an X-ray machine by which the tube loading is automatically controlled and terminated when a preset radiation exposure to a dose detector located under the image receptor is reached (Huda et al., 2003). Most mammographic X-ray units have automatic exposure control systems. In mammography, the AEC detector is normally located behind the image receptor, this is because placing it in front would attenuate the X-ray beam too severely and cast its own X-ray shadow. The shadow is significant especially at the low X-ray energies used in mammography. When it is placed behind, the amount of X-ray flux reaching the controlling detector is influenced strongly by absorption in the image receptor, which is highly dependent on the energy of the X-ray photons emerging from the patient. The AEC should be capable of maintaining optical density within ± 0.15 OD as the peak kilovoltage is varied from 25 to 35; and as the breast thickness is varied from 2.5 to 8 cm for each technique. A range of density selections are available. Also, there are adjustments to provide proper compensation for different film-screen combinations. Exposure is terminated when the radiation dose received by the detector reaches a pre-determined level which corresponds to the desired optical density. For many mammography units, the position of the radiation detector can be varied between two or more predetermined positions to facilitate the exposure of breast of different size and density (Assiamah, 2004)

2.2.6 Magnification

A magnification is the enlargement of a suspicious area of a mammogram. A magnification view is performed to evaluate and count microcalcifications, and assess the borders and tissue structures of the suspicious area or mass by using a magnification device which brings the breast away from the film plate and closer to the x-ray source. This allows the acquisition of magnified images of the region of interest (Hacking et al., 2000).

2.2.7 Source-to-image distance

This is the entire distance of the X-ray beam from the focal spot (source) to the image receptor, the greater the distance, the lesser the occurrence of geometric blurring. This affects the focal spot size, which in turn affects the size of the object being imaged. The larger the SID, the larger the field size. With a larger source to image distance (65cm), more beam penetrability is required, which in turn increases the heel effect (Barnes et al., 1990).

2.3 Interactions of X-rays with Matter

X-ray photons are created by the interaction of energetic electrons with matter at the atomic level. X-ray photons end their lives by transferring their energy to electrons contained in matter. X-ray interactions are important in diagnostic examinations for many reasons. For example, the selective interaction of X-ray photons with the structure of the human body produces the image, and the interaction of photons with the receptor converts an X-ray image into one that can be viewed or recorded. As an X-ray beam passes through matter, there are three possible outcomes, it can penetrate the section of matter without interacting, it can also interact with the matter and be completely absorbed by depositing its energy, or it can interact and be scattered or deflected from its original direction and deposit part of its energy (Sprawls, 2014). There are two kinds of interactions through which photons deposit their energy into matter, by photoelectric effect, where the photon loses all its energy into the object, or by Compton scattering, where the photon loses a portion of its energy into the object and the remaining energy is scattered. Other possible interaction mechanisms are Rayleigh scattering and pair production. However, photoelectric effect, Compton scattering and pair production are the most important interactions in radiation dose measurements as they lead to partial or complete transfer of photon energy to electron energy which in turn transfer energy into matter. In photoelectric effect, the incident photon has energy that is slightly higher than the binding energy of the atomic electron. In this process, the photon transfers all of its energy to an inner shell electron and ceases to exist. The inner electron escapes its orbit with a kinetic energy equal to the difference between the photon energy and its own binding energy. With Compton scattering, the photon interacts with an outer shell electron. The electron is ejected from its orbit by a sufficient amount of energy with the photon retaining a portion of its original energy. It then moves in a new direction. In Rayleigh scattering, when the photon interacts with an atom, it may or may not impart some energy to it. The photon may be deflected with no energy transfer. This occurs for very low-energy photons. In pair production, photons with energy greater than 1.024 MeV are converted into an electron and a positron under the influence of the electromagnetic field of a nucleus. The relative importance and efficiency of each process strongly depends on the energy of the photons and on the density and atomic number of the absorbing medium (Assiamah, 2004).

2.3.1 Effects of Radiation

There are two types of radiation; non- ionizing and ionising radiation. Non-ionising radiation refers to any type of electromagnetic radiation that does not carry enough energy per quantum to ionise atoms or molecules, which is to completely remove an electron from an atom or molecule. Examples are microwaves, ultraviolet light, lasers, radio waves, infrared light, and radar. Ionising radiation consists of subatomic particles or electromagnetic waves that are energetic enough to eject electrons from atoms or molecules, ionising them. Examples are alpha particles, beta particles, neutrons, gamma rays, and X-rays. Ionization of an atom is the removal of one of its orbital electrons. When an electron is removed, two charged particles, the free electron, which is electrically negative, and the rest of the atom, which bears a positive charge, are produced. These are called an ion pair. Ionizing radiation has sufficient energy to cause chemical changes in cells and damage them. Some cells may die or become abnormal, either temporarily or permanently. Radiation can cause cancer by damaging the genetic material (DNA) contained in the body's cells. The extent of damage to the cells depends on the amount of and duration of the exposure, as well as the organs exposed. Very large amount of radiation exposure can cause sickness or even death within hours or days. In general, the amount and duration of radiation exposure affects the severity or type of health effect. Current studies suggest there is some cancer risk from any radiation. According to the U.S radiation protection Agency, any radiation dose carries some risk, and that risk increases directly with dose (Nordqvist, 2014).

2.4 The need for QA/QC in mammography

Quality assurance (QA) refers to all those planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily in service. This refers to the optimum quality of the entire diagnostic process; consistent production of adequate diagnostic information with minimum exposure of both patient and personnel. QC refers to the technical aspects of mammography and is evaluated with outlined procedures and performed by the QC technologist (Hogge et al-1999). It includes monitoring, evaluation, and maintenance at optimum levels of all characteristics of performance that can be defined, measured, and controlled. The testing of equipment must address the various critical stages of the imaging chain, that is, acquisition, processing, and display. Because of the relevance of mammography in accurately diagnosing breast cancer, especially in its early stages, and reducing high mortality rate in women, it is essential that all mammograms be performed and interpreted with the highest possible quality standards. QA and QC measurements and guidelines must be present in all mammography facilities. These guidelines must be strictly adhered to, in order to assure accurate diagnosis for all patients. The importance of QC on the equipment is to assure that images are not degraded with artifacts that may mimic microcalcifications. It is also to assure that view boxes and viewing conditions are optimised and maintained at an optimal level. It is also to assure that the breast dose is As Low As Reasonably Achievable (ALARA) for the mammographic information required (Reis et al-2013).

2.5 Mammography Dosimetry

There is a significant risk of radiation induced carcinogenesis associated with mammography. The determination of mean glandular breast dose forms an important part of the quality control of mammography imaging systems since it gives an indication of the performance of the imaging system as well as estimating risk to the patient. As a result of the fact that breast cancer almost always arises from the glandular tissue of the breast, and also based on the assumption that it is the glandular tissue in the breast that is most sensitive to radiation effects. The mean or average radiation absorbed dose of the glandular tissue is used to measure the radiation risk associated with mammography (IAEA RPOP-2013). The mean glandular dose is defined as the average dose to the glandular tissue. Because of the difficulty of estimating mean glandular dose (MGD) directly, the entrance air kerma, without back scatter, at the upper surface of the breast is determined and the MGD is estimated by multiplying by appropriate conversion factors (Dance et al -2000). The mean glandular dose is calculated using equation (2.1);

$$MGD = K.g.c.s \tag{2.1}$$

where K is the incident air kerma (without back scatter) at the upper surface of the breast, g is the incident air kerma to mean glandular dose conversion factor (g-factor), c corrects for any difference in breast composition from 50% glandularity and the factor s corrects for any difference due to the use of a different X-ray spectrum. The conversion factors g, c and s are extrapolated from the work of Dance et al 2000, 2009, and 2011.

2.6 Overview of Related Works Done

Despite the fact that mammography uses low kilo voltage in the production of images, dose assessment is essential since there is nothing like small dose. It is also to ensure effective optimization of radiation protection in digital mammography practices. To achieve the aim of radiation protection, a lot of work has been done worldwide on mammography dose assessment, both on conventional systems and digital systems.

In Ghana, Akrobortu et al. (2013) did an inter-comparison of dose indicators and mean glandular dose for some selected diagnostic mammography units in Accra, Ghana. The study was carried out in three facilities in Accra, and in all 300 patients (100 from each facility) was selected at random for the MGD estimation. Mammography screening and diagnostic examinations were performed by specialists (radiologists) and qualified radiographers at the respective facilities. Quality assurance programmes were carried out in the three mammography units using standard performance criteria. Darkroom quality control and a number of quality control tests with respect to: tube voltage accuracy and reproducibility, radiation output linearity and consistency, MGD to patients were assessed for each unit. MGD estimated from free in air measurements were found to be 0.32-1.45 mGy, 0.33-1.30 mGy and 1.05-2.70 mGy with grid for facilities A, B, and C respectively using a standard breast thickness of 45 mm. The performance criteria of key quality control parameters were found to be within acceptable limits except base + fog and contrast index of radiographic films.

In Kenya, Wambani et al. (2011) assessed patient doses during mammography practice at the Kenyatta National Hospital. The study was carried out over a period of one year where the annual numbers of mammography examination were counted from the hospital patient records. The objective of the study was to evaluate the MGD in mammography for craniocaudal (CC), medio-lateral oblique (MLO) projections and the dose per woman. A mammography equipment performance test was done based on quality control parameters. Viewing box luminance and room luminance were assessed as well as image quality on each mammogram. All the quality control tests performed were passed except luminance and ambient light. The viewing boxes were less bright while ambient light in the reporting room was too bright to the extent that it may affect the level of viewing diagnostic information in the mammograms. In the end, there were 3264 films from 1252 women of between 25 to 90 years old. The MGD per film was 2.14 mGy (range 0.27-9.43 mGy) for the CC projection and 2.44 mGy (range 0.20-10.12 mGy) for the MLO projection. 17% of CC films and 30% of MLO films recorded doses above the 3 mGy diagnostic reference level. There were high image quality scores in this study due to the skilled technologist and regular quality control tests performance.

In Ethiopia, Seife et al. (2012) did an evaluation of mean glandular dose during diagnostic mammography examination for detection of breast pathology, in Ethiopia. The study was done in a period of ten months. Five mammographic units were included in this study. From 518 breast patients of all ages and all CBT values, clinical data were collected. Exposure factors for each mammogram was collected and the MGD was estimated making use of the ESAK and tabulated conversion factors. The maximum to minimum ratio of the average MGD recorded in the five units was 4.71. The MGD to breast dose was found to vary from 0.23 mGy to 7.89 mGy, with 16.5% of the dose above the upper limit of the ACR recommendation established for the reference medium-sized breast of 4.2 cm CB. The need for strict quality control was recommended.

In Thailand, Theeraku l(2014) studied patient dose measurement in digital mammography. The purpose for the study was to determine the entrance skin exposure (ESE) and the MGD per exposure with grid for each projection of mammography service at King Chulalongkorn Memorial Hospital. The mammography equipment used for this study was a Selenia Dimensions, manufactured in 2009 by HologicLorad and verified by the department of medical science, Thailand in 2011. The study involved 200 patients. At the end of the study, the MGD was found to be 1.78 mGy for (RCC), 1.77 mGy for (LCC), 1.86 mGy for (RMLO) and 1.98 mGy for (LMLO) respectively. The average entrance skin exposure (ESE) was 6.79 mGy for (RCC), 6.83 mGy for (LCC), 7.15 mGy for (RMLO) and 7.83 mGy for (LMLO) respectively. The ESE and MGD from MLO views were greater than those from the CC views for the right and left sides because the MLO CBT is slightly thicker than the CC CBT. Overall, 91.41% of CC view and 89.14% of MLO view were lower than the reference level of 3.0mGy. The MGD per image was significantly different between the CBT as classified by glandular content groups. It increased with increasing CBT, while decreasing with increasing age.

A study was done on image quality and dose in mammography in 17 countries in Africa, Asia and Eastern Europe in 2011 by Olivera et al. A total of 17 countries from Africa, Asia and Eastern Europe including Malta and Greece, participated in the survey, and the total number of mammography units were 54 ranging from 1 to 9 per country. The objective was to study mammography practice from an optimisation point of view by assessing the impact of simple and immediately implementable corrective actions on image quality. More than 21,000 mammography images were evaluated using a three-level image quality scoring system. Following initial assessment, appropriate corrective actions were implemented and image quality was re-assessed in 24 units. The fraction of images that were considered acceptable without any remark in the first phase (before the implementation of corrective actions) was 70% and 75% for cranio-caudal and medio-lateral oblique projections, respectively. The main causes for poor image quality before corrective actions were related to film processing, damaged or scratched image receptors, or film-screen combinations that are not spectrally matched, inappropriate radiographic techniques and lack of training. Average glandular dose to a standard breast was 1.5 mGy (mean and range 0.59–3.2 mGy). After optimisation the frequency of poor quality images decreased, but the relative contributions of the various causes remained similar. Image quality improvements following appropriate corrective actions were up to 50 percentage points in some facilities (European journal-2011).

In Italy, Gisella et al (2002) conducted a study on patient dose in full-field digital mammography. This study was carried out on four GE senographe 2000D digital mammography units installed in four different Italian sites from January to May 2002. Two mammography units worked mainly in contrast mode, while the other two worked in standard mode. The main aim of the study was to compare performance and patient dose of full-field digital mammography units for clinical use. Measurements of linearity and automatic exposure control stability were performed on the four units. The tube output was also obtained by the same ionization chamber. The entrance air-kerma of 800 sampled cranio caudal mammograms was calculated, as well as the average glandular dose. The linearity of the digital systems was very good, and the stability of the automatic exposure control was better than 5% for all systems with regards to the dose, the two units that worked mainly in contrast mode delivered 17 and 28 % respectively, more dose compared to those that worked in standard mode. For the standard mode units, the mean average glandular dose was in the range 1.25-1.37mGy and 1.37-1.49mGy for 50 and 30% glandular composition, respectively. The results showed that full-field digital mammography allows a significant clinical dose reduction compared with screen film mammography.

In Turkey, Bor et al (2002) did a study on variations in breast doses for an automatic mammography unit. The purpose of the study was to assess variations of glandular doses for a group of patients when different dose modes are selected for a specific system. All measurements were obtained with a Senographe DMR mammography unit (GE Medical Systems). Automatic exposure control with either contrast or standard mode was routinely used in patient examinations. Entrance surface air kerma (ESAK) values were estimated from the post exposure mAs and from the recorded data. Subsequently the mean glandular dose (MGD) for each view was calculated using the conversion factors assuming 50% glandular and 50% adipose tissue composition. At the end of the study, the average MGD for the right craniocaudal view for all beam qualities was 1.65 mGy, and 46.7 mm was the average compressed breast thickness for this view. Average MGDs were 1.61, 1.76, and 1.35 mGy for Mo-Mo, Mo-Rh, and Rh-Rh anode filter selections, respectively. Conversely, 2.18 and 1.47 of breast doses were measured for contrast and standard dose modes at the most often used (Mo-Mo) anode filter selection.

In Ireland, a study was done by McCullagh et al on Clinical dose performance of full field digital mammography in a breast screening program. The aim of this study was to use the results from a clinical breast dose survey to examine the differences between three different FFDM models in terms of exposure selection, breast mean glandular dose (MGD) and automatic exposure control (AEC) dose contribution. A total of 28 X-ray units (11 GE Essential, 10 HologicSelenia, 7 Sectra MDM L30) encompassing a mixture of static and mobile settings were included in the survey. At the end of the study, the accuracy of the dose estimation was improved by inclusion of the AEC pre-exposure dose contribution. The photon-counting system demonstrated the lowest average MGD. The GE Healthcare and Hologic flat-panel detector systems demonstrated a small but statistically significant dose difference. The pre-exposure dose contribution did not exceed 13% of the total exposure dose for any system in the survey. A comparison of the system calculated organ dose estimate from each machine with the corresponding MGD calculated from medical physics measurements indicated reasonably accurate organ dose estimates for most systems in the survey.

Looking at the various works done by other authors, one will see that a lot of study has been, and is being done on digital mammography all over the world. However, it is evident that no such study has been done on digital mammography in Ghana. It is therefore very important to undertake this study to provide a baseline data for future research.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Overview

This chapter describes the materials and methods used for the study, the selection criteria for the mammography equipment used and data collection.

3.1 Materials

The materials used for this study are mammography equipment, rectangular PMMA (Polymethylmethacrylate) slabs, Piranha QC kit, Ocean software, aluminium filters, Microsoft excel software and a ruler.

3.1.1 Mammography equipment

A total of three digital mammography units from three different facilities (2 hospitals and 1 diagnostic radiological centre) were used in this study; Korle - Bu Teaching Hospital, the Trust Hospital, and Supreme Specialist Centre. The details of the equipments used are presented in table 3.1.

Table 3.1: Details of mammography equipments used.

CHARACTERISTIC	KBTH	TH	SSC
Type of equipment	DR	CR	CR
Manufacturer	Varian medical systems	Philips	GE
Model	Fujifilm-Amulet f	MammoDiagnost AR	Alpha RT
Year of make	2011	2013	2012
Serial number	MXA11B0317	67N157	2871
Mode of operation	AEC/Manual	AEC/Manual	AEC/Manual
Anode/filter combination	W/Rh	Mo/Rh	Mo/Rh
kVp range	23-35	20-35	23-35
mAs range	2-600	1-600	0.004-450

The figure below shows a typical mammography system.

Figure 3. 1: Image of a typical mammography system

3.2 METHODOLOGY

A data sheet was designed (Appendix A Table 2) and used to collect patient data from the three facilities offering digital mammography services and analyzed. Quality control (QC) tests were done on the mammography equipment to ensure their optimum performance. The QC tests that were performed are; kVp accuracy, kVp repeatability, output repeatability, output linearity, half value layer (HVL) and automatic exposure control (AEC) performance. Mean glandular Dose (MGD) was estimated and compared with equipment values (for KBTH system) and compared with IAEA and European protocols.

3.2.1 kVp Accuracy

The objective of this test was to verify the accuracy of the kVp. A total of five exposures were taken in the manual mode with a nominal kVp set at 28kVp and the mAs set at 40mAs. The detector was placed on the breast support, 40mm from the chest wall, and centred laterally (the reference point). The readings (measured kVp) were recorded. The kVp accuracy was calculated by finding the percentage deviation of the measurements recorded, using equation (3.1).

$$Deviation(\%) = \frac{(kVp_{nom} - kVp_{meas})}{kVp_{nom}} \times 100 \qquad (3.1)$$

Where, kVp_{nom} is the value displayed on the console and kVp_{meas} is the measured value. This percentage deviation is taken as a measure of the accuracy and the acceptable range for accuracy is ±5% (IAEA, 2011).

3.2.2 kVp Repeatability

The objective of this test was to verify the repeatability of the kVp. For this test, two exposures were made in the manual mode with a nominal kVp of 28 kVp and mAs of 40 mAs, with the detector positioned at the reference point. The readings were recorded on a data sheet. The two readings can be used to calculate the repeatability but for a more accurate and true result, it is best to use more than three readings. Three additional exposures were therefore made using the same parameters, making a total of five exposures. The kVp repeatability was calculated by finding the Difference (%) of the first two values and the coefficient of variance (COV) of the five readings using the following equations;

$$Difference(\%) = \frac{(Max - Min)}{Min} \quad (3.2)$$

Where, 'Max' is the maximum measurement, and 'Min' is the minimum measurement. For kVp repeatability, the percentage difference should be within the range ≤5% (IAEA, 2011).

$$COV(\%) = \frac{SD}{Mean} \times 100 \quad (3.3)$$

Where, SD is the standard deviation of the measurements, and Mean is the mean of the measurements. For repeatability, the COV (%) should be within the range ≤2% (IAEA, 2011).

3.2.3 Output Repeatability

The objective of this test was to evaluate the repeatability of the air kerma for a given mAs. For output repeatability, a nominal kVp of 28 kVp with mAs of 40 mAs was used to make five exposures, with the output readings recorded. After the five exposures, the mAs was increased to 80 mAs, and two exposures were made and the output recorded. After that, the mAs is increased to 120 mAs, and two exposures made. The output repeatability was then determined by finding the percentage difference and COV (%) using equations 3.2 and 3.3.

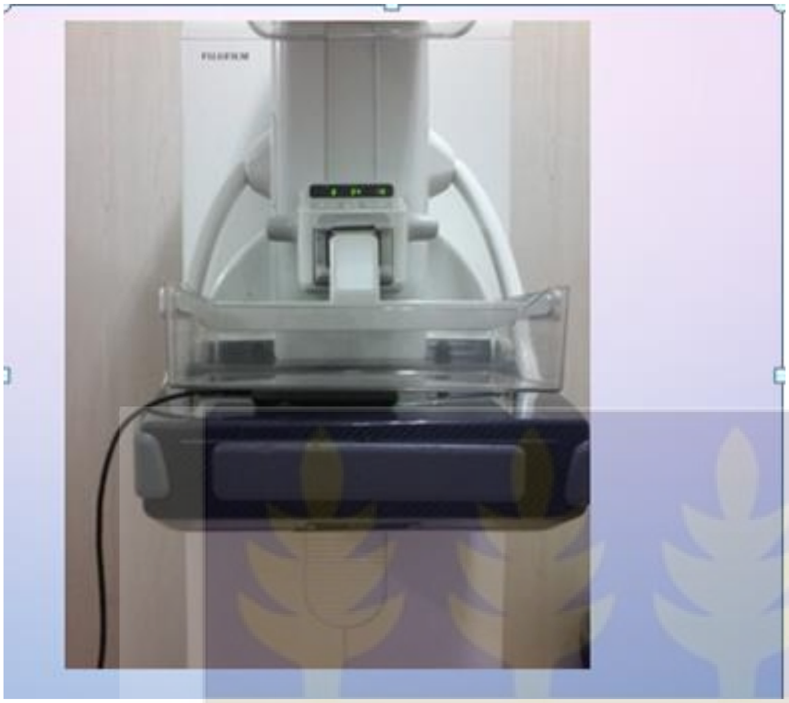

Figure 3. 2: Setup for Output and kVp repeatability and kVp accuracy

3.2.4 Output Linearity

The objective of this test is to evaluate the linearity of the air kerma for a given mAs. With the output linearity measurement, the set up used was the same as that of kVp accuracy and repeatability. After the five exposures were made in the output repeatability test, the mAs was increased to 80 mAs and then to 120 mAs, while maintaining the kVp at 28 kVp. Two exposures each were made with the two additional mAs values selected. For each mAs selected, the average value of the obtained readings of air kerma was calculated and recorded on a data collection sheet. The output linearity was then calculated using equation (3.4).

$$Linearity = \frac{(y_1 - y_2)}{(y_1 + y_2)} \quad (3.4)$$

Where y_1 and y_2 are the output values obtained by dividing each average air kerma value by the corresponding mAs.

3.2.5 Half Value Layer (HVL)

The objective of this test was to confirm that the total filtration of the X-ray beam was in agreement with the minimum requirements of the international standards. This measurement was done with a kVp of 28 kVp and mAs of 40 mAs. The detector was placed at the reference point, with the sensitive volume of the detector completely covered by the radiation field. The compression paddle was placed half way between the focus and the detector and an exposure made. The reading was recorded on a data sheet. A 0.2 mm of aluminium was placed on the compression paddle, totally covering the active volume of the detector, and an exposure was made with the same parameters. The readings were recorded as well. A 0.1 mm of aluminium was added (total 0.3 mmAl), an exposure made with the same parameters and the readings recorded. Two more exposures were made with the aluminium thickness increased to 0.4 mm and 0.5 mmAl, and the readings recorded. All the aluminium filters were removed and a final exposure made. This reading is recorded as well. The HVL was then calculated using equation (3.5).

$$HVL = \frac{t_1 \ln\left[{2M_1}/{M_0}\right] - t_2 \ln\left[{2M_2}/{M_0}\right]}{\ln\left[{M_1}/{M_2}\right]} \quad (3.5)$$

Where t_1 and t_2 are the thicknesses (mm) of the filters used, M_1 and M_2 are the average values of the readings measured and M_0 is the average value of the reading measured without any added filter.

The measured HVL is acceptable when it falls within the range;

$$\frac{kVp}{100} + 0.03 \leq HVL \leq \frac{kVp}{100} + c \quad (3.6)$$

Where: C = 0.12 for Mo/Mo, 0.19 for Mo/Rh, 0.22 for Rh/Rh, 0.30 for W/Rh and kVp is the measured value for the nominal kVp selected (IAEA, 2011).

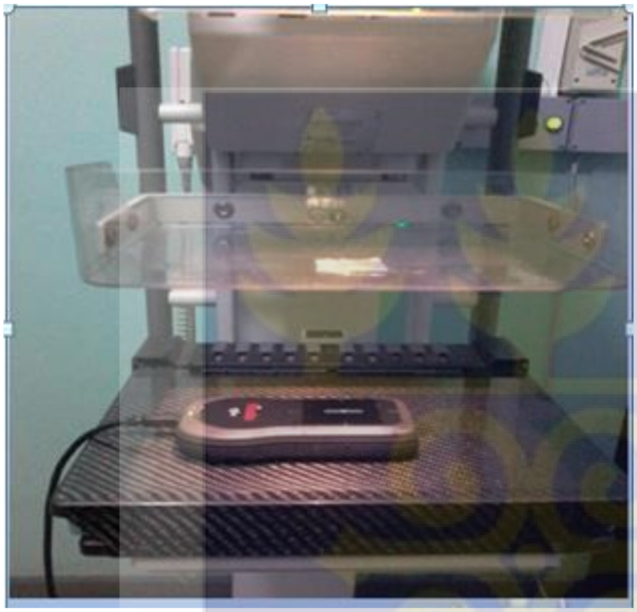

Figure 3. 3: Setup for half value layer measurement

3.2.6 Automatic Exposure Control (AEC)

The objective of this test is to test the repeatability of the AEC. This was done by making ten exposures of 45mm PMMA slabs in the automatic mode, with the mAs readings recorded. The AEC repeatability was estimated by finding the coefficient of variance (COV) using equation 3.3.For repeatability, the acceptable value of COV should be ≤5% (IAEA, 2011).

3.2.7 Mean Glandular Dose (MGD) Estimation

The MGD values are based on measurements of ESAK (Entrance Surface Air Kerma) and HVL (Half Value Layer). The exposure factors (CBT, kVp, mAs, and age) for

297patients were recorded, and the exposure factors simulated for some selected breast thicknesses using PMMA slabs. To do the measurements correctly and according to standards, the radiation detector (Piranha) was placed directly below the compression paddle; this mimics the exposure of the fully automatic mode in manual mode using the same exposure factors obtained from the previously exposed patients, in order to obtain the ESAK. MGD was then calculated for various breast thicknesses and composition equivalent to the thickness of PMMA by using equation (2.1).

To get the ESAK from the exposure recorded from the piranha, the distance was first corrected to attain the final radiation intensity to the surface of the breast. This was done using the inverse square law equation; equation (3.7).

$$I_2 = I_1 \times \frac{D_1^2}{D_2^2} \quad (3.7)$$

Where, $I_1$is the initial intensity of radiation, $I_2$is the final radiation intensity, $D_1$is the initial distance, and D_2 is the final distance.

This was necessary because, the distance at which the detector was measuring the incident radiation was different from the distance at which the various simulated breast thicknesses received the incident radiation. Hence I_2 was calculated for. After that, the output was calculated using the equation;

$$Output = \frac{I_2(mGy)}{mAs(measured)} \quad (3.8)$$

From equation (3.8) the output is gotten in mGy/mAs. ESAK was then calculated by multiplying the output (mGy/mAs) by the recorded mAs;

$$ESAK = Output(mGy/mAs) \times mAs(Recorded) \quad (3.9)$$

This gave the ESAK in mGy. The conversion factors g, c, s, used for this study were extrapolated from Dance et al (2000, 2009, and 2011). The g and c factors for the measured half-value layers were interpolated from the compiled data for age groups 40-49 yrs and 50-64 yrs, according to the breast thickness, and the s factor according to the anode/filter combination used. For all the mammography units, the mean, standard deviation, range of MGD were calculated. Finally, an inter unit comparison of the results of calculated ESAK and MGDs was made. The results were also compared to the IAEA and European protocol standard MGDs.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Overview

This chapter presents and discusses the results obtained from the study. It describes the various results for the quality control tests, the MGD measurements and the various results obtained with graphs. Results for kVp accuracy and repeatability test, output repeatability and linearity test, and AEC repeatability test.

4.1 Quality Control Test

The final results of kVp accuracy and repeatability, output linearity and repeatability, half value layer, and automatic exposure control measurements are presented in Table 4.1 (Primary/ raw data is presented in appendix c).

Table 4. 1:Mammography equipment performance tests results

QUALITY CONTROL TEST (Acceptable range)	RESULTS KBTH	TH	SSC	COMMENTS (PASS/FAIL)
kVp accuracy (±5%)	0.25	-4.6	0.3	Pass
kVp Repeatability (COV≤2%)	1.28	1.71	0.3	Pass
HVL (mmAl) (kVp/100+0.03≤HVL≤kVp/100+c)	0.58	0.35	0.31	Pass
Output repeatability (COV≤5%)	0.13	0.20	0.30	Pass
Output Linearity (<10%)	0.12	-0.20	0.22	Pass
AEC repeatability (≤5%)	1.52	0.74	1.94	Pass

The kVp accuracy for Korle-Bu Teaching Hospital mammography equipment was 0.25%, that of Trust Hospital's equipment was -4.6% and Supreme Specialist Centre's equipment had a kVp accuracy of 0.30%, which falls within the acceptable range of ±5%. All three facilities recorded kVp repeatability as 1.28%, 1.71%, and 0.30% respectively, which also falls within the normal range of ≤2%.The HVL measured on the Korle-Bu Teaching Hospital mammography equipment was 0.58 mmAl, while that of Trust Hospital was 0.35 mmAl, and Supreme Specialist Centre was 0.31 mmAl. Korle-Bu Hospital recorded an output repeatability of 0.13% and an output linearity of 0.12 µGy/mAs, Trust Hospital recorded an output repeatability of 0.20% and a linearity of -0.20 µGy/mAs, and that of Supreme Specialist Centre was 0.30% and 0.22 µGy/mAs respectively. The Automatic Exposure Control assessment showed that, the three facilities recorded repeatability values within the acceptable levels. These values are 1.52%, 0.74%, and 1.94% for KBTH, TH, and SSC respectively. And the limiting value is ≤5%.

4.2 Secondary Data Taken

A total of 297 patient data from 3 facilities rendering digital mammography services were taken. The parameters recorded were age, type of examination, number of views taken, kVp, mAs, CBT, and dose/IAK. Table 4.2 shows a summary of the patient data collected.

Table 4. 2:Summary of data collected

FACILITY	TYPE OF EXAM		NUMBER OF VIEWS	NUMBER OF PATIENTS	AGE		
	DIAGNOSTIC	SCREENING			MIN	MAX	MEAN
KBTH	198	18	993	216	33	82	52.92
TH	26	32	230	58	39	70	52
SSC	19	4	92	23	31	70	47.91
TOTAL	**243**	**54**	**1315**	**297**	**31**	**82**	**52.29**

In total, 297 patient data were recorded. Out of this number, 243 were for diagnostic purposes and 54 for screening purposes. In all, 1315 views were analysed. The minimum age recorded was 31 years, maximum age was 82 years, and the mean age was 52.29 years. Korle-Bu Teaching Hospital recorded a total of 216 patients, out of which 198 were for diagnostic purposes and 18 were for screening purposes. The minimum age recorded in Korle-bu was 33years, maximum age was 82years, and the mean age was 52.92years. The number of views recorded was 993. Trust Hospital recorded a total of 58 patients, out of which 26 underwent diagnostic mammography and 32 underwent screening mammography. The minimum age recorded was 39years, maximum age was 70years, and the mean age was 52years. The total number of views recorded was 230. Supreme Specialist Centre recorded a total of 23 patients, out of this number, 19 patients came for diagnostic mammography, and 4 patients came for screening mammography.

The minimum age recorded was 31years, maximum age was 70years, and the mean age was 47.91years.

Table 4.3 shows a summary of the secondary MGD values recorded at KBTH.

Table 4. 3: MGD (mGy) recorded at Korle-Bu

VIEW	MINIMUM (mGy)	MAXIMUM (mGy)	MEAN (mGy)	SD	VALUE (mGy)
LCC	0.37	7.44	2.13	0.93	2.13 ± 0.93
LMLO	0.58	8.11	2.93	1.51	2.93 ± 1.51
RCC	0.35	6.58	2.26	1.02	2.26±1.02
RMLO	0.83	12.08	3.05	1.78	3.05±1.78

The minimum MGD recorded at Korle-Bu Teaching Hospital for the LCC view was 0.37 mGy, the maximum for this view was 7.44 mGy, the mean and standard deviation was 2.13 mGy and 0.93 mGy respectively. For the RCC view, the minimum MGD recorded was 0.35 mGy, maximum MGD was 6.58 mGy, the mean MGD recorded for RCC was 2.26 mGy and the standard deviation was 1.02 mGy. The minimum value for the LMLO view was 0.58 mGy, maximum value was 8.11 mGy, mean value was 2.93 mGy, and that of the standard deviation was 1.51 mGy. The RMLO view had a minimum value of 0.83 mGy, maximum was 12.08 mGy, mean was 3.05 mGy, and standard deviation was 1.78 mGy.

Table 4. 4: Incident Air Kerma (mGy) recorded at Trust Hospital

VIEW	MIN (mGy)	MAX (mGy)	MEAN (mGy)	SD	VALUE (mGy)
LCC	0.64	2.68	1.54	0.54	1.54±0.54
LMLO	0.55	4.42	1.98	0.77	1.98±0.77
RCC	0.64	2.77	1.39	0.47	1.39±0.47
RMLO	0.63	5.01	1.96	0.74	1.96±0.74

Trust Hospital recorded a minimum IAK value of 0.64 mGy for the LCC view, the maximum value was 2.68 mGy and the mean and standard deviation was 1.54 mGy and 0.54 mGy respectively. The minimum value for the RCC view was also 0.64 mGy, maximum value was 2.77 mGy, the mean and standard deviation was 1.39 mGy and 0.47 mGy respectively. The minimum value for the LMLO view was 0.55 mGy, maximum value was 4.42 mGy, mean value was 1.98 mGy, and that of the standard deviation was 0.77 mGy. The RMLO view had a minimum value of 0.63 mGy, maximum was 5.01 mGy, mean was 1.96 mGy, and standard deviation was 0.74 mGy.

Table 4. 5: Summary of Compressed Breast Thickness (mm) recorded

VIEW	KBTH			TH			SSC		
	MIN (mm)	MAX (mm)	VALUE (mm)	MIN (mm)	MAX (mm)	VALUE (mm)	MIN (mm)	MAX (mm)	VALUE (mm)
LCC	2	86	32.74 ± 13.01	29	87	57.41 ± 11.93	23	28	44.13 ± 14.19
LMLO	1	102	38.29 ± 16.58	29	97	66.37 ± 13.02	24	31	53.7 ± 18.23
RCC	2	69	34.48 ± 13.00	6.3	85	56.57 ± 12.89	24	29	43.7 ± 13.83
RMLO	1	79	40.42 ± 16.68	41	89	64.78 ± 11.43	24	32	52.17 ± 20.16

Korle-Bu recorded a maximum breast thickness of 86 mm and a minimum of 2 mm for LCC view, and a maximum breast thickness of 102 mm and a minimum of 1 mm for LMLO view. The mean breast thickness for LCC and LMLO views were 32.74 mm and 38.29 mm respectively. The minimum and maximum breast thickness for RCC view in Korle-Bu was 2 mm and 69 mm respectively, minimum breast thickness for RMLO was 1 mm, and maximum was 79 mm. The mean breast thickness for RCC and RMLO views were 34.48 mm and 40.42 mm respectively. Trust Hospital recorded a maximum of 87 mm for LCC view and 29 mm as minimum, LMLO view recorded a maximum of 97 mm and a minimum of 29 mm. Mean for LCC and LMLO views were 57.41 mm and 66.37 mm respectively. Supreme Specialist Centre recorded a maximum breast thickness of 28 mm for LCC view, a minimum of 23 mm and a mean thickness of 44.13 mm. For the LMLO view, the maximum thickness was 31 mm with a minimum of 24 mm and a mean thickness of 53.7 mm. The maximum and minimum breast thickness for the RCC view in Supreme Specialist Centre was 29 mm and 24 mm respectively, maximum breast thickness for RMLO was 32 mm, and minimum was 24 mm. The mean breast thickness for RCC and RMLO was 43.7 mm and 52.17 mm respectively.

Table 4. 6: Summary of recorded kVp from the three facilities

VIEW	KBTH			TH			SSC		
	MIN (kVp)	MAX (kVp)	VALUE (kVp)	MIN (kVp)	MAX (kVp)	VALUE (kVp)	MIN (kVp)	MAX (kVp)	VALUE (kVp)
LCC	23	32	26.88 ± 1.42	28	57.7	30.00 ± 3.78	23	28	25.91 ± 1.41
LMLO	23	32	27.49 ± 1.79	25.5	51.7	30.34 ± 3.13	24	31	27.61 ± 2.31
RCC	23	30	27.10 ± 1.40	28	30.5	29.38 ± 0.52	24	29	26.09 ± 1.50
RMLO	23	31	27.77 ± 1.78	20.3	31	29.64 ± 1.37	24	32	27.61 ± 2.23

The minimum kVp used for LCC views in Korle-Bu was 23 kVp, while the maximum was 32 kVp. For LCC views in Trust Hospital, the minimum kVp used was 28 kVp, and the maximum was 57.7 kVp. For Supreme Specialist Centre, the minimum kVp used for LCC views was 23 kVp and the maximum was 28 kVp. The mean kVp used for the LCC views in all three facilities were 26.88 kVp, 30 kVp, and 25.91 kVp respectively. For the LMLO views, the minimum kVp used in the three facilities was 23 kVp, 25.5 kVp, and 24 kVp respectively, while the maximum kVp used was 32 kVp, 51.7 kVp, and 31 kVp respectively.

Table 4.7 shows a summary of the recorded mAs that were used for the imaging in the three facilities.

Table 4. 7: Summary of recorded mAs used in the three facilities

VIEW	KORLE-BU			TRUST			SUPREME		
	MIN (mAs)	MAX (mAs)	VALUE (mAs)	MIN (mAs)	MAX (mAs)	VALUE (mAs)	MIN (mAs)	MAX (mAs)	VALUE (mAs)
LCC	29	509	132.83 ± 51.94	1.13	236	81.7 ± 40.44	52	205	105.04 ± 38.85
LMLO	43	556	173.01 ± 88.56	1.09	296.4	113.52 ± 8.47	49	172	112.74 ± 31.89
RCC	27	473	137.95± 57.11	27.7	186.8	73.45 ± 32.19	58	150	101.13 ± 27.97
RMLO	30	483	180.42 ± 92.44	40	301.5	105.42±46.68	60	168	105.09±31.69

The mean mAs used for LCC and RCC views in Korle-bu teaching hospital were 132.83mAs and 137.95mAs respectively, and their standard deviations were 51.94 and 57.11 respectively. Trust Hospital recorded mean mAs for LCC and RCC views as 81.7mAsand 113.52mAs respectively, while the recorded standard deviations were 40.44 for LCC and 32.19 for RCC. Supreme Specialist Centre recorded a mean of 105.04mAs for LCC views and 112.74mAs for RCC views. The standard deviations recorded were 38.85 for LCC and 27.97 for RCC.

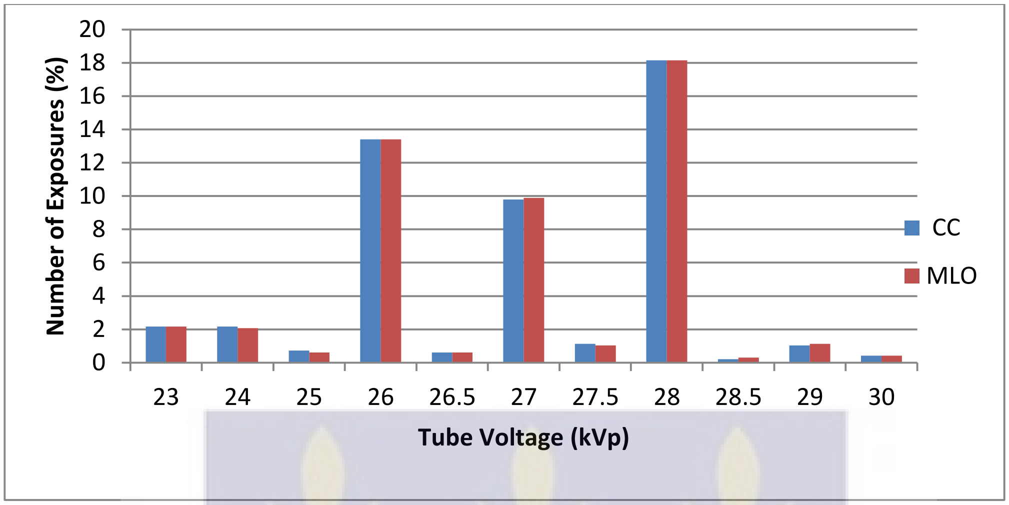

Figure 4. 1: Distribution of tube voltages used in mammography (KBTH)

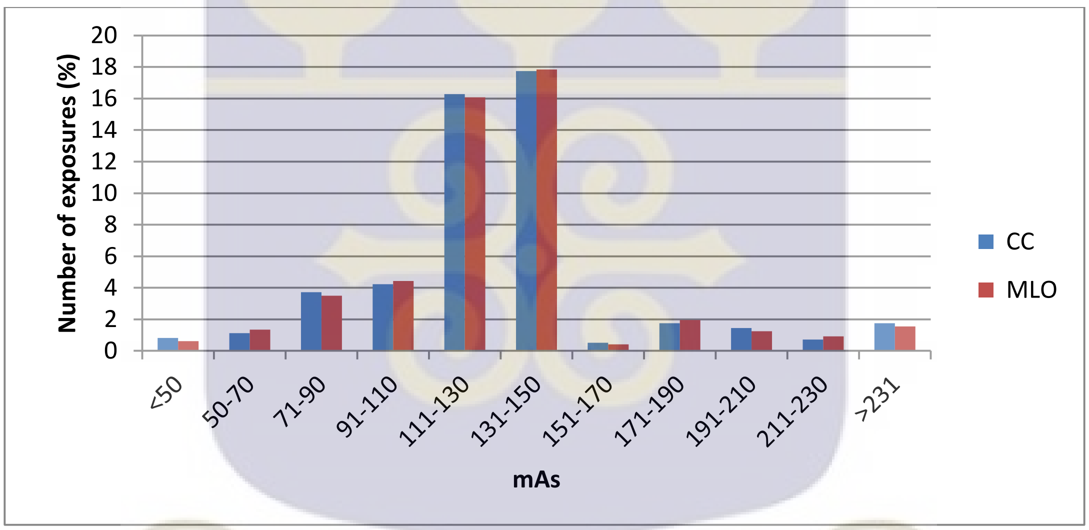

Figure 4. 2: Distribution of tube loading used in mammography (KBTH)

Figure 4.1 and 4.2 shows that majority of CC and MLO views were performed using a kVp of 28kVp and an mAs range of 131-150 mAs at Korle-Bu Teaching Hospital.

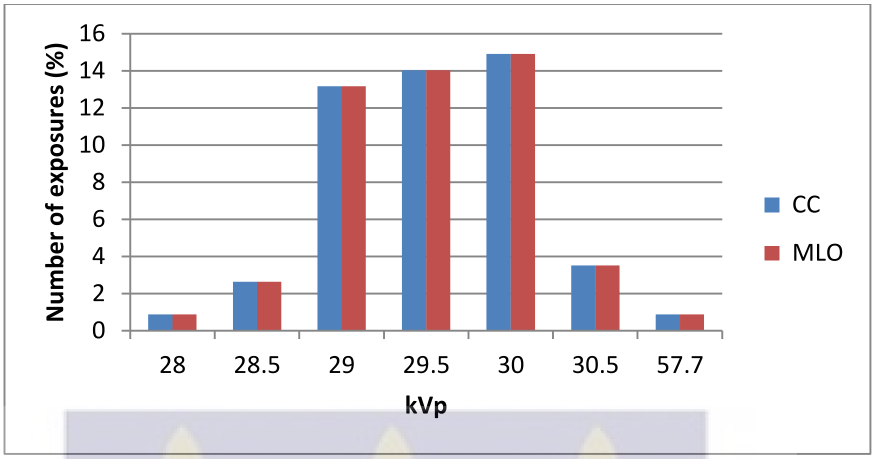

Figure 4. 3: Distribution of tube voltages used in mammography (TH)

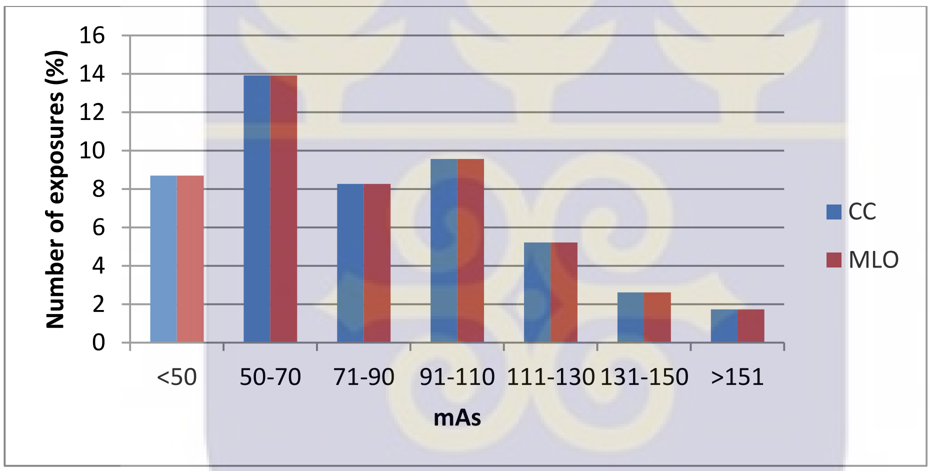

Figure 4. 4: Distribution of tube loading used in mammography (TH)

The figures above show that majority of CC and MLO views in Trust Hospital were performed using a kVp of 30kVp and an mAs range of 50-70mAs.

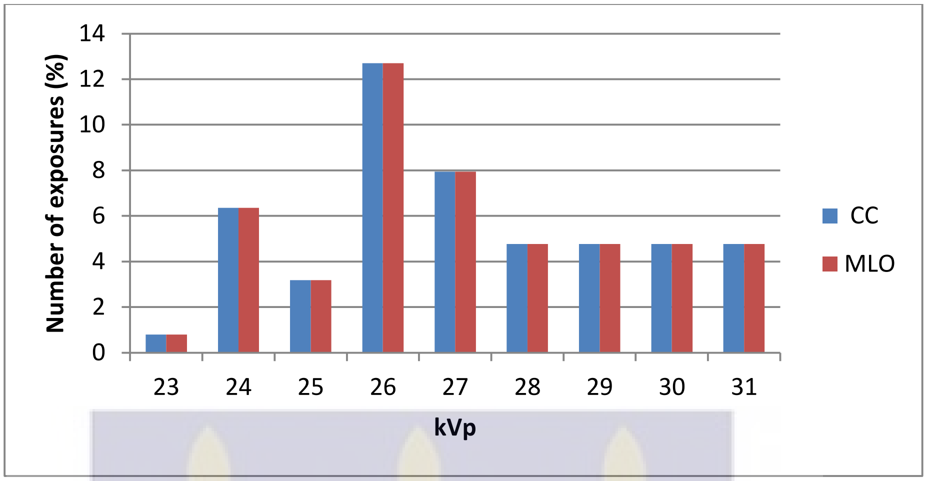

Figure 4. 5: Distribution of tube voltages used in mammography (SSC)

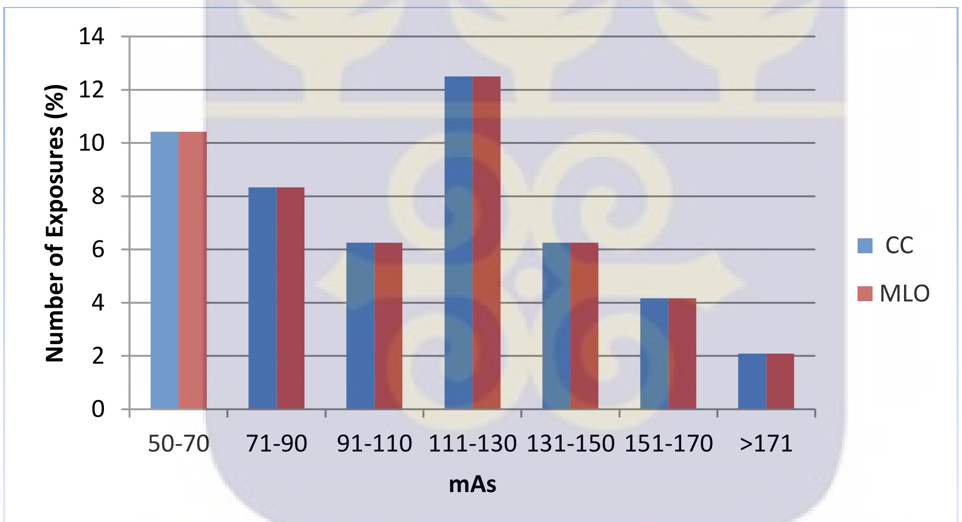

Figure 4. 6: Distribution of tube loading used in mammography (SSC)

It is evident from figures 4.6and 4.5 that, majority of CC and MLO views were performed in Supreme Specialist Centre using an mAs range of 111-130mAs with a kVp of 26 kVp.

4.3 Dose Estimation

Table 4.8 is a tabular representation of the recorded MGD and the calculated MGD of patients with their corresponding compressed breast thickness, in the Korle-Bu Teaching Hospital that fell within the age groups 40-49years and 50-64years.

Table 4. 8: Calculated and recorded MGD for the two age groups (KBTH)

CBT (mm)	40-49 years		50-64 years	
	Recorded MGD (mGy)	Calculated MGD (mGy)	Recorded MGD (mGy)	Calculated MGD (mGy)
30	2.10	1.83	1.58	1.44
40	1.88	1.63	1.88	1.63
50	2.62	2.23	2.64	2.24
60	4.36	3.66	3.48	2.87
70	6.58	5.42	-	-

From the table above, the calculated MGDs are lower than the equipment generated MGDs, both for age group 40–49years and 50–64years.

Table 4.9 shows a tabular representation of the calculated MGDs received by patients at the Trust Hospital, with their corresponding compressed breast thicknesses.

Table 4. 9: Calculated MGD for the two age groups (TH)

CBT (mm)	40-49years	50-64years
	Calculated MGD (mGy)	Calculated MGD (mGy)
300	0.51	-
40	0.64	0.52
50	0.99	0.85
60	1.11	1.08
70	1.50	1.27
80	1.98	2.04

Table 4.10 shows results of the calculated MGDs received by some patients at the Supreme Specialist Centre, with their corresponding breast thicknesses.

Table 4. 10: Calculated MGD for the two age groups (SSC)

CBT (mm)	40- 49 years	50 -64 years
	Calculated MGD (mGy)	Calculated MGD (mGy)
30	1.55	-
40	1.72	-
45	1.96	-
50	2.06	2.51
60	-	2.94
70	-	3.30
80	-	-

Table 4.11 shows a comparison of the recorded and calculated MGDs from Korle-Bu Teaching Hospital with the standard MGD from the European protocol for the Quality Control of the Physical and Technical Aspects of Mammography Screening.

Table 4. 11: Comparison of recorded and calculated MGD (KBTH) with Standard MGD (European protocol)

Thickness of PMMA (mm)	Thickness of equivalent breast (mm)	Maximum MGD to equivalent breast		40–49years		50–64years	
		Acceptable level (mGy)	Achievable level (mGy)	Calculated MGD (mGy)	Recorded MGD (mGy)	Calculated MGD (mGy)	Recorded MGD (mGy)
30	32	<1.5	<1.0	1.83	2.10	1.44	1.58
40	45	<2.0	<1.6	1.63	1.88	1.63	1.88
45	53	<2.5	<2.0	-	-	-	-
50	60	<3.0	<2.4	2.23	2.62	2.24	2.64
60	75	<4.5	<3.6	3.66	4.36	2.87	3.48
70	90	<6.5	<5.1	5.42	6.58	-	-

From the table, it is clear that the patients with a breast thickness of 30mm under the two age groups received doses a little higher than the acceptable dose levels. The calculated as well as the recorded dose of 1.83mGy, 2.10mGy, and 1.58mGy are all higher than 1.5mGy which is the standard dose for a breast thickness of 30mm. Also patients with breast thickness of 70mm under the age group 40–49years had a recorded dose of 6.58mGy, which is higher than the standard value of 6.50 mGy by a percentage deviation of 1.23%, for that breast thickness. Apart from that, the rest of the calculated and measured doses fell within the acceptable dose level.

Table 4.12shows a comparison of the calculated MGDs from Trust Hospital with the standard MGD from the European protocol for the Quality Control of the Physical and Technical Aspects of Mammography Screening.

Table 4. 12: Comparison between the calculated MGD (TH) and Standard MGD (European protocol)

Thickness of PMMA (mm)	Thickness of equivalent breast (mm)	Maximum MGD to equivalent breast		40–49years	50–64years
		Acceptable level (mGy)	Achievable level (mGy)	Calculated MGD (mGy)	Calculated MGD (mGy)
30	32	<1.5	<1.0	0.51	-
40	45	<2.0	<1.6	0.64	0.52
45	53	<2.5	<2.0	-	-
50	60	<3.0	<2.4	0.99	0.85
60	75	<4.5	<3.6	1.11	1.08
70	90	<6.5	<5.1	1.50	1.27

From the table above, all the calculated MGDs under the age groups 40–49years and 50–64years fell under the acceptable levels given by the European protocol for the quality control of Physical and Technical Aspects of Mammography Screening.

Table 4.13shows a comparison of the calculated MGDs from Supreme Specialist Centre with the standard MGD from the European protocol for the Quality Control of the Physical and Technical Aspects of Mammography Screening.

Table 4. 13: Comparison between the calculated MGD (SSC) and Standard MGD (European protocol)

Thickness of PMMA (mm)	Thickness of equivalent breast (mm)	Maximum MGD to equivalent breast		40–49years	50–64years
		Acceptable level (mGy)	Achievable level (mGy)	Calculated MGD (mGy)	Calculated MGD (mGy)
30	32	<1.5	<1.0	1.55	
40	45	<2.0	<1.6	1.72	
45	53	<2.5	<2.0	1.96	
50	60	<3.0	<2.4	2.06	2.51
60	75	<4.5	<3.6		2.94
70	90	<6.5	<5.1		3.30

Deducing from the table, only patients with a compressed breast thickness of 30mm under the age 40-49years recorded MGD slightly above the acceptable level, which is 1.55mGy against 1.50mGy. The rest of the calculated MGDs were within the acceptable level.

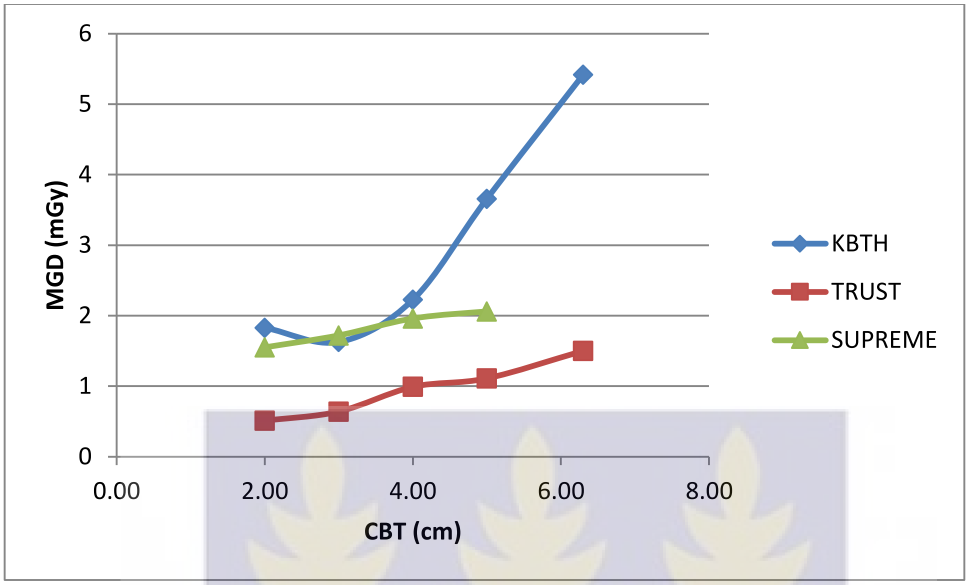

Figure 4. 7: A graph of calculated MGD (mGy) against CBT (cm) from the three facilities

From figure 4.7, results show that MGD increases with an increase in the thickness of the breast. An increase of the breast thickness will lead to an increase in the exposure factors (kVp and mAs) which will increase the penetrability and amount of radiations as well. Also, it shows that KBTH which has a DR system gave more dose to patients as the breast thickness increased; followed by Trust Hospital and Supreme Specialist Hospital which both have CR systems.

Table 4. 14: Variation of MGD with kVp and mAs (KBTH)

mAs	kVp	Calculated MGD (mGy)
111.00	26.00	1.83
140.00	27.00	1.63
131.00	28.00	2.23
200.00	28.00	3.66
300.00	30.00	5.42
473.00	30.00	-

Table 4.14 shows how MGD varies when the mAs and kVp were increased at KBTH. It is clear from the table that increasing the mAs resulted in an increase in the MGD to the patients. This is because an increase in the mAs setting means an increase in the power applied to the filament, which releases more electrons upon heating. These electrons collide with the target which produces more X-rays. Also, increasing the kVp increases the MGD. This is as a result of the fact that increasing the kVp increases the beam quality (i.e. more penetrability) which results in an increased MGD.

This trend was the same for TH and SSC, and it is shown in tables 4.15 and 4.16.

Table 4. 15: Variation of MGD with kVp and mAs (TH)

MAs	kVp	Calculated MGD (mGy)
27.7	28.50	0.51
39.60	29.00	0.64
64.90	29.50	0.99
80.60	29.50	1.11
113.70	30.00	1.50
149.70	30.50	1.98

Table 4. 16: Variation of MGD with kVp and mAs (SSC)

MAs	kVp	Calculated MGD (mGy)
72.00	25.00	1.55
97.00	25.00	1.72
102.00	26.00	1.96
113.00	27.00	2.06

The objective of verifying kVp accuracy and repeatability has been met since all three equipment passed the QC test on kVp. All three equipment recorded HVL values within the acceptable range; this confirms that the total filtrations of the X-ray beam from the equipment are in agreement with the minimum requirements of the International Standards. Also, the equipment passed the output repeatability and linearity tests, this means the repeatability and linearity of the air kerma for a given mAs have been evaluated. The equipment passed the AEC test and this means, the repeatability of the AECs have been tested and this establishes a baseline value for future measurements. Even though there were a few calculated and recorded doses being higher than the acceptable value, majority of the calculated and recorded doses were within the acceptable values. This means the doses delivered to patients by the equipment are in agreement with the minimum requirements of the International Standards.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Radiation dose to patients undergoing digital mammography was assessed and forms basis for developing imaging protocols, which will ensure effective optimisation of radiation protection in digital mammography practice. The performance of the three mammography equipment that were used for the study was assessed by performing some quality control tests on them. The study indicated that all quality control tests performed on all the three mammography systems which included; kVp repeatability and accuracy test, output repeatability and linearity test, half value layer measurement, as well as automatic exposure control repeatability measurement were all within the acceptable levels.

The Mean Glandular Dose (MGD) to patients was estimated, and the results showed that, the calculated MGDs received by patients with various breast thicknesses from the three facilities were within the dose limits of the European Protocol for the Quality Control of Physical and Technical Aspects of Mammography Screening. However, patients with a breast thickness of 30mm within the two age groups of 40-49years and 50-64years received doses that were higher than the acceptable dose values. A patient in the age group of 40-49years with breast thickness of 30mm received 1.83mGy as calculated MGD, 2.10mGy was the recorded dose and 1.58mGy was recorded under the age group 50-64years. These values have deviated by -22%, -40%, and -5.33% respectively from 1.5mGy which is the recommended dose for a breast thickness of 30mm.Also patients with breast thickness of 70 mm in the age group 40–49years had a recorded dose of

6.58mGy, which deviated by -1.21% from the recommended value of 6.5mGy for that breast thickness. These were all values from the Korle-Bu Teaching Hospital. The study revealed that the equipment at the Korle-Bu Teaching Hospital, which is a full field digital (DR) system, delivered more doses to patients than Trust Hospital and Supreme Specialist Centre which use Computed Radiography systems.

5.2 Recommendations

From the conclusion of this study the following recommendations are made for relevant stakeholders to help optimise radiation protection in digital mammography practices.

5.2.1 Radiographers

It is recommended that dose optimisation should be done in the various mammography units, especially the mammography unit at the Korle-Bu Teaching Hospital by using the manufacturers recommended protocols.

5.2.2 Hospital Authorities

It is recommended that health facilities should employ medical physicists to perform quality control tests on their equipment.

5.2.3 Further Research Work

- From literature, conventional systems deliver most doses to patients, followed by CRs and then DRs. This means DRs are supposed to give the least dose to patients, but the results of this work show otherwise. This goes to prove that the assessment of dose to patients is an important study and more work should be done to know why Korle-Bu Teaching Hospital is delivering more doses.
- Due to time constraints and the breakdown of the Korle-Bu mammography equipment, image quality assessment was not performed. It is therefore recommended that further research should be done in that areato determine the

tradeoff between image quality and patient dose for optimization of the protection of patient.

- It is also recommended that, more quality control tests should be done to include more facilities.
- Due to the limited number of patients data collected, risk assessment was not done; it is therefore recommended that further work should be done in the area of risk assessment.

REFERENCES

.

- ACR (2003). ACR practice Guideline for the performance of diagnostic mammography.
- Akrobortu, M., Boadu, M., Yeboah, J., Schandoff, C. and Gyekye, P. K. (2013).Inter-Comparison of Dose Indicators and Mean Glandular Dose for some selected Diagnostic Mammography Units in Accra, Ghana. *International Journal of Science and Technology- Volume 3 No. 5, May 2013. 291-295.*
- American Cancer Society (2013). Breast cancer facts and figures. Retrieved from: www.cancer.org/research/cancerfactsstatistics/breast-cancer-facts-figures, Retrieved on (23/09/2015).
- American College of Radiology (1998). ACR BI-RADS Breast imaging reporting and data system. *3rd edition. Reston, Va: ACR; 1998.3*
- Amoako, A. (2014). Breast cancer cases up. *Daily Guide newspaper.*
- Assiamah, M. (2004). Dosimetric Techniques for Mammography Mass Screening Programs. *4-10*
- Bick, U. and Diekmann, F. (2010). Digital mammography. *Medical radiology-Diagnostic imaging.332-345.*
- Breast Imaging Center (2015). Advantages of Digital mammography- Speed and the ability to manipulate the digital image. *University of Rochester Medical Center, Rochester NY.1-5*
- Breastcancer.org (2013). Mammography Technique and Types. Retrieved from: www.breastcancer.org. Retrieved on (25/092015).

- Chevalier, M., Leyton, F., Nogueira, M. T., Oliveira, M., da Silva, T. A. and Peixoto, E. (2012). Image Quality Requirements for Digital Mammography in Breast Cancer Screening, Imaging of the Breast - Technical Aspects and Clinical Implication, Laszlo Tabar (Ed.), ISBN:978-953-51-0284-7.
- Ciraj-Bjelac, O., Avramova-Cholakova, S., Beganovic, A., Economide, S. Faj, D. Gershan, V., Grupetta, E., Kharita, M. H., Milakovic, M., Milu, C,Muhogora, W. E., Muthuvelu, P. Oola, S., Setayeshi, S., Schandorf, C., Ursulean, I., Zaman, I. R. V. A., Ziliukas, J.and Rehani, M. M. (2011). Image quality and dose in mammography in 17 countries in Africa, Asia andEastern Europe: Results from IAEA projects. *European Journal of Radiology. 1-8.*
- Crosta, P. (2015). Cancer; Facts, types and causes. Retrieved from: www.medicalnewstoday.com/info/cancer-oncology/, Retrieved on: (09/10 2015) at 10:15 Am.
- Dance, D. R., Christofides, S., Maidment, A. D. A., Mclean, I. D. and Ng, K. H. (2014)Diagnostic Radiology Physics –A handbook for teachers and students. *274-300*
- Dance, D. R., Skinner, C. L., Young, K. C., Beckett, J. R. and Kotre, C. J. (2000). Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol.*Phys. Med. Biol. 45 (2000) 3225–3240. Printed in the UK.*
- Dellie, S. T., Rao, A. D. P., Admassie, D .and Meshesha, A. Z. (2012). Evaluation of mean Glandular Dose during Diagnostic Mammography Examination for

Detection of Breast Pathology, in Ethiopia. *OMICS Journal of Radiology, Volume 1. Issue 4. 1000109.1-6.*

- Donga, L., Chua, T. C., Lee, J. S., Lanc, G. Y., Wua, T. H., Yeh, Y. H. and Hwang, J. J. (2002). Estimation of mean-glandular dose from monitoring breast entrance skin air kerma using a high sensitivity metal oxide Semiconductor field effect transistor (MOSFET) dosimeter system in mammography. *Applied Radiation and Isotopes 57 (2002) 791–799.*
- Dustler, M., Andersson, I, Brorson, H., Frojd, P., Mattsson, S., Tingberg, A., Zackrisson, S. and Fornvik, D. (2012). Breast Compression in Mammography: Pressure Distribution Patterns.
- Engen, R. V., Young, K., Bosmans, H. and Thijssen, M. (2005). European protocol for the quality control of the physical and technical aspects of mammography screening.
- European Nuclear Society (2015). TissueWeighting Factor. Retrieved fromhttps://www.euronuclear.org/info/encyclopedia/t/tissue-weigh-factor.htm. Retrieved on (23/09/2015).
- Ghanaweb (2015). Health statistics. Retrieved from: www.ghanaweb.com/ghanahomepage/health/stats.php, Retrieved on (17/08/2015).
- Goodman, T. R. (2015). Ionizing Radiation Effects and their risk to humans. Retrieved from www.imagewisely.org/imaging-modalities/. Retrieved on (28/09/2015).

- Haus, G. and Yaffe, M. J. (2000). Screen-film and Digital mammography. *Image Quality and Radiation Dose considerations- volume 38, issue 4,871-898.*
- Huda W, Sajewicz A.M, Ogden K.M, and Dance D.R (2003). Experimental investigation of the dose and image quality characteristics of a digital mammography imaging system. *Med. Phys. 30, 442–448 (2003).*
- International Atomic Energy Agency (2009). Quality Assurance Program For Screen Film Mammography. *IAEA Human Health Series No. 2. 125-130/203-205*
- International Atomic Energy Agency (2011). Quality Assurance Programfor Digital Mammography. *IAEA Human Health Series No. 17. 109-114*
- Kattar, Z. A., Balaa, H. E., Mazeh, Z., Fakih, M. Z., Shamas, N. and Eldeen, G. A. (2015). Radiation Dose Levels Assessment in Digital Mammography. *International Conference on Advances in Biomedical Engineering (ICABME). 37-40.*
- Marieb, E. N. (2006). *Essentials of Human Anatomy & Physiology*. (8th Edition). San Francisco, CA: PearsonBenjaminCummings. http://www.cancer.ca/en/cancer-information/cancer-type/breast/anatomy-and-physiology/?region=on#ixzz4LYPsAjFX. Retrieved on 28/09/2016 at 1:05pm
- Nordqvist, C. (2014). What are the effects of radiation on humans? What is radiation poisoning? Retrieved from: www.medicalnewstoday.com/articles/219615.php Retrieved on (18/11/2015).
- Pedram Argani, Ashley Cimino-Matthews. Anatomy and Physiology of the Breast (http://pathology.jhu.edu/breast/anatomy.php) Retrieved on 28/09/2016 at 1:00pm

- Rahmatnezhad, L., Behrouzkia, Z., Zeinali, A., Mohammady, M. H. and Jabbari, N. (2012). An Investigation of Mean Glandular Dose from Routine Mammography in Urmia, Northwestern Iran and the Factors Affecting It. *Research Journal of Applied Sciences, Engineering and Technology 4 (18): 3348-3353*.
- Theerakul, K. (2014). Patient Dose Measurement in Digital Mammography at King Chulalongkorn Memorial Hospital. *Journal of Siriraj Radiology Vol. 1 No. 1, 85-89.*
- Thomas, A. (2013). Latest world cancer statistics, Global cancer burden rises to 14.1 million new cases in 2012: Marked increase in breast cancers must be addressed. *International Agency for Research on cancer. WHO press release No 223. 1*
- United States Environmental Protection Agency (2015). Radiation Health Effects.
- Wambani, J. S., Korir,G. K., Shiyanguya B. M. N. and Korir, I. K. (2011). Assessment of patient doses during mammography practice at Kenyatta National Hospital. *East Africa Medical Journal Vol. 88 No. 11.368-376.*
- Wang, D and Jones, J. (2012). Deterministic effects. Retrieved from www.radiopaedia.org/articles/deterministic-effects. Retrieved on 28/09/2015).
- World Health Organisation (2015). Cancer. *Fact sheet No 297*

APENDICES

APENDIX A: DATA COLLECTION

TABLE 1: EQUIPMENT INFORMATION SHEET

	Characteristic	Results	
1	Type of Equipment	CR	DR
2	Manufacturer		
3	Model		
4	Year of make		
5	Serial number		
6	Mode of operation		
7	Anode/filter combination		
9	kVp range		
10	mAs range		

TABLE 2: SECONDARY DATA COLLECTION SHEET

	PARAMETERS	RESULTS	
1	Age of patient		
2	Type of exam	Diagnostic	Screening
3	Number of breasts imaged	Left	Right
4	Number of views taken	CC	MLO
5	Dose produced by each view	CC	MLO
6	CBT (mm)		
7	kVp		
8	mAs		
9	MGD (mGy)		

APPENDIX B: QUALITY CONTROL TESTS

TABLE 1: DATA SHEET FOR KVP ACCURACY AND REPEATABILITY MEASUREMENT

7.3.2 Accuracy and repeatability of kVp

kVp meter used:					
Meter setting:					
Nominal kVp setting					
Focal spot (large/small)					
mA setting					
mAs setting					
Measured kVp values					
kVp1					
kVp2					
Repeatability: difference (%)					
Additional measurements (if needed)					
kVp3					
kVp4					
kVp5					
Mean kVp <kVp>					
Standard deviation (SD)					
Repeatability: COV (%)					
Repeatability: acceptable?					
Nominal kVp - <kVp>					
Accuracy (%)					

	Tolerance	
Pass (Y/N)?	Repeatability: Difference ≤ 5% or	Accuracy: ±5%

Comments:

TABLE 2: DATA SHEET FOR HALF VALUE LAYER MEASUREMENT

7.3.3 Half-value layer

Dosimetry system used					
Units (mGy, mR)					
Nominal kVp setting					
Anode					
Filter					
Parameter, C					
mAs setting:					
Air kerma or exposure measurements:					
No aluminium filtration, M_0					
0.2 mm of added aluminium, M_1					
0.3 mm of added aluminium, M_2					
0.4 mm of added aluminium, M_3					
0.5 mm of added aluminium, M_4					
0.6 mm of added aluminium, M_5					
Repeat no aluminium filtration, M_0					
Average no aluminium filtration, M_0					
Record thicknesses (t_a<t_b) and air kerma or exposure values that bracket $k_0/2$: (K_a>K_b) — t_a					
t_b					
M_a					
M_b					
Calculated HVL (mm Al)					
Tolerance					
Minimum allowed HVL (mm Al)					
Maximum allowed HVL (mm Al)					
Acceptable (HVL)					
All HVLs acceptable					

TABLE 3: DATA SHEET FOR OUTPUT LINEARITY AND REPEATABILITY TEST

7.3.4 Output repeatability and linearity						
Dosimetry system used			Energy correction factor (N_{mammo})			
Units (enter "mGy" or "mR")			Focus-detector distance (cm)			
P(mbar)		Temp (°C)		T_0 (°C)		P_0 (mbar)
Pressure and temperature correction factor (k_{TP})* (for auto correction = 1)						1.00
		Focus size	Large			
		Anode	Mo			
		Filter	Mo			
		Nominal kVp setting	28			
mAs_1=	40	R1				
		R2				
		R3				
		R4				
		R5				
		Repeatability: Difference (%)				
		Average value				
		Standard deviation				
		Repeatability: COV (%)				
		Output (Y_1)				
mAs_2=	80	R1				
		R2				
		Average value				
		Output (Y_2)				
mAs_3=	120	R1				
		R2				
		Average value				
		Output (Y_3)				
Linearity		L_1				
		L_2				

APPENDIX C: PRIMARY/RAW RESULTS

TABLE 1: ACCURACY AND REPEATABILITY OF KVP

Nominal kVp setting		28
mAs setting		40
Measured kVp values		
	kVp 1	28.70
	kVp 2	28.05
Repeatability: difference (%)		2.32
Additional measurements		
	kVp 3	27.90
	kVp 4	27.82
	kVp 5	27.90
Mean kVp		28.07
Standard deviation (SD)		0.36
Repeatability: COV (%)		1.28
Accuracy (%)		-0.25
	Tolerance	
Pass (Y/N) ?	**Repeatability: Difference ≤5%**	**Accuracy: ± 5%**
	Y	**Y**

TABLE 2: HALF VALUE LAYER MEASUREMENT (KBTH)

Nominal kVp setting		28
Anode		W
Filter		Rh
Parameter, C		0.22
mAs setting:		40
Air kerma or exposure measurements:		
No aluminium filtration, K_0		1.450
0.2 mm of added aluminium, K_1		1.097
0.3 mm of added aluminium, K_2		0.967
0.4 mm of added aluminium, K_3		0.852
0.5 mm of added aluminium, K_4		0.752
0.6 mm of added aluminium, K_5		0.651
Repeat no aluminium filtration, K_0		1.445
Average no aluminium filtration, K_0		1.448
Record thicknesses (t_a<t_b) and air kerma or exposure values that bracket $k_0/2$: (K_a>K_b)	T_a	0.50
	T_b	0.60
	K_a	0.752
	K_b	0.651
Calculated HVL (mm Al)		0.580

Tolerance					
Minimum allowed HVL (mm Al)	0.31				
Maximum allowed HVL (mm Al)	0.58				
Acceptable (HVL)	**Y**				
All HVLs acceptable	**Y**				

Calculated HVL = $\frac{t_b \ln[2K_a/K_o] - t_a \ln[2K_b/K_o]}{\ln[K_a/K_b]}$

Minimum allowed HVL (mm Al):	kVp/100 + 0.03 (in mm Al)
Maximum allowed HVL (mm Al):	(kVp/100)+ C (in mm Al)
where C = 0.12 for Mo/Mo, 0.19 for Mo/Rh, 0.22 for Rh/Rh, and 0.30 for W/Rh	

TABLE 3: OUTPUT REPEATABILITY AND LINEARTY

Nominal kVp setting			28			
mAs_1 =	40	R1	1.445			
		R2	1.448			
		R3	1.444			
		R4	1.448			
		R5	1.447			
Repeatibility: Difference (%)			0.3			
Average value			1.446			
Standard deviation			0.0019			
Repeatibility: COV (%)			0.1			
Output (Y_1)			0.03615			
mAs_2 =	80	R1	2.902			
		R2	2.896			
Average value			2.899			
Output (Y_2)			0.036			
mAs_3 =	130	R1	4.519			
		R2	4.518			
Average value			4.519			
Output (Y_3)			0.036			
Linearity		L_1	-0.12			
		L_2				
Normalised output (µGy/mAs at 1m)						

Tolerance				
Repeatability @ 28 kVp: Difference ≤ 5% or COV ≤ 5%	Y			
Linearity:<± 10%	Y			

APENDIX D: FACTORS FOR THE ESTIMATION OF MEAN GLANDULAR BREAST DOSE

Table 2. *g*-factors (mGy/mGy) for breast thicknesses of 2–11 cm and the HVL range 0.30–0.60 mm Al. The *g*-factors for breast thicknesses of 2–8 cm are taken from Dance (1990).

Breast thickness (cm)	HVL (mm Al)						
	0.30	0.35	0.40	0.45	0.50	0.55	0.60
2	0.390	0.433	0.473	0.509	0.543	0.573	0.587
3	0.274	0.309	0.342	0.374	0.406	0.437	0.466
4	0.207	0.235	0.261	0.289	0.318	0.346	0.374
4.5	0.183	0.208	0.232	0.258	0.285	0.311	0.339
5	0.164	0.187	0.209	0.232	0.258	0.287	0.310
6	0.135	0.154	0.172	0.192	0.214	0.236	0.261
7	0.114	0.130	0.145	0.163	0.177	0.202	0.224
8	0.098	0.112	0.126	0.140	0.154	0.175	0.195
9	0.0859	0.0981	0.1106	0.1233	0.1357	0.1543	0.1723
10	0.0763	0.0873	0.0986	0.1096	0.1207	0.1375	0.1540
11	0.0687	0.0786	0.0887	0.0988	0.1088	0.1240	0.1385

Table 3. *s*-factors for clinically used spectra and maximum errors that can be incurred when they are used.

Spectrum	*s*-factor	Maximum error (%)
Mo/Mo	1.000	3.1
Mo/Rh	1.017	2.2
Rh/Rh	1.061	3.6
Rh/Al	1.044	2.4
W/Rh	1.042	2.1

Table 5. Average breast composition as a function of compressed breast thickness. Surface layers of 100% adipose tissue 0.5 cm thick are assumed.

Compressed breast thickness (cm)	Glandularity age 40–49 (%)	Glandularity age 50–64 (%)
2	100	100
3	82	72
4	65	50
5	49	33
6	35	21
7	24	12
8	14	7
9	8	4
10	5	3
11	5	3

Table 6. *c*-factors for glandularities of 0.1–100% in the central region of the breast, br thicknesses of 2–11 cm and HVLs of 0.30–0.60 mm Al. Surface layers of 100% adipose ti 0.5 cm thick are assumed.

HVL	Thickness	Breast glandularity				
(mm Al)	(cm)	0.1%	25%	50%	75%	100%
0.30	2	1.130	1.059	1.000	0.938	0.885
0.30	3	1.206	1.098	1.000	0.915	0.836
0.30	4	1.253	1.120	1.000	0.898	0.808
0.30	5	1.282	1.127	1.000	0.886	0.794
0.30	6	1.303	1.135	1.000	0.882	0.785
0.30	7	1.317	1.142	1.000	0.881	0.784
0.30	8	1.325	1.143	1.000	0.879	0.780
0.30	9	1.328	1.145	1.000	0.879	0.780
0.30	10	1.329	1.147	1.000	0.880	0.780
0.30	11	1.328	1.143	1.000	0.879	0.779
0.35	2	1.123	1.058	1.000	0.943	0.891
0.35	3	1.196	1.090	1.000	0.919	0.842
0.35	4	1.244	1.112	1.000	0.903	0.816
0.35	5	1.272	1.121	1.000	0.890	0.801
0.35	6	1.294	1.132	1.000	0.886	0.793
0.35	7	1.308	1.138	1.000	0.886	0.788
0.35	8	1.312	1.140	1.000	0.884	0.786
0.35	9	1.319	1.145	1.000	0.884	0.786
0.35	10	1.319	1.144	1.000	0.881	0.785
0.35	11	1.322	1.142	1.000	0.882	0.784
0.40	2	1.111	1.054	1.000	0.949	0.900
0.40	3	1.181	1.087	1.000	0.922	0.851
0.40	4	1.227	1.105	1.000	0.907	0.825
0.40	5	1.258	1.120	1.000	0.899	0.810
0.40	6	1.276	1.125	1.000	0.890	0.798
0.40	7	1.292	1.132	1.000	0.887	0.793
0.40	8	1.302	1.136	1.000	0.885	0.790
0.40	9	1.308	1.138	1.000	0.884	0.789
0.40	10	1.311	1.138	1.000	0.883	0.788
0.40	11	1.315	1.140	1.000	0.885	0.791
0.45	2	1.099	1.052	1.000	0.948	0.905
0.45	3	1.169	1.080	1.000	0.924	0.858
0.45	4	1.209	1.102	1.000	0.909	0.829
0.45	5	1.248	1.115	1.000	0.898	0.815
0.45	6	1.267	1.125	1.000	0.891	0.801
0.45	7	1.283	1.129	1.000	0.892	0.797
0.45	8	1.298	1.137	1.000	0.887	0.799
0.45	9	1.301	1.135	1.000	0.886	0.792
0.45	10	1.305	1.138	1.000	0.886	0.791
0.45	11	1.312	1.138	1.000	0.885	0.789
0.50	2	1.098	1.050	1.000	0.955	0.910
0.50	3	1.164	1.078	1.000	0.928	0.864
0.50	4	1.209	1.094	1.000	0.912	0.835
0.50	5	1.242	1.111	1.000	0.903	0.817
0.50	6	1.263	1.120	1.000	0.896	0.807
0.50	7	1.278	1.127	1.000	0.890	0.800
0.50	8	1.289	1.132	1.000	0.889	0.794
0.50	9	1.295	1.134	1.000	0.887	0.793
0.50	10	1.302	1.138	1.000	0.886	0.791
0.50	11	1.303	1.140	1.000	0.885	0.789

Table 6. (Continued)

HVL (mm Al)	Thickness (cm)	Breast glandularity				
		0.1%	25%	50%	75%	100%
0.55	2	1.086	1.043	1.000	0.955	0.914
0.55	3	1.154	1.071	1.000	0.932	0.870
0.55	4	1.196	1.093	1.000	0.918	0.843
0.55	5	1.227	1.105	1.000	0.906	0.824
0.55	6	1.252	1.115	1.000	0.900	0.814
0.55	7	1.267	1.122	1.000	0.896	0.805
0.55	8	1.278	1.125	1.000	0.890	0.800
0.55	9	1.285	1.128	1.000	0.890	0.798
0.55	10	1.290	1.133	1.000	0.889	0.796
0.55	11	1.293	1.134	1.000	0.888	0.793
0.60	2	1.089	1.045	1.000	0.959	0.919
0.60	3	1.142	1.065	1.000	0.933	0.874
0.60	4	1.185	1.090	1.000	0.923	0.850
0.60	5	1.216	1.102	1.000	0.910	0.830
0.60	6	1.238	1.113	1.000	0.904	0.820
0.60	7	1.252	1.120	1.000	0.899	0.812
0.60	8	1.266	1.123	1.000	0.894	0.806
0.60	9	1.272	1.124	1.000	0.893	0.801
0.60	10	1.279	1.125	1.000	0.891	0.797
0.60	11	1.284	1.129	1.000	0.893	0.798

Table 7. *c*-factors for average breasts for women in age group 40 to 49.

Breast thickness (cm)	HVL (mm Al)						
	0.30	0.35	0.40	0.45	0.50	0.55	0.60
2	0.885	0.891	0.900	0.905	0.910	0.914	0.919
3	0.894	0.898	0.903	0.906	0.911	0.915	0.918
4	0.940	0.943	0.945	0.947	0.948	0.952	0.955
5	1.005	1.005	1.005	1.004	1.004	1.004	1.004
6	1.080	1.078	1.074	1.074	1.071	1.068	1.066
7	1.152	1.147	1.141	1.138	1.135	1.130	1.127
8	1.220	1.213	1.206	1.205	1.199	1.190	1.183
9	1.270	1.264	1.254	1.248	1.244	1.235	1.225
10	1.295	1.287	1.279	1.275	1.272	1.262	1.251
11	1.294	1.290	1.283	1.281	1.273	1.264	1.256

Table 8. *c*-factors for average breasts for women in age group 50 to 64.

Breast thickness (cm)	HVL (mm Al)						
	0.30	0.35	0.40	0.45	0.50	0.55	0.60
2	0.885	0.891	0.900	0.905	0.910	0.914	0.919
3	0.925	0.929	0.931	0.933	0.937	0.940	0.941
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	1.086	1.082	1.081	1.078	1.075	1.071	1.069
6	1.164	1.160	1.151	1.150	1.144	1.139	1.134
7	1.232	1.225	1.214	1.208	1.204	1.196	1.188
8	1.275	1.265	1.257	1.254	1.247	1.237	1.227
9	1.299	1.292	1.282	1.275	1.270	1.260	1.249
10	1.307	1.298	1.290	1.286	1.283	1.272	1.261
11	1.306	1.301	1.294	1.291	1.283	1.274	1.266

APENDIX E: RAW DATA COLLECTED

Table 9: Raw data from SSC

AGE	TYPE OF EXAM	NO OF BREAST IMAGED	NO OF VIEWS TAKEN	CBLCC	CBLMLO	CBRCC	CBRMLO	kVLCC	kVLMLO	kVRCC	kVRMLO	mALCC	mALMLO	mARCC	mARMLO
31	1	1	4	20.00	20.00	25.00	25.00	23.00	24.00	24.00	24.00	52.00	49.00	58.00	60.00
35	2	1	4	25.00	25.00	25.00	25.00	24.00	24.00	24.00	24.00	58.00	62.00	58.00	61.00
36	2	1	4	25.00	30.00	25.00	25.00	24.00	25.00	24.00	25.00	61.00	72.00	65.00	68.00
36	1	1	4	30.00	30.00	25.00	30.00	24.00	25.00	25.00	25.00	67.00	76.00	68.00	72.00
38	1	1	4	30.00	35.00	30.00	30.00	24.00	25.00	25.00	25.00	69.00	88.00	71.00	74.00
42	1	1	4	30.00	40.00	30.00	40.00	25.00	25.00	25.00	26.00	71.00	89.00	72.00	79.00
44	1	1	4	30.00	45.00	30.00	40.00	25.00	26.00	25.00	26.00	74.00	92.00	76.00	81.00
45	1	1	4	30.00	45.00	35.00	40.00	26.00	26.00	25.00	26.00	78.00	98.00	87.00	83.00
46	2	1	4	35.00	45.00	40.00	40.00	26.00	27.00	25.00	27.00	78.00	99.00	89.00	84.00
46	1	1	4	40.00	50.00	40.00	40.00	26.00	27.00	25.00	27.00	93.00	104.00	97.00	96.00
47	1	1	4	45.00	50.00	45.00	45.00	26.00	27.00	26.00	27.00	96.00	107.00	102.00	104.00
47	1	1	4	50.00	55.00	45.00	50.00	26.00	28.00	26.00	28.00	106.00	120.00	105.00	104.00
48	1	1	4	50.00	55.00	45.00	50.00	26.00	28.00	26.00	28.00	113.00	123.00	105.00	106.00
48	1	1	4	50.00	60.00	45.00	55.00	26.00	28.00	26.00	29.00	116.00	129.00	109.00	107.00
49	1	1	4	55.00	65.00	50.00	60.00	26.00	29.00	27.00	29.00	118.00	130.00	113.00	107.00
53	1	1	4	55.00	65.00	50.00	65.00	27.00	29.00	27.00	29.00	118.00	130.00	118.00	121.00
53	1	1	4	55.00	70.00	55.00	70.00	27.00	29.00	27.00	29.00	119.00	131.00	119.00	123.00
54	1	1	4	55.00	70.00	55.00	70.00	27.00	30.00	27.00	29.00	119.00	133.00	128.00	129.00
55	1	1	4	60.00	70.00	55.00	70.00	27.00	30.00	27.00	29.00	143.00	136.00	130.00	140.00
57	1	1	4	60.00	75.00	60.00	80.00	27.00	30.00	28.00	30.00	144.00	140.00	130.00	147.00
61	2	1	4	60.00	75.00	60.00	80.00	28.00	31.00	28.00	30.00	158.00	146.00	136.00	149.00
61	1	1	4	60.00	75.00	65.00	80.00	28.00	31.00	29.00	31.00	160.00	167.00	140.00	154.00
70	1	1	4	65.00	85.00	70.00	90.00	28.00	31.00	29.00	32.00	205.00	172.00	150.00	168.00

Note: [1] and [2] under type of examination represent diagnostic and screening respectively.

: [1] and [2] under number of breast imaged represents both breast and one breast respectively

Table 10: Raw data from KBTH

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
33	1	BOTH	4	1.65	2.32	0.60	1.57	21.00	17.00	25.00	20.00	26.00	26.00	26.00	26.00	142.00	134.00	40.00	96.00
34	1	BOTH	5	1.72	1.92	1.82	2.88	25.00	32.00	24.00	36.00	26.00	27.00	26.00	27.50	116.00	131.00	120.00	100.00
36	1	BOTH	4	1.96	3.31	1.32	3.29	39.00	45.00	44.00	46.00	28.00	28.00	28.00	28.00	135.00	244.00	96.00	244.00
37	1	BOTH	4	1.16	3.36	1.99	1.82	35.00	46.00	38.00	45.00	27.00	28.00	28.00	28.00	82.00	250.00	134.00	134.00
37	1	BOTH	4	1.96	1.08	1.68	2.30	36.00	40.00	34.00	49.00	28.00	28.00	27.00	29.00	129.00	75.00	117.00	156.00
38	1	BOTH	4	2.07	2.29	2.08	1.39	33.00	38.00	31.00	33.00	27.00	28.00	27.00	27.00	143.00	154.00	140.00	96.00
40	1	BOTH	6	1.02	0.89	0.83	1.75	2.00	2.00	3.00	3.00	23.00	23.00	23.00	23.00	75.00	66.00	62.00	40.00
40	1	BOTH	6	1.02	1.58	0.83	1.06	2.00	2.00	3.00	2.00	23.00	23.00	23.00	23.00	75.00	66.00	62.00	40.00
40	1	BOTH	5	1.18	1.28	3.40	1.98	29.00	26.00	30.50	33.00	26.00	26.00	26.50	27.00	88.00	88.00	134.00	137.00
40	1	BOTH	5	1.18	1.28	3.40	1.98	29.00	26.00	32.00	33.00	26.00	26.00	26.50	27.00	88.00	88.00	134.00	137.00
40	1	BOTH	4	1.67	1.71	1.78	1.51	25.00	25.00	26.00	27.00	26.00	26.00	26.00	26.00	113.00	115.00	123.00	106.00
40	1	BOTH	7	3.29	4.06	5.37	9.38	44.50	60.00	41.50	60.00	28.00	30.00	28.00	29.50	113.00	274.00	238.00	348.00
40	1	BOTH	7	3.29	4.06	5.37	9.38	44.50	60.00	41.50	60.00	28.00	30.00	28.00	29.50	113.00	274.00	238.00	348.00
41	1	BOTH	4	1.66	0.58	1.72	1.21	29.00	29.00	25.00	30.00	26.00	26.00	26.00	26.00	123.00	43.00	117.00	92.00
41	1	BOTH	5	2.02	1.97	4.33	1.94	20.00	30.00	18.00	33.00	26.00	27.00	26.00	27.00	123.00	132.00	126.00	134.00
41	1	BOTH	4	1.72	1.92	1.93	1.61	40.00	40.00	42.00	38.00	28.00	28.00	28.00	28.00	120.00	134.00	137.00	109.00
41	1	BOTH	8	3.55	7.77	3.32	2.98	45.00	44.50	43.50	39.00	28.00	28.00	28.00	28.00	262.00	256.00	120.00	52.00
41	1	BOTH	8	3.55	6.76	3.32	3.99	45.00	47.00	43.50	40.00	28.00	28.00	28.00	28.00	262.00	256.00	120.00	52.00
41	1	BOTH	4	3.26	4.37	3.28	3.78	53.00	54.00	56.00	58.00	29.00	29.00	30.00	30.00	228.00	308.00	212.00	250.00
41	1	BOTH	4	3.26	4.37	3.28	3.78	53.00	54.00	56.00	58.00	29.00	29.00	30.00	30.00	228.00	308.00	212.00	250.00
42	1	BOTH	4	1.38	1.48	1.75	1.88	28.00	41.00	22.00	36.00	26.00	28.00	26.00	28.00	100.00	104.00	111.00	123.00
42	1	BOTH	4	1.43	1.92	1.48	2.27	29.00	34.00	27.00	35.00	26.00	27.00	26.00	28.00	106.00	134.00	104.00	146.00
42	1	BOTH	6	1.82	2.01	1.61	4.67	25.00	30.00	28.00	27.80	26.00	27.00	26.00	26.50	123.00	134.00	116.00	134.00
42	1	BOTH	4	1.90	1.53	2.13	1.86	22.00	33.00	17.00	31.00	26.00	27.00	26.00	27.00	120.00	106.00	123.00	126.00
42	1	BOTH	4	1.90	2.03	2.07	1.99	22.00	33.00	21.00	31.00	26.00	27.00	26.00	27.00	120.00	140.00	129.00	135.00
42	1	BOTH	5	1.98	2.33	2.01	4.34	21.00	17.00	19.00	18.50	26.00	26.00	26.00	26.00	123.00	135.00	120.00	129.00
42	1	BOTH	4	2.02	1.97	1.99	2.01	37.00	32.00	33.00	32.00	28.00	27.00	27.00	27.00	134.00	135.00	137.00	137.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
42	1	BOTH	4	2.02	1.97	1.99	2.01	37.00	32.00	33.00	32.00	28.00	27.00	27.00	27.00	134.00	135.00	137.00	137.00
43	1	BOTH	4	1.76	1.20	0.91	1.99	34.00	30.00	35.00	41.00	27.00	26.00	27.00	28.00	123.00	92.00	65.00	140.00
43	1	BOTH	4	1.87	2.06	1.97	2.01	34.00	37.00	32.00	32.00	27.00	28.00	27.00	27.00	131.00	137.00	134.00	137.00
43	1	BOTH	4	1.92	1.76	1.89	3.35	34.00	44.00	37.00	61.00	27.00	28.00	28.00	30.00	134.00	129.00	126.00	228.00
43	1	BOTH	4	1.58	2.48	1.97	1.90	39.00	36.00	42.00	38.00	28.00	28.00	28.00	28.00	109.00	162.00	140.00	128.00
43	1	BOTH	5	2.35	3.98	1.86	1.87	50.00	32.00	43.00	31.00	28.00	27.00	28.00	27.00	180.00	140.00	134.00	126.00
43	1	BOTH	5	2.35	3.98	1.86	1.87	50.00	32.00	43.00	31.00	28.00	27.00	28.00	27.00	180.00	140.00	134.00	126.00
44	1	BOTH	5	1.45	3.38	2.10	2.01	26.00	30.50	30.00	32.00	26.00	27.00	27.00	27.00	100.00	134.00	140.00	138.00
44	1	BOTH	4	1.64	1.71	1.64	1.74	26.00	25.00	25.00	26.00	26.00	26.00	26.00	26.00	113.00	115.00	111.00	120.00
44	1	BOTH	5	1.78	4.04	1.82	1.71	23.00	19.50	20.00	22.00	26.00	26.00	26.00	26.00	115.00	129.00	111.00	109.00
44	2	BOTH	4	1.98	2.02	1.18	2.04	33.00	37.00	30.00	31.00	27.00	28.00	26.00	27.00	137.00	134.00	90.00	137.00
44	1	BOTH	4	0.84	3.35	2.93	3.34	45.00	50.00	50.00	47.00	28.00	28.00	28.00	28.00	62.00	256.00	224.00	250.00
44	1	BOTH	4	0.84	3.35	2.93	3.34	45.00	50.00	50.00	47.00	28.00	28.00	28.00	28.00	62.00	256.00	224.00	250.00
44	1	BOTH	6	1.80	2.55	3.77	6.55	44.00	48.00	42.00	54.50	28.00	28.00	28.00	29.50	131.00	192.00	129.00	220.00
44	1	BOTH	6	1.80	2.55	3.77	6.55	44.00	48.00	42.00	54.50	28.00	28.00	28.00	29.50	131.00	192.00	129.00	220.00
44	1	BOTH	4	1.82	4.96	2.33	5.18	47.00	69.00	48.00	69.00	28.00	30.00	28.00	30.00	126.00	357.00	176.00	373.00
44	1	BOTH	4	1.82	4.96	2.33	5.18	47.00	69.00	48.00	69.00	28.00	30.00	28.00	30.00	136.00	357.00	176.00	373.00
44	1	BOTH	7	4.27	4.77	3.84	3.22	45.00	40.00	41.00	49.00	28.00	28.00	28.00	28.00	200.00	113.00	128.00	244.00
44	1	BOTH	7	4.27	4.77	3.84	3.22	45.00	44.50	44.00	49.00	28.00	28.00	28.00	28.00	200.00	113.00	128.00	244.00
45	1	BOTH	4	1.58	1.64	1.61	1.64	24.00	26.00	24.00	25.00	26.00	26.00	26.00	26.00	104.00	113.00	107.00	111.00
45	1	BOTH	7	1.73	5.30	1.93	10.31	35.00	41.50	32.00	52.00	27.00	27.50	27.00	28.00	123.00	250.00	132.00	188.00
45	1	BOTH	7	1.73	7.84	1.93	7.77	35.00	56.00	32.00	48.50	27.00	29.50	27.00	29.00	123.00	250.00	132.00	188.00
45	1	BOTH	4	1.93	2.12	2.00	1.96	37.00	38.00	36.00	46.00	28.00	28.00	28.00	28.00	129.00	143.00	131.00	145.00
45	1	BOTH	4	4.92	6.78	4.36	4.31	67.00	76.00	63.00	72.00	30.00	31.00	30.00	31.00	348.00	474.00	300.00	292.00
46	1	BOTH	4	2.18	1.26	2.31	1.62	9.00	7.00	11.00	9.00	24.00	24.00	25.00	24.00	147.00	82.00	141.00	109.00
46	2	BOTH	4	1.57	1.98	1.85	1.99	23.00	22.00	20.00	18.00	26.00	26.00	26.00	26.00	102.00	126.00	113.00	117.00
46	2	BOTH	4	2.15	1.63	2.04	2.08	19.00	27.00	18.00	31.00	26.00	26.00	26.00	27.00	129.00	115.00	120.00	140.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
46	1	BOTH	4	1.86	4.88	1.75	2.45	41.00	53.00	34.00	46.00	28.00	29.00	27.00	28.00	131.00	340.00	123.00	256.00
46	1	BOTH	5	1.88	7.20	1.71	3.06	42.00	42.00	43.00	49.00	28.00	28.00	28.00	28.00	134.00	216.00	123.00	232.00
46	1	BOTH	4	2.82	3.29	3.06	3.17	48.00	50.00	49.00	59.00	28.00	29.00	28.00	30.00	212.00	224.00	232.00	212.00
46	1	BOTH	4	2.82	3.29	3.06	3.17	48.00	50.00	49.00	59.00	28.00	29.00	28.00	30.00	212.00	224.00	232.00	212.00
46	1	BOTH	6	4.05	3.96	3.66	3.92	37.50	56.00	41.00	57.00	28.00	30.00	28.00	30.00	137.00	256.00	137.00	256.00
46	1	BOTH	6	4.05	3.96	3.66	3.92	37.50	56.00	41.00	57.00	28.00	30.00	28.00	30.00	137.00	256.00	137.00	256.00
47	1	BOTH	4	0.37	0.80	2.14	1.46	5.00	4.00	4.00	6.00	23.00	23.00	24.00	24.00	29.00	61.00	135.00	94.00
47	1	BOTH	4	1.93	1.64	1.93	2.02	14.00	24.00	19.00	20.00	25.00	26.00	26.00	26.00	123.00	108.00	115.00	123.00
47	1	BOTH	4	1.93	1.64	1.93	2.02	14.00	24.00	19.00	20.00	25.00	26.00	26.00	26.00	123.00	108.00	115.00	123.00
47	1	BOTH	4	0.91	2.06	4.76	3.54	29.00	32.00	53.00	49.00	26.00	27.00	29.00	28.00	68.00	141.00	332.00	268.00
47	1	LEFT	3	2.64	5.08			31.50	51.00			26.50	29.00			120.00	348.00		
47	1	LEFT	3	2.64	5.08			33.00	51.00			26.50	29.00			120.00	348.00		
47	1	BOTH	4	0.84	1.62	1.15	1.27	35.00	32.00	34.00	35.00	27.00	27.00	27.00	27.00	60.00	111.00	81.00	90.00
47	1	BOTH	4	2.04	1.91	2.30	1.86	38.00	41.00	36.00	41.00	28.00	28.00	28.00	28.00	138.00	135.00	151.00	131.00
47	1	RIGHT	2			1.88	4.76			40.00	53.00			28.00	29.00			131.00	333.00
48	1	BOTH	6	0.95	1.41	0.53	1.76	4.00	1.00	4.00	1.50	23.00	23.00	23.00	23.00	72.00	57.00	40.00	71.00
48	1	BOTH	6	0.95	1.41	0.53	1.76	4.00	1.00	4.00	1.50	23.00	23.00	23.00	23.00	72.00	57.00	40.00	71.00
48	1	BOTH	5	2.17	2.12	1.80	4.10	8.00	8.00	15.00	8.00	24.00	24.00	25.00	24.00	143.00	141.00	117.00	140.00
48	1	BOTH	5	2.17	2.12	1.80	4.10	8.00	8.00	15.00	9.00	24.00	24.00	25.00	24.00	143.00	141.00	117.00	140.00
48	1	BOTH	4	1.61	2.12	1.91	2.36	30.00	38.00	34.00	46.00	26.00	28.00	27.00	28.00	123.00	143.00	134.00	175.00
48	1	BOTH	4	1.61	2.12	1.91	2.36	30.00	38.00	34.00	46.00	26.00	28.00	27.00	28.00	123.00	143.00	134.00	175.00
48	1	BOTH	7	1.09	5.32	3.81	8.18	33.00	38.50	45.00	49.00	27.00	27.50	28.00	28.50	75.00	144.00	244.00	332.00
48	1	BOTH	7	3.91	5.83	2.73	3.21	35.50	50.00	30.50	58.00	27.50	29.00	27.00	30.00	137.00	333.00	134.00	212.00
48	1	BOTH	5	1.84	4.37	2.62	3.09	46.00	50.00	50.00	56.00	28.00	28.50	28.00	30.00	137.00	224.00	200.00	200.00
48	1	BOTH	5	1.84	3.29	2.62	4.17	46.00	47.00	50.00	56.00	28.00	29.00	28.00	30.00	137.00	224.00	200.00	200.00
48	2	BOTH	5	1.87	5.02	1.82	12.08	39.00	56.00	41.00	61.00	28.00	30.00	28.00	30.00	129.00	324.00	129.00	381.00
48	1	RIGHT	2			2.16	2.89			37.00	47.00			28.00	28.00			143.00	216.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
49	2	BOTH	5	1.44	1.61	3.01	1.57	19.00	28.00	20.00	27.00	26.00	26.00	26.00	27.00	86.00	116.00	88.00	111.00
49	1	BOTH	4	1.61	1.80	1.70	2.14	26.00	40.00	27.00	36.00	26.00	28.00	26.00	28.00	111.00	126.00	120.00	140.00
49	1	BOTH	4	1.95	1.37	1.87	1.93	31.00	34.00	34.00	40.00	27.00	27.00	27.00	28.00	132.00	96.00	131.00	134.00
49	1	BOTH	4	1.95	2.22	2.42	2.22	31.00	35.00	36.00	38.00	27.00	28.00	28.00	28.00	132.00	143.00	158.00	150.00
49	1	BOTH	5	2.02	5.17	1.66	3.27	29.00	46.00	29.00	53.00	27.00	28.50	26.00	29.00	131.00	224.00	123.00	228.00
49	2	BOTH	4	2.08	1.35	1.87	4.45	38.00	44.00	43.00	55.00	28.00	28.00	28.00	29.00	140.00	98.00	134.00	316.00
49	2	BOTH	4	2.08	1.35	1.87	4.45	38.00	44.00	43.00	55.00	28.00	28.00	28.00	29.00	140.00	98.00	134.00	316.00
49	1	BOTH	4	2.53	3.90	1.82	3.18	49.00	55.00	45.00	52.00	28.00	30.00	28.00	29.00	192.00	250.00	134.00	220.00
49	1	BOTH	4	2.75	3.75	3.26	5.97	59.00	65.00	55.00	78.00	30.00	30.00	29.00	31.00	184.00	262.00	232.00	423.00
49	1	RIGHT	2			6.58	7.01			69.00	60.00			30.00	30.00			473.00	473.00
49	1	RIGHT	2			6.58	7.01			69.00	60.00			30.00	30.00			473.00	473.00
50	1	BOTH	4	0.91	1.01	0.95	0.83	2.00	1.00	2.00	1.00	23.00	23.00	23.00	23.00	68.00	74.00	71.00	61.00
50	1	BOTH	4	1.63	2.28	1.57	1.99	18.00	18.00	20.00	18.00	26.00	26.00	26.00	26.00	96.00	134.00	96.00	117.00
50	1	BOTH	8	1.83	4.69	2.06	3.66	34.00	33.50	30.00	35.00	27.00	27.00	27.00	27.00	129.00	123.00	138.00	140.00
50	1	BOTH	4	1.64	4.80	1.87	3.23	46.00	60.00	47.00	59.00	28.00	30.00	28.00	30.00	121.00	324.00	140.00	216.00
50	1	BOTH	4	1.80	1.97	1.63	1.84	42.00	42.00	45.00	40.00	28.00	28.00	28.00	28.00	129.00	140.00	120.00	129.00
50	1	BOTH	4	1.84	3.23	1.49	2.08	42.00	59.00	44.00	47.00	28.00	30.00	28.00	28.00	131.00	216.00	109.00	155.00
50	1	BOTH	4	2.17	3.07	2.57	1.47	35.00	46.00	47.00	43.00	28.00	28.00	28.00	28.00	140.00	228.00	192.00	106.00
50	1	BOTH	4	2.52	6.49	2.64	3.59	49.00	68.00	50.00	61.00	28.00	30.00	29.00	30.00	191.00	463.00	180.00	244.00
50	1	BOTH	4	5.63	3.44	1.96	3.08	54.00	46.00	39.00	48.00	29.00	28.00	28.00	28.00	397.00	256.00	134.00	232.00
50	1	BOTH	4	5.63	3.44	1.96	3.08	54.00	46.00	39.00	48.00	29.00	28.00	28.00	28.00	397.00	556.00	134.00	232.00
51	1	BOTH	4	1.65	1.62	1.57	1.62	27.00	29.00	27.00	28.00	26.00	26.00	26.00	26.00	117.00	120.00	111.00	117.00
51	1	BOTH	4	2.19	1.93	1.40	2.05	19.00	40.00	30.00	40.00	26.00	28.00	26.00	28.00	131.00	134.00	106.00	143.00
51	1	BOTH	4	2.19	1.93	1.40	2.05	19.00	40.00	30.00	40.00	26.00	28.00	26.00	28.00	131.00	134.00	106.00	143.00
51	1	LEFT	4	3.32	3.42			23.50	31.50			26.00	27.00			129.00	88.00		
51	1	LEFT	4	3.32	3.42			23.50	31.50			26.00	27.00			129.00	88.00		
51	1	BOTH	4	1.83	2.26	1.88	1.86	34.00	37.00	40.00	43.00	27.00	28.00	28.00	28.00	129.00	150.00	131.00	134.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
51	1	BOTH	6	2.54	1.87	2.33	1.93	36.50	41.00	35.50	42.00	27.50	28.00	27.50	28.00	126.00	132.00	111.00	138.00
51	1	BOTH	4	1.63	4.13	1.85	3.69	45.00	61.00	44.00	64.00	28.00	30.00	28.00	30.00	120.00	281.00	135.00	256.00
51	1	BOTH	4	1.90	1.67	0.94	3.40	38.00	45.00	41.00	48.00	28.00	28.00	28.00	28.00	128.00	123.00	66.00	256.00
51	1	BOTH	5	2.18	2.13	2.02	3.92	42.00	39.00	34.00	38.50	28.00	28.00	28.00	28.00	156.00	146.00	129.00	134.00
52	1	BOTH	6	3.26	3.00	1.78	1.87	32.00	29.50	38.00	34.00	26.50	26.00	28.00	27.00	131.00	109.00	120.00	131.00
52	1	BOTH	6	3.26	1.43	3.35	1.87	32.00	30.00	38.00	34.00	27.00	26.00	28.00	27.00	131.00	109.00	120.00	131.00
52	1	BOTH	4	1.80	3.78	1.86	2.87	44.00	64.00	45.00	55.00	28.00	30.00	28.00	30.00	131.00	262.00	137.00	184.00
52	2	BOTH	4	1.82	2.66	1.85	2.37	45.00	56.00	44.00	49.00	28.00	30.00	28.00	28.00	135.00	172.00	135.00	180.00
52	1	BOTH	4	1.88	3.41	2.00	6.77	40.00	65.00	49.00	68.00	28.00	30.00	28.00	30.00	131.00	238.00	152.00	483.00
52	1	BOTH	4	1.88	3.41	2.00	6.77	40.00	65.00	49.00	68.00	28.00	30.00	28.00	30.00	131.00	238.00	152.00	483.00
52	1	BOTH	4	2.14	1.86	1.78	2.40	36.00	43.00	43.00	47.00	28.00	28.00	28.00	28.00	140.00	134.00	129.00	179.00
52	1	BOTH	4	2.76	4.50	1.59	3.03	48.00	51.00	45.00	48.00	28.00	29.00	28.00	28.00	208.00	308.00	118.00	228.00
52	1	BOTH	4	7.44	6.66	3.48	5.78	86.00	102.00	59.00	68.00	32.00	32.00	30.00	30.00	509.00	508.00	232.00	413.00
52	1	RIGHT	4			3.96	4.12			30.50	43.00			27.00	28.00			131.00	176.00
53	1	LEFT	3	3.91	1.55			17.00	29.00			26.00	26.00			134.00	115.00		
53	1	BOTH	4	0.57	2.17	0.35	2.22	32.00	31.00	5.00	6.00	27.00	27.00	23.00	24.00	39.00	147.00	27.00	143.00
53	1	LEFT	2	1.90	1.77			33.00	35.00			27.00	27.00			132.00	126.00		
53	1	BOTH	5	3.59	4.42	2.01	2.56	32.50	53.00	32.00	50.00	27.00	29.00	27.00	28.00	138.00	308.00	138.00	195.00
53	1	BOTH	5	1.76	1.40	3.94	1.58	44.00	44.00	45.00	44.00	28.00	28.00	28.00	28.00	129.00	102.00	138.00	115.00
53	1	BOTH	5	1.76	1.40	3.94	1.58	44.00	44.00	45.00	44.00	28.00	28.00	28.00	28.00	129.00	102.00	138.00	115.00
53	1	BOTH	4	2.14	3.12	2.77	3.46	47.00	55.00	52.00	63.00	28.00	30.00	29.00	30.00	160.00	200.00	192.00	238.00
53	1	BOTH	4	2.20	1.96	2.09	3.41	37.00	39.00	39.00	50.00	28.00	28.00	28.00	29.00	146.00	134.00	143.00	232.00
53	1	RIGHT	3			5.63	4.73			49.50	57.00			28.50	30.00			204.00	309.00
54	1	BOTH	4	2.03	3.08	1.58	2.68	31.00	48.00	30.00	51.00	27.00	28.00	26.00	29.00	137.00	232.00	120.00	184.00
54	1	BOTH	4	2.11	1.59	1.66	1.65	29.00	28.00	28.00	32.00	27.00	26.00	26.00	27.00	138.00	115.00	120.00	113.00
54	2	BOTH	4	1.86	1.95	1.83	2.42	41.00	43.00	43.00	49.00	28.00	28.00	28.00	28.00	131.00	140.00	132.00	184.00
55	1	BOTH	4	2.10	2.12	1.47	1.90	7.00	8.00	10.00	11.00	24.00	24.00	24.00	25.00	138.00	140.00	100.00	115.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
55	1	BOTH	4	1.96	1.88	1.85	1.91	34.00	42.00	35.00	43.00	27.00	28.00	27.00	28.00	137.00	134.00	132.00	137.00
55	1	BOTH	6	3.45	8.11	1.90	3.96	34.50	54.00	41.00	56.00	27.00	29.00	28.00	30.00	129.00	433.00	134.00	256.00
55	1	BOTH	6	3.45	8.11	1.90	3.96	34.50	54.00	41.00	56.00	27.00	29.00	28.00	30.00	129.00	433.00	134.00	256.00
55	1	BOTH	4	2.35	3.29	2.38	3.71	50.00	59.00	51.00	63.00	28.00	30.00	29.00	30.00	179.00	220.00	163.00	256.00
55	1	BOTH	4	2.35	3.29	2.38	3.71	50.00	59.00	51.00	63.00	28.00	30.00	29.00	30.00	179.00	220.00	163.00	256.00
56	1	BOTH	4	1.59	2.97	1.97	2.71	32.00	56.00	28.00	56.00	27.00	30.00	26.00	30.00	134.00	125.00	115.00	192.00
56	2	BOTH	5	1.82	3.76	2.39	1.37	33.00	36.50	35.00	39.00	27.00	28.00	28.00	28.00	126.00	116.00	154.00	94.00
56	1	BOTH	4	1.92	3.22	1.86	1.88	32.00	49.00	31.00	40.00	27.00	28.00	27.00	28.00	131.00	244.00	126.00	131.00
56	1	BOTH	5	2.01	3.93	1.91	1.78	30.00	37.00	34.00	45.00	27.00	27.00	27.00	28.00	134.00	137.00	134.00	131.00
56	1	BOTH	5	2.01	3.93	1.91	1.78	30.00	37.00	34.00	45.00	27.00	27.50	27.00	28.00	134.00	137.00	134.00	131.00
56	1	BOTH	4	1.84	2.47	2.11	2.09	44.00	46.00	49.00	46.00	28.00	28.00	29.00	28.00	134.00	184.00	143.00	156.00
57	1	BOTH	4	1.78	2.03	1.99	1.91	20.00	21.00	18.00	20.00	26.00	26.00	26.00	26.00	108.00	126.00	117.00	116.00
57	1	BOTH	4	1.91	4.80	1.96	5.69	47.00	60.00	49.00	65.00	28.00	30.00	28.00	30.00	143.00	324.00	149.00	397.00
57	1	BOTH	4	1.93	3.70	1.34	4.37	42.00	64.00	44.00	63.00	28.00	30.00	28.00	30.00	138.00	256.00	98.00	301.00
58	1	BOTH	4	0.72	1.01	2.54	1.47	5.00	3.00	11.00	10.00	23.00	23.00	25.00	24.00	55.00	75.00	155.00	100.00
58	1	BOTH	4	1.57	1.95	1.98	1.84	25.00	31.00	33.00	40.00	26.00	27.00	27.00	28.00	106.00	131.00	137.00	129.00
58	1	BOTH	4	1.70	1.60	1.46	1.82	27.00	27.00	29.00	24.00	26.00	26.00	26.00	26.00	120.00	113.00	109.00	120.00
58	1	BOTH	5	3.37	1.99	1.55	1.48	26.50	31.00	29.00	30.00	26.00	27.00	26.00	26.00	111.00	134.00	115.00	113.00
58	1	BOTH	7	3.96	2.08	3.04	1.18	34.00	31.00	32.50	26.50	27.00	27.00	27.00	26.00	137.00	141.00	100.00	30.00
58	1	BOTH	7	3.96	2.08	3.04	1.18	34.00	31.00	32.50	26.50	27.00	27.00	27.00	26.00	137.00	141.00	100.00	30.00
58	1	RIGHT	2			1.78	1.90			36.00	41.00			28.00	28.00			116.00	134.00
59	1	BOTH	4	2.03	1.88	2.01	1.89	31.00	42.00	22.00	42.00	27.00	28.00	27.00	28.00	137.00	134.00	137.00	134.00
59	1	BOTH	4	1.80	3.77	1.97	5.65	40.00	56.00	42.00	56.00	28.00	30.00	28.00	30.00	126.00	244.00	141.00	365.00
59	1	BOTH	4	1.83	2.98	1.83	4.25	47.00	53.00	47.00	56.00	28.00	29.00	28.00	30.00	137.00	208.00	137.00	274.00
59	1	BOTH	4	1.83	2.98	1.83	4.25	47.00	53.00	47.00	56.00	28.00	29.00	28.00	30.00	137.00	208.00	137.00	274.00
59	1	BOTH	6	2.16	4.21	1.88	3.66	37.00	42.50	40.00	42.00	28.00	28.00	28.00	28.00	143.00	176.00	131.00	105.00
59	1	BOTH	5	2.29	2.21	1.85	1.42	36.00	29.00	35.00	30.00	28.00	26.00	27.00	26.00	150.00	104.00	132.00	109.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
60	1	BOTH	5	1.60	1.85	2.93	1.78	18.00	20.00	22.50	20.00	26.00	26.00	26.00	26.00	94.00	113.00	90.00	109.00
60	1	BOTH	6	1.80	3.78	1.84	4.10	16.00	17.00	13.00	15.00	26.00	25.50	25.00	25.50	102.00	115.00	115.00	113.00
60	1	BOTH	5	1.74	1.66	1.79	2.19	31.00	34.00	29.00	36.00	27.00	27.00	26.00	28.00	117.00		92.00	
60	1	BOTH	4	1.86	1.69	1.71	1.86	31.00	29.00	24.00	23.00	27.00	26.00	26.00	26.00	126.00	126.00	113.00	120.00
60	1	BOTH	5	2.00	3.92	1.83	1.65	36.00	39.50	34.00	44.00	28.00	27.50	27.00	28.00	131.00	146.00	128.00	120.00
61	1	BOTH	5	1.54	2.95	5.07	5.56	10.00	10.00	48.00	51.00	24.00	24.00	28.00	29.00	105.00	94.00	381.00	381.00
61	1	BOTH	6	2.11	2.74	0.92	1.51	7.00	6.00	5.00	3.00	24.00	24.00	23.00	23.00	138.00	132.00	71.00	51.00
61	2	BOTH	5	3.08	2.00	1.55	1.96	29.50	39.00	29.00	39.00	26.00	28.00	26.00	28.00	115.00	137.00	115.00	134.00
61	2	BOTH	5	3.08	2.00	1.55	1.96	29.50	39.00	29.00	39.00	26.00	28.00	26.00	28.00	115.00	137.00	115.00	134.00
61	1	BOTH	4	1.83	2.00	1.86	1.91	34.00	39.00	38.00	39.00	27.00	28.00	28.00	28.00	129.00	137.00	126.00	131.00
61	1	BOTH	4	1.90	2.04	1.78	2.35	33.00	46.00	31.00	50.00	27.00	28.00	27.00	28.00	132.00	151.00	120.00	179.00
61	1	BOTH	4	1.69	1.87	1.97	2.77	36.00	47.00	37.00	54.00	28.00	28.00	28.00	30.00	111.00	140.00	131.00	175.00
62	1	BOTH	4	1.48	1.52	3.61	3.22	30.00	29.00	52.00	49.00	26.00	26.00	29.00	28.00	113.00	113.00	250.00	244.00
62	1	BOTH	4	1.48	1.52	3.61	3.22	30.00	29.00	52.00	49.00	26.00	26.00	29.00	28.00	113.00	113.00	250.00	244.00
62	1	BOTH	7	1.73	4.74	1.77	7.62	42.00	50.50	44.00	50.00	28.00	28.50	28.00	28.50	123.00	167.00	129.00	180.00
62	1	BOTH	4	1.75	2.40	2.17	1.82	43.00	47.00	48.00	45.00	28.00	28.00	28.00	28.00	126.00	179.00	164.00	134.00
63	1	BOTH	4	1.32	1.71	1.56	1.65	20.00	19.00	18.00	16.00	26.00	26.00	26.00	26.00	81.00	102.00	92.00	94.00
63	1	BOTH	4	1.32	1.71	1.56	1.65	20.00	19.00	18.00	16.00	26.00	26.00	26.00	26.00	81.00	102.00	92.00	94.00
63	1	BOTH	6	1.53	5.66	4.95	6.29	30.00	38.50	54.00	63.00	26.00	27.50	29.00	30.00	116.00	145.00	348.00	433.00
63	1	BOTH	5	2.96	1.85	1.62	1.88	30.00	35.00	29.00	34.00	26.00	27.00	26.00	27.00	113.00	131.00	120.00	132.00
63	1	BOTH	5	1.75	1.36	1.91	4.39	39.00	45.00	41.00	49.50	28.00	28.00	28.00	28.50	120.00	100.00	135.00	159.00
63	1	BOTH	5	4.51	3.11	1.57	3.28	52.50	59.00	41.00	56.00	28.50	30.00	28.00	30.00	176.00	208.00	111.00	212.00
63	1	BOTH	5	2.47	3.11	3.61	3.28	55.00	59.00	45.50	56.00	29.00	30.00	28.00	30.00	176.00	208.00	111.00	212.00
64	1	BOTH	4	1.78	3.09	1.76	2.84	48.00	55.00	46.00	56.00	28.00	29.00	28.00	30.00	134.00	220.00	131.00	183.00
64	1	BOTH	4	1.78	3.09	1.76	2.84	48.00	55.00	46.00	56.00	28.00	29.00	28.00	30.00	134.00	220.00	131.00	183.00
64	2	BOTH	4	2.30	6.20	2.57	6.06	50.00	79.00	53.00	79.00	28.00	31.00	29.00	31.00	175.00	443.00	179.00	433.00
64	1	RIGHT	3			3.87	3.29			46.50	59.00			28.00	30.00			139.00	220.00

Table 10. (Continued)

AGE	EXAM	BREAST	VIEWS	DLCC	DLMLO	DRCC	DRMLO	CBLCC	CBLMLO	CBRCC	CBRMLO	KLCC	KLMLO	KRCC	KRMLO	MLCC	MLMLO	MRCC	MRMLO
65	1	BOTH	4	1.48	1.63	2.05	2.26	24.00	27.00	32.00	37.00	26.00	26.00	27.00	28.00	98.00	115.00	140.00	150.00
65	2	BOTH	4	1.88	3.32	1.24	2.95	32.00	51.00	44.00	49.00	27.00	29.00	28.00	28.00	129.00	228.00	90.00	224.00
65	1	RIGHT	3			1.93	4.02			11.00	16.00			25.00	25.50			118.00	132.00
66	2	BOTH	6	0.60	2.21	1.75	4.29	5.00	5.00	9.00	6.00	23.00	24.00	24.00	23.50	46.00	141.00	118.00	56.00
66	1	BOTH	6	1.70	5.86	2.14	3.16	27.00	46.50	34.00	48.00	26.00	28.00	27.00	28.00	120.00	216.00	143.00	238.00
66	1	BOTH	4	1.93	2.23	1.95	2.01	32.00	36.00	31.00	32.00	27.00	28.00	27.00	27.00	132.00	146.00	131.00	137.00
67	1	BOTH	5	1.73	2.71	2.03	1.53	10.00	5.50	11.00	10.00	25.00	23.50	25.00	24.00	104.00	59.00	123.00	104.00
67	2	BOTH	4	1.48	1.59	1.49	1.69	24.00	28.00	29.00	26.00	26.00	26.00	26.00	26.00	98.00	115.00	111.00	116.00
67	1	BOTH	5	1.62	4.45	2.01	1.70	29.00	40.00	32.00	41.00	26.00	27.50	27.00	27.00	120.00	192.00	138.00	120.00
67	1	BOTH	6	2.55	1.63	2.22	1.65	32.00	45.00	31.50	44.00	27.00	28.00	26.50	28.00	134.00	120.00	116.00	120.00
67	1	BOTH	8	2.24	4.47	5.13	3.77	36.00	36.00	37.50	40.50	28.00	28.00	28.00	28.00	147.00	146.00	140.00	135.00
69	1	BOTH	5	1.59	4.17	1.60	1.91	28.00	35.00	27.00	29.00	26.00	27.50	26.00	28.00	115.00	131.00	113.00	131.00
69	1	BOTH	4	1.92	1.29	1.86	1.88	32.00	30.00	33.00	39.00	27.00	26.00	27.00	28.00	131.00	98.00	129.00	129.00
69	2	BOTH	8	3.89	4.57	3.55	6.82	36.00	45.00	37.00	45.00	27.50	28.00	27.50	28.50	146.00	212.00	131.00	332.00
69	2	BOTH	4	2.20	2.77	1.91	4.72	37.00	50.00	39.00	54.00	28.00	28.00	28.00	29.00	146.00	212.00	131.00	332.00
69	1	BOTH	6	3.84	3.02	3.31	2.65	49.50	63.00	35.50	56.00	28.00	30.00	27.00	30.00	131.00	208.00	126.00	171.00
70	1	BOTH	4	1.80	2.01	1.69	1.92	17.00	13.00	16.00	17.00	26.00	25.00	26.00	26.00	104.00	126.00	96.00	111.00
70	1	BOTH	6	2.84	2.03	3.06	1.99	27.00	31.00	25.50	31.00	26.00	27.00	26.00	27.00	100.00	137.00	100.00	134.00
71	1	BOTH	5	1.76	1.91	3.72	2.58	40.00	41.00	42.00	46.00	28.00	28.00	28.00	28.00	123.00	134.00	126.00	192.00
72	1	BOTH	6	1.50	3.40	1.51	3.37	18.00	20.00	20.00	17.50	26.00	26.00	26.00	26.00	88.00	94.00	92.00	88.00
72	1	BOTH	6	1.50	3.40	1.51	3.37	18.00	20.00	20.00	17.50	26.00	26.00	26.00	26.00	88.00	94.00	92.00	88.00
73	1	BOTH	4	1.35	1.74	1.54	1.79	10.00	14.00	11.00	11.00	24.00	25.00	25.00	25.00	92.00	111.00	94.00	109.00
76	1	BOTH	6	1.49	3.20	1.61	3.63	29.00	27.00	35.00	29.00	26.00	26.00	28.00	26.50	111.00	111.00	104.00	131.00
76	1	BOTH	6	1.49	3.17	1.61	3.63	29.00	27.00	35.00	29.00	26.00	26.00	28.00	27.00	111.00	111.00	104.00	131.00
77	1	BOTH	4	2.01	2.09	1.74	1.95	9.00	9.00	28.00	33.00	24.00	24.00	26.00	27.00	135.00	141.00	126.00	135.00
80	1	BOTH	4	2.09	2.12	1.51	1.79	9.00	8.00	10.00	11.00	24.00	24.00	24.00	25.00	141.00	141.00	102.00	109.00
82	1	BOTH	4	1.88	2.21	1.80	1.99	17.00	11.00	23.00	16.00	26.00	25.00	26.00	26.00	109.00	135.00	116.00	113.00

Note: [1] and [2] under examination represent Diagnostic and screening respectively.

Table 11: Raw data from TH

AGE	EXAM	BREAST	VIEWS	IAK (mGy) BY EACH VIEW				CBT (mm)				kVp				mAs			
39	Diagnostic	Both	4	0.64	0.55	0.64	0.63	29.00	29.00	6.30	41.00	28.00	25.50	28.00	20.30	1.13	1.09	27.70	40.00
40	Diagnostic	Both	4	0.71	0.88	0.66	0.99	29.50	42.00	34.00	44.00	28.50	28.00	28.50	28.00	28.70	40.00	29.40	42.90
40	Diagnostic	Both	4	0.76	0.96	0.69	1.01	33.00	42.00	36.00	45.00	28.50	29.00	28.50	29.00	34.00	40.10	34.00	44.60
41	Diagnostic	Both	4	0.77	1.01	0.76	1.03	41.00	47.00	41.00	48.00	28.50	29.00	28.50	29.00	34.80	45.30	37.40	44.60
42	Diagnostic	Both	4	0.89	1.04	0.81	1.07	43.00	47.00	43.00	48.00	29.00	29.00	28.50	29.00	35.00	46.90	39.60	45.80
42	Screening	Both	4	0.90	1.06	0.85	1.09	43.00	48.00	44.00	50.00	29.00	29.00	28.50	29.00	40.00	47.80	39.80	52.00
42	Screening	Both	4	0.97	1.09	0.86	1.11	44.00	50.00	45.00	51.00	29.00	29.00	29.00	29.00	40.10	49.90	40.00	53.10
43	Screening	Both	4	0.98	1.12	0.87	1.12	44.00	52.00	45.00	51.00	29.00	29.00	29.00	29.00	45.60	53.10	40.30	55.30
44	Screening	Both	4	1.08	1.20	0.89	1.22	45.00	54.00	45.00	52.00	29.00	29.50	29.00	29.00	49.30	61.20	40.40	58.00
44	Screening	Both	4	1.09	1.29	0.91	1.26	45.00	55.00	45.00	53.00	29.00	29.50	29.00	29.00	49.40	62.80	40.60	61.60
45	Diagnostic	Both	4	1.10	1.32	0.93	1.34	46.00	55.00	46.00	54.00	29.00	29.50	29.00	29.00	50.00	65.00	43.00	62.20
45	Diagnostic	Both	4	1.10	1.35	0.96	1.34	48.00	57.00	46.00	54.00	29.00	29.50	29.00	29.50	51.50	65.20	44.60	63.50
45	Screening	Both	4	1.11	1.37	0.96	1.36	48.00	58.00	47.00	55.00	29.00	29.50	29.00	29.50	52.20	67.20	45.60	63.80
46	Screening	Both	4	1.12	1.41	0.97	1.37	50.00	58.00	47.00	55.00	29.00	29.50	29.00	29.50	52.20	68.90	45.90	68.30
46	Screening	Both	4	1.12	1.43	0.97	1.38	50.00	60.00	47.00	55.00	29.00	29.50	29.00	29.50	54.00	71.00	46.40	68.40
46	Screening	Both	4	1.13	1.45	1.04	1.43	51.00	60.00	48.00	55.00	29.00	29.50	29.00	29.50	57.00	73.10	49.00	70.00
46	Screening	Both	4	1.14	1.54	1.13	1.47	51.00	61.00	48.00	56.00	29.00	29.50	29.00	29.50	57.00	75.60	56.30	75.60
47	Diagnostic	One	2	1.14	1.55	1.14	1.51	52.00	62.00	51.00	57.00	29.00	29.50	29.00	29.50	57.10	77.80	56.90	76.30
47	Diagnostic	Both	4	1.15	1.60	1.14	1.51	53.00	63.00	51.00	57.00	29.00	29.50	29.00	29.50	57.40	84.50	57.00	76.50
47	Diagnostic	Both	4	1.20	1.67	1.16	1.53	53.00	63.00	52.00	58.00	29.50	29.50	29.00	29.50	60.50	86.50	57.20	77.60
48	Diagnostic	Both	4	1.21	1.68	1.18	1.60	56.00	63.00	52.00	58.00	29.50	29.50	29.00	29.50	60.90	88.30	59.00	78.60
48	Diagnostic	Both	4	1.28	1.80	1.20	1.63	56.00	63.00	53.00	58.00	29.50	30.00	29.50	29.50	62.10	94.30	59.10	80.60
49	Diagnostic	Both	4	1.30	1.80	1.30	1.64	56.00	64.00	54.00	60.00	29.50	30.00	29.50	29.50	63.50	94.90	59.70	81.30
50	Screening	Both	4	1.30	1.82	1.32	1.71	56.00	64.00	54.00	60.00	29.50	30.00	29.50	29.50	64.80	96.30	62.70	87.00

Table 11. (Continued)

AGE	EXAM	BREAST	VIEWS	IAK (mGy) BY EACH VIEW				CBT (mm)				kVp				mAs			
50	Screening	Both	4	1.34	1.86	1.32	1.80	57.00	65.00	55.00	62.00	29.50	30.00	29.50	29.50	65.20	96.30	64.90	94.00
51	Diagnostic	Both	4	1.34	1.87	1.32	1.89	57.00	66.00	56.00	62.00	29.50	30.00	29.50	30.00	66.70	96.50	66.10	97.90
51	Screening	Both	4	1.36	1.87	1.35	1.93	58.00	66.00	56.00	65.00	29.50	30.00	29.50	30.00	72.20	97.90	67.20	101.50
51	Screening	Both	4	1.45	1.90	1.36	2.01	58.00	66.00	57.00	65.00	29.50	30.00	29.50	30.00	73.80	99.00	67.80	105.20
51	Screening	Both	4	1.48	1.93	1.37	2.05	58.00	66.00	57.00	66.00	29.50	30.00	29.50	30.00	76.10	100.00	68.70	107.30
52	Diagnostic	Both	4	1.50	1.95	1.38	2.06	58.00	66.00	57.00	67.00	29.50	30.00	29.50	30.00	77.30	105.60	69.30	107.80
52	Screening	Both	4	1.50	2.01	1.41	2.14	59.00	66.00	58.00	68.00	29.50	30.00	29.50	30.00	78.70	106.80	69.80	108.40
52	Screening	Both	4	1.51	2.07	1.44	2.14	59.00	66.00	59.00	68.00	29.50	30.00	29.50	30.00	79.30	108.60	72.50	109.10
53	Screening	Both	4	1.53	2.10	1.47	2.17	60.00	67.00	60.00	69.00	29.50	30.00	29.50	30.00	80.10	112.10	74.10	112.10
54	Screening	Both	4	1.54	2.12	1.51	2.17	60.00	67.00	60.00	69.00	29.50	30.00	29.50	30.00	82.40	117.10	77.20	114.30
54	Screening	Both	4	1.62	2.17	1.52	2.18	61.00	70.00	60.00	69.00	29.50	30.00	29.50	30.00	86.60	117.10	77.70	116.60
54	Diagnostic	Both	4	1.71	2.20	1.54	2.18	61.00	71.00	60.00	70.00	30.00	30.00	29.50	30.00	90.20	120.00	77.90	117.10
54	Diagnostic	Both	4	1.75	2.28	1.55	2.22	61.00	72.00	62.00	70.00	30.00	30.00	29.50	30.00	90.70	122.70	78.20	117.90
55	Screening	Both	4	1.82	2.29	1.56	2.23	61.00	72.00	62.00	70.00	30.00	30.00	29.50	30.00	92.10	128.00	78.80	119.80
55	Screening	Both	4	1.83	2.31	1.59	2.23	62.00	73.00	62.00	71.00	30.00	30.00	29.50	30.00	92.60	130.00	80.60	119.90
55	Screening	Both	4	1.91	2.34	1.61	2.25	62.00	74.00	63.00	71.00	30.00	30.00	29.50	30.00	93.60	131.20	83.70	122.00
56	Screening	Both	4	1.92	2.51	1.65	2.25	63.00	74.00	63.00	71.00	30.00	30.50	29.50	30.00	97.00	144.20	83.80	123.60
56	Diagnostic	Both	4	1.96	2.62	1.65	2.29	63.00	74.00	64.00	73.00	30.00	30.50	29.50	30.00	97.60	144.40	84.20	124.40
57	Diagnostic	Both	4	1.96	2.75	1.66	2.31	64.00	75.00	64.00	75.00	30.00	30.50	29.50	30.00	102.50	145.30	87.40	124.50
57	Screening	Both	4	1.98	2.77	1.66	2.33	64.00	75.00	64.00	75.00	30.00	30.50	29.50	30.00	103.70	145.40	88.30	126.70
59	Screening	Both	4	2.07	2.78	1.69	2.39	64.00	76.00	65.00	75.00	30.00	30.50	29.50	30.00	107.60	146.90	89.10	132.10
59	Screening	Both	4	2.11	2.80	1.70	2.50	64.00	76.00	66.00	75.00	30.00	30.50	29.50	30.50	109.70	148.60	89.70	135.50
59	Diagnostic	Both	4	2.16	2.81	1.72	2.68	65.00	77.00	66.00	76.00	30.00	30.50	29.50	30.50	114.20	152.00	90.50	138.00
59	Screening	Both	4	2.16	2.96	1.73	2.70	67.00	77.00	66.00	76.00	30.00	30.50	29.50	30.50	121.50	153.60	91.20	138.70

Table 11. (Continued)

AGE	EXAM	BREAST	VIEWS	IAK (mGy) BY EACH VIEW				CBT (mm)				kVp				mAs			
60	Diagnostic	Both	4	2.21	3.00	1.87	2.75	69.00	78.00	67.00	76.00	30.00	30.50	30.00	30.50	122.40	162.10	97.60	144.70
60	Diagnostic	Both	4	2.25	3.01	2.02	2.77	70.00	78.00	67.00	77.00	30.00	30.50	30.00	30.50	126.20	172.30	98.50	145.30
61	Screening	Both	4	2.32	3.18	2.09	2.86	72.00	80.00	69.00	78.00	30.00	31.00	30.00	30.50	128.10	176.40	104.20	154.60
62	Diagnostic	Both	4	2.36	3.84	2.12	2.90	74.00	82.00	69.00	79.00	30.00	31.00	30.00	30.50	129.70	185.20	105.40	156.50
62	Screening	Both	4	2.59	4.42	2.12	2.98	76.00	83.00	71.00	79.00	30.50	31.00	30.00	30.50	134.00	225.20	113.70	157.10
62	Diagnostic	Both	4	2.60		2.17	3.10	78.00	89.00	72.00	79.00	30.50	31.00	30.00	30.50	136.50	225.50	115.10	164.40
62	Screening	Both	4	2.67		2.66	3.11	79.00	91.00	78.00	82.00	30.50	31.00	30.50	30.50	144.90	232.20	144.60	167.60
69	Screening	Both	4	2.68		2.77	5.01	79.00	91.00	79.00	82.00	30.50	36.50	30.50	30.50	189.50	269.40	149.70	186.60
70	Diagnostic	Both	4					87.00	97.00	82.00	83.00	57.70	51.70	30.50	30.50	236.00	296.40	154.30	194.00
70	Diagnostic	Both	4							85.00	89.00			30.50	31.00			186.80	301.50