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Assessment of conventional x-ray machine resolution using modulation transfer function

تقويم دقة جهاز الأشعة السينية التقليدية باستخدام وظيفة التعديل التحويلية

A thesis submitted for partial fulfillment of M.Sc. degree in Medical Physic

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الآية

(لَا يُكَلِّفُ اللَّهُ نَفْسًا إِلَّا وُسْعَهَا لَهَا مَا كَسَبَتْ وَعَلَيْهَا مَا
اكْتَسَبَتْ رَبَّنَا لَا تُؤَاخِذْنَا إِنْ نَسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلَا
تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِنْ قَبْلِنَا رَبَّنَا
وَلَا تُحَمِّلْنَا مَا لَا طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا
وَارْحَمْنَا أَنْتَ مَوْلَانَا فَانْصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ)

صدق الله العظيم

سورة البقرة - الآية 286

Dedication

To the spirit of my father

Acknowledgements

Great thanks and grace to Allah for guidance helping me finishing this research, my deep thanks and grateful appreciation extend to my teacher and supervisor Dr. Mohammed Elfadil for his support and guidance; without his help this work could not have been accomplished.

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List of contents

List of figures

Abstract

X-ray image resolution is important for resolving different structure since the diagnosis depends on visual perception ; therefore the main object of this study was to assess the diagnostic X-ray machine resolution using MTF in order to find the optimum exposure factor that preserve X-ray machine resolution. In order to determine the spatial resolution and to find the optimum KV, the phantom is placed on the detector surface then an image is acquired, with constant equal to 2 and KV of 40, 42, 44 and 46 kVp respectively. The images of the phantom were scanned to a computer, and Interactive Data Language IDL was used to apply modulation transfer function for the lines image to find the resolution for different KV and thickness. The result of this study showed that the resolution at 40 KV is better for the object image with low frequency 0.5 cycle/mm at 40 KV which is equal to 96% and reach 100% at 44 KV. The object with higher frequency 0.63 it is resolution increases from 48% at 40 KV progressively till it reach 92% at 46 KV. In summary the resolution get better for object image with higher frequency as the x-ray quanta increases but objects with lower frequency approaches the optimum level before that considerably.

المستخلص

الوضوح لصورة الاشعه السينية مهم لحل التراكيب المختلفة حيث إن التشخيص يعتمد على الملاحظة البصرية ، لذلك فان الهدف الأساسي من هذه الدراسة هو تقييم دقة وضوح جهاز الاشعه السينية باستخدام وظيفة التعديل التحويلي بالاضافه إلى ذلك إيجاد أفضل معامل للتعرض والذي يحافظ على دقة وضوح جهاز الأشعة السينية ولإيجاد أفضل وضوح وأفضل فولتيه تم وضع فانتم على سطح الكاشف وبعدها تم الحصول على الصورة بعد ضبط التيار عند 2 أمبير وتغير الفولتيه المستخدمة ب 40' 42'44و 46 كيلو فولت. مسحت صور الفانتوم الناتجة بالكمبيوتر وتم استخدام برنامج لغة البيانات التفاعلية لتطبيق وظيفة التعديل التحويلي لخطوط الصورة لإيجاد دقة الوضوح لمختلف الفولتيه والسمك. نتيجة هذه الدراسة وجد إن دقة الوضوح في 40 كيلو فولت للصورة أفضل مع تردد منخفض 0.5 دوره/مليمتر خلال والذي يساوي 96% ويصل إلى 100% في 44 كيلو فولت. الجسم بتردد عالي 0.63 دقة وضوحه تزيد من 48% خلال 40كيلوفولت بالتدرج إلى إن يصل 92% في 46 كيلو فولت. الخلاصة إن دقة الوضوح يكون أفضل لصورة جسم بتردد عالي عند زيادة كمية الأشعة السينية ولكن الجسم ذو التردد المنخفض يكون في أفضل مستوى قبل ذلك إلى حد كبير.

Chapter one

Introduction

Medical imaging is a multi step process by which information concerning patient anatomy and physiology is gathered and displayed with the modern technology. Radiography was the first medical imaging technology, made possible when the physicist Wilhelm Roentgen discovered x-rays on November 8, 1895. Roentgen also made the first radiographic images of human anatomy. Radiography (also called roentgenography) defined the field of radiology, and gave rise to radiologists, physicians who specialize in the interpretation of medical image.(Jerrold et al,2002). Radiography is performed with an x-ray source on one side of the patient, and an x-ray detector on the other side. A short duration less than 1/2 second pulse of x-rays is emitted by the x-ray tube, a large fraction of the x-rays interacts in the patient, and some of the x-rays pass through the patient and reach the detector, where a radiographic image is formed. The homogeneous distribution of x-rays that enter the patient is modified by the degree to which the x-rays are removed from the beam (i.e., attenuated) by scattering and absorption within the tissues (Jerrold et al , 2002).Image quality is a generic concept that applies to all types of images. It applies to medical images, photography, television images, and satellite reconnaissance images. "Quality" is a subjective notion and is dependent on the function of the image. In radiology, the outcome measure of the quality of a radiologic image is its usefulness in determining an accurate diagnosis. It is important to establish at the outset that the concepts of image quality discussed below are fundamentally and intrinsically related to the diagnostic utility of an image. Large masses can be seen on poor-quality images, and no amount of image fidelity will demonstrate pathology that is too small or faint to be detected. The true test of an imaging system, and of the radiologist that uses it, is the reliable detection and accurate depiction of subtle abnormalities. With diagnostic excellence as the goal, maintaining the highest image fidelity possible is crucial to the practicing radiologist and to his or her imaging facility. While technologists take a quick glance at the images they produce, it is the radiologist who sits down and truly analyzes them. Consequently, understanding the image characteristics that comprise image quality is important so that the radiologist can recognize problems, and articulate their cause, when they do occur (Jerrold et al , 2002)The need for sound quality control (QC) practices as part of a quality management program is important in digital imaging. Radiographers are the operators of complex imaging equipment and therefore are the individuals who may first recognize equipment malfunction. In addition, as with film-screen radiography,

human error can occur with digital imaging, and these errors must be acknowledged and corrected to prevent trends that could jeopardize patient radiation safety. Even more important, problems that occur in digital acquisition or processing equipment tend to be systematic problems, which can affect the quality of every image and the radiation exposure of every patient until the problems are identified and corrected. Acceptance testing, regular calibration and proactive and consistent QC can prevent thesesystematic errors; repeat analyses can contribute to overall department quality improvement . The attenuation properties of tissues such as bone, soft tissue, and air inside the patient are very different, resulting in the heterogeneous distribution of x-rays that emerges from the patient. The radiographic image is a picture of this x-ray distribution. The detector used in radiography can be photographic film (e.g., screen-film radiography) or an electronic detector system (i.e., digital radiography). Radiographic images are useful for a very wide range of medical indications, including the diagnosis of broken bones, lung cancer, cardiovascular disorders, etc. A number of parameters of an imaging device play a major role in the delineation of x-rays distribution (Jerrold et al , 2002).

1.1 X-ray

X-rays (or Roentgen rays) are a form of electromagnetic radiation with a wavelength in the range of 10 to 0.01 nanometers, corresponding to frequencies in the range 30 to 30 000 PHz (1015 hertz). X-rays are classified as ionizing radiation and are extensively used for industrial, medical diagnostic radiography and therapeutic purposes (Jerrold et al , 2002) .

1.2 Production of the x-ray

X-rays are produced when highly energetic electrons interact with matter and convert their kinetic energy into electromagnetic radiation. A device that accomplishes such a task consists of:

- X-ray tube.
- High tension generator.
- Control panel.

Specifically, the X-ray tube consist of X-ray tube insert which contains the cathode which is a helical filament of tungsten wire surrounded by a focusing cup ,negatively charged and is the source of electron ; the anode is a metal electrode, positively charged and is the target of electrons ; the tube housing is the supports, insulates, protects the x-ray tube insert from the environment and provides shielding and a coolant oil bath for the tube insert; collimators adjust the size and shape of the X-ray field emerging from the tube port ; filters are a sheets of metal intentionally placed in the beam to change its effective energy because the low-energy X-rays are absorbed by the filters instead of the patient. The generator is the energy source that supplies the voltage and the large voltage applied between two electrodes (the cathode and the anode) in an evacuated envelope to accelerate the electrons from the cathode to impact with the target and attain kinetic energy ,the conversion of electron kinetic energy into electromagnetic radiation which produces 1% X-rays and 99% unwanted heat. The generator also permits control of the X -ray output through the selection of voltage, current, and exposure time by selector knobs on the control panel (Jerrold et al , 2002).

A simplified diagram of an x-ray tube (Fig.1-1 and 1-2) illustrates the minimum components.

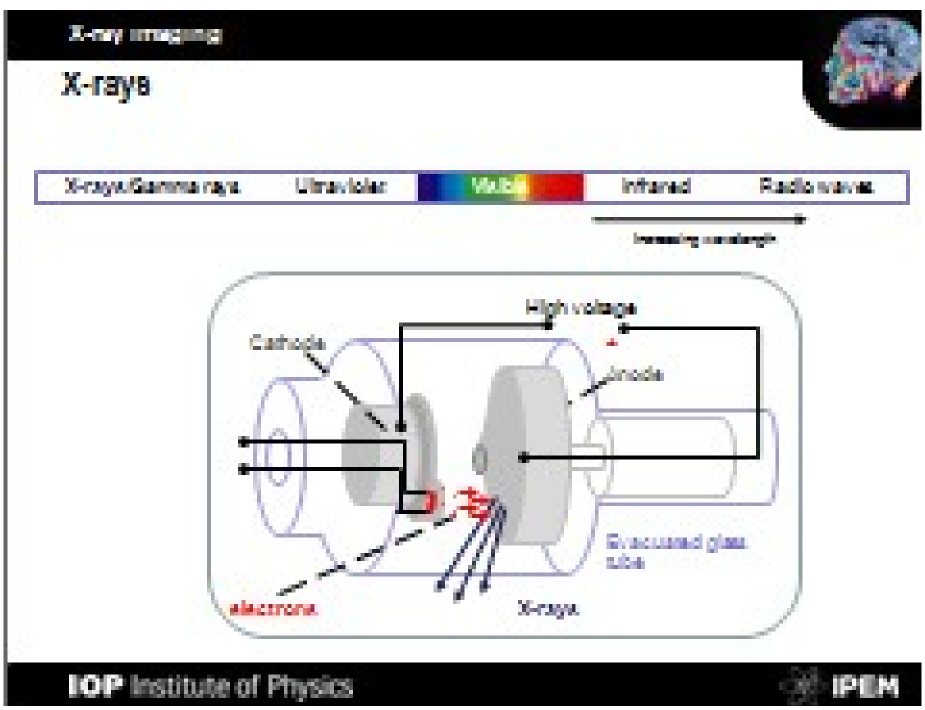


Fig (1-1).The minimum components of x-ray tube

1.3 The parameter of x-ray exposure

In radiography, dose and image quality are dependent on exposure parameters. The main exposure parameters are the x-ray tube current (MA), tube voltage (kVp), exposure time (s), focal spot size and focus to detector distance (cm). These exposure parameters define the dosage and work in concert to create a beam of x-ray photons of well-defined intensity, penetrability, and spatial distribution.

1.4 Historical review:

The discovery of X rays in 1895 was the beginning of a revolutionary change in our understanding of the physical world.

1.5 Problem of study:

The diagnostics x-ray machine produces electromagnetic radiation used to image the body in case of pathology, therefore this exposure were justified. But if the exposure parameters were not chosen satisfactory the image has to be repeated where the patient subjected to a substantial amount of radiation. In case of resolution were ever the exposures were repeated the quality will not be improved, therefore assessing the exposure factors that provides the optimum resolution will help in the judgment.

1.6 Objectives:

The general objective of this study was to assess the diagnostic x-ray machine resolution using MTF in order to find the optimum exposure factor that preserve x-ray machine resolution.

Specific objective:

- To acquire x-ray images for Hunger phantom using different KV.
- To generate a line transfer function (LTF) using phantom x-ray image profile for wires with different thickness and KV.
- To find the x-ray machine resolution from the phantom images using MTF through a computer function generated using IDL.

1.7 Significance of the study

This study will make it possible to obtain an optimize image ideal for diagnosis of the disease as well as applying the lowest dose to the patient in order to protect the patient while getting the best image quality. Also this study will introduce the a more reliable method of measuring the resolution which is modulation transfer function (MTF) which gives a complete description of the resolution instead of using full width half maximum (FWHM) or the visibility method which is more qualitative where MTF is a real quantitative method.

1.8 Overview of the study

This study is providing knowledge about the proper type of x- ray equipment selection to get best image quality with lower patient dose. Which is written in a simple and concise manner, including not only essential details but also many practice The Basic principles and underlying concepts are explained. The study consisted of five chapters; with Chapter one is an introduction which includes medical imaginig, definition of x-ray, x-ray production, as well as the problem of the study, an objective and significant of the study. Similarly Chapter two includes theoretical background and a comprehensive literatures review. Chapter three includes the methodology of the study which discussed the material used to collect the data and in the method followed in data acquisition. Chapter four which presented the results and Finally Chapter five which included discussion, conclusion and recommendations of the study.

Chapter two

Theoretical background

2.1 Medical X-ray:

X-ray are capable of penetrating some thickness of matter. Medical X-ray are produced by letting stream of fast electrons come to as sudden stop at metal plate ; it is believed that X-ray emitted by the sun or stars also come from fast electrons. The image produced by X-ray are due to the different absorption rates of different tissue . calcium in bones absorbs X-ray the most , so bones look white on a film recording of the X-ray image called a radiograph. Fat and other soft tissues absorb less, and look gray. Air absorbs the least , so lungs look black on a radiograph(Tracy L. Herrmann et al , 2014).

2.2 spatial resolution:

A two-dimensional image really has three dimensions: height, width, and gray scale. The height and width dimensions are spatial (usually), and have units such as millimeters. Spatial resolution is a property that describes the ability of an imaging system to accurately depict objects in the two spatial dimensions of the image. Spatial resolution is sometimes referred to simply as the *resolution.* The classic notion of spatial resolution is the ability of an image system to distinctly depict two objects as they become smaller and closer together. The closer together they are, with the image still showing them as separate objects, the better the spatial resolution. At some point, the two objects become so close that they appear as one, and at this point spatial resolution is lost (Jerrold et al , 2002).

2.2.1 Spatial Domain: The Point Spread Function:

The *spatial domain* simply refers to the two spatial dimensions of an image, for instance its width (X-dimension) and length (Y-dimension). One conceptual way of understanding (and measuring) the spatial resolution of a detector system in the spatial domain is to stimulate the detector system with a single point input, and then observe how it responds. The image produced from a single point stimulus to a detector is called a point response function or a point spread function (PSF). For example, a tiny hole can be drilled into a sheet of lead and used to expose an X-ray detector to a very narrow beam of X-rays. A point source of radioactivity can be used in nuclear imaging. For modalities that are topographic, a point spread function can be produced by placing a line stimulus through (and perpendicular to) the slice plane. A very thin metal wire is used in computed tomography (CT), a monofilament is used in ultrasound, and a small hole filled with water can be used in MRI (Jerrold et al , 2002).

2.2.2 The frequency domain:

The PSF and other spread functions are apt descriptions of the resolution properties of an imaging system in the spatial domain. Another useful way to express the resolution of an imaging system is to make use of the spatial frequenry domain. Most readers are familiar with sound waves and temporal frequency. The amplitude of sound waves vary as a function of time (measured in seconds), and temporal frequency is measured in units of cycles/see (see-I), also known as hertz. For example, the note middle A on a piano corresponds to 440 cycles/second. If the peaks and troughs of a sound wave are separated by shorter periods of time, the wave is of higher frequency. Similarly, for objects on an image that are separated by shorter distances (measured in millimeters),these objects correspond to high spatial frequencies (cycles/mm(Jerrold et al , 2002).

2.3 Modulation transfer function (MTF):

Modulation transfer function or MTF is the most widely used scientific method of describing lens performance .what is it exactly , how is it defined, and how is it measured . The modulation transfer function is, as the name suggests, a measure of the transfer of modulation (or contrast) from the subject to the image . in other words, it measure how faithfully the lens reproduces (or transfers) detail from the object to the image produced by the lens. First, look at the black and white bars in row A of the test pattern below. This pattern consist of totally black bars o a totally white background. If we assign the number 255 to the totally white areas, and 0to the totally black areas, and we plot aline profile of the test pattern , we get the graph shown in C. the regions at 0 correspond to the whit lines (Jerrold et al , 2002).

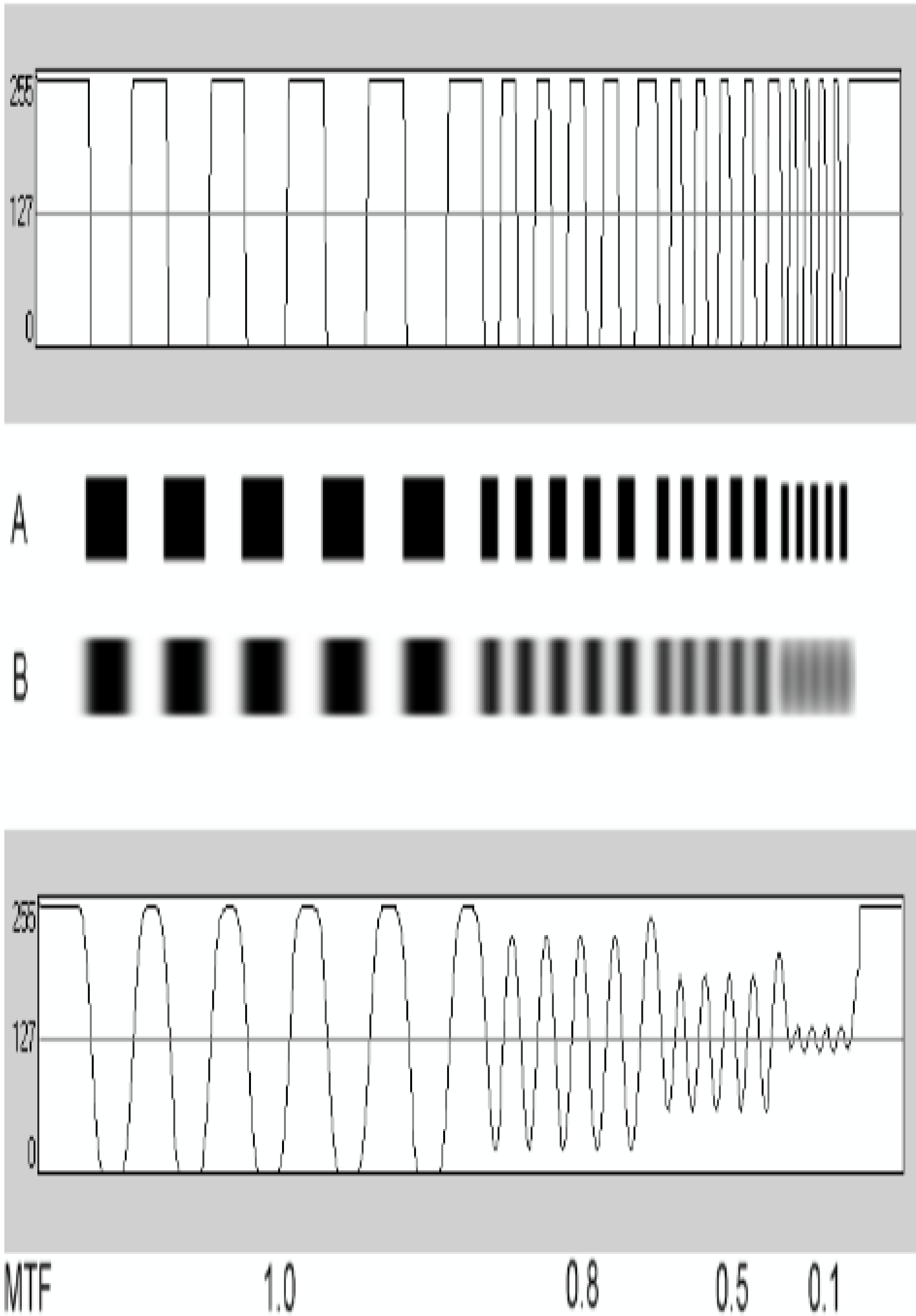


Fig 2-1 explain the original &image test

[A] is the original test pattern, [B] is the image of the test pattern, [C] is the profile of the original test pattern where 255 =white and 0=black, [D] is the line profile of the image of the test pattern where 255 =white and 0=black

MTF is a plot of signal modulation versus spatial frequency and mathematically can be given as follows: MTF(f) = **|** FFT{LTF(x)} **|;** where LTF stand for line transfer function; therefore The TF illustrates the fraction (or percentage) of an object's contrast that is recorded by the imaging system, as a function of the size

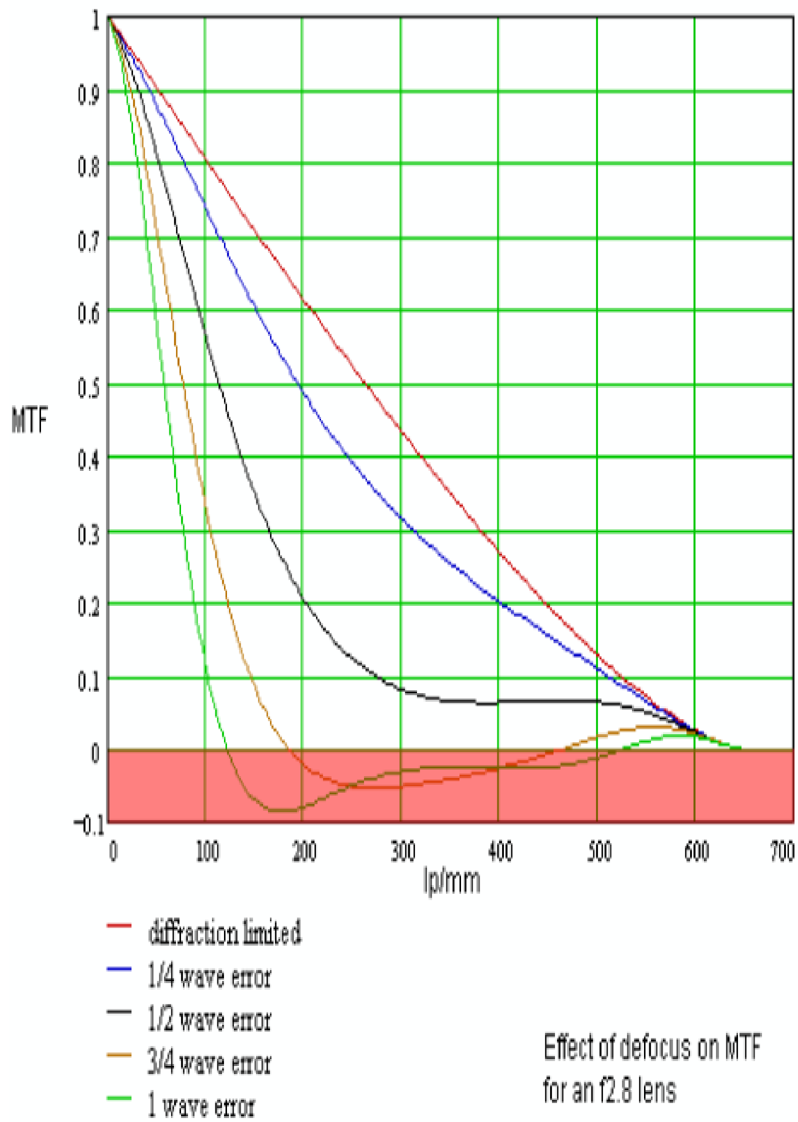


Fig 2-2 explain MTF vs. Lp/mm

2.4 Literature review (previous study):

Sezdi (2011) investigated dose optimization for the quality control tests of X-ray Equipment; to provide optimal X-ray parameters that may be used for quality control tests so making quality control activities more efficient and can be controlled. This study was performed by investigating the effects of X-ray parameters' changes on dose and by modeling of dose related to these parameters. After the modeling, according to the related parameters, the dose level can be controlled, in different x-ray units the dose levels that are obtained by applying the same parameter setting, can be compared. Thus, in addition to obtain optimal parameters, controlling of the accuracy of the measured dose values may be possible by calculating the dose value during quality control tests. The result showed that the optimized dose in which parameters' value gave the high quality image was determined.

Kumar et al. (2011) evaluated X-ray exposure parameters considering tube voltage and exposure time; to explore and analyze the x-ray exposure parameters levels which helps to diagnose and also has some hazardous health effects upon human exposure or the tissue which is being irradiated, Work has been carried out on people of different age groups ranging from 5 – 70 years. X-ray projections have been considered and the parameters influencing the radiography are being observed and are tabulated, the results there is adequate inverse proportionality between the Kvp and mAs, as the Kvp is increased the mAs is decreased irrespective of the age groups of different radiographic projections.

Son et al. (2006) x-ray imaging optimization using virtual phantoms and computerized observer modeling, The aim exposure, of This study is to develops and demonstrates a realistic X-ray imaging simulator with Computerized observers to maximize lesion detestability and minimize patient, A software package, ViPRIS, incorporating two computational patient phantoms, has been developed for simulating x-ray radiographic images. A tomographic phantom, VIP-Man, constructed from Visible Human anatomical color images is used to simulate the scattered portion using the ESGnrc Monte Carlo code, Several model observer tasks were used including SKE/BKE, MAFC and SKEV. The energy levels and fluency at the minimum dose required to detect a small lesion were determined with respect to lesion size, location and system parameters.

Ichikawa et al. (2003) Novel MTF Measurement Method for Medical Image Viewers Using a Bar Pattern Image, the aim of this study was to compare the measurements of MTF (modulation transfer function)for two models of medical image viewer equipped with monochrome displays using a bar pattern image, A bar-pattern image produced by a personal computer was displayed on a cathode-ray-tube (CRT) display and was imaged with a high resolution single-lens reflex digital camera equipped with a close-up lens. The discrete blurred square-waveform data acquired from the imaged bar patterns were interpolated using the waveform reproduction technique with Fourier analysis in order to obtain interpolated wave curves. All of the measured pixel values in this process were converted into luminance data. The MTF was calculated from the amplitude values of the extracted basic frequency components in the square waveform, in which an aliasing error was excluded, Resultant MTFs clearly indicated the difference in resolution for two viewers, as well as visual evaluation did. The standard deviations of MTF values of 5 measurements at Nyquist frequency were 0.004 and 0.01 for horizontal and vertical directions, respectively. Employment of a commercial single-lens reflex digital camera enabled easy and correct focusing and simple data handling.

Desaia et al. (2010) practical evaluation of image quality in computed Radiographic (CR) Imaging Systems, This study aims at explaining the image quality metrics in relation to visual changes observed in anthropomorphic phantom images in order to make comparisons between CR3600 digital imaging system with a test system which had one photomultiplier tube disabled, that by using Some of the commonly used metrics include Contrast to Noise ratio (CNR), limiting spatial resolution, Modulation Transfer Function (MTF), Noise Power Spectrum (NPS) and the Detective Quantum Efficiency (DQE). They developed practical and easy to use test objects (phantoms) and implemented software to aid in calculating each metric. The algorithm consists of the acquisition of an image of a tilted edge, construction of an oversampled edge spread function (ESF), differentiation of the ESF to obtain the line spread function (LSF), and finally, calculation of the Fourier transform of the LSF to obtain the MT. The plot of the MTF calculated by the software, the results of the experiment helped in identifying the differences between the images features that the image which obtained from the CR3600 machine has sharper edges and lower noise as compared to the other image which obtained from a test system which had one photomultiplier tube disabled.

Connor et al. (1988), the Line Resolution Pattern: A New Intrinsic Resolution Test Pattern for Nuclear Medicine, The purpose of this study was to examine the relationship between a four-quadrant bar pattern image and system intrinsic resolution and to design and evaluate a resolution test pattern that would permit rapid and easy quantitative assessment of intrinsic resolution without the need for computer analysis or comparison with previous test pattern images, The design considerations for the line resolution phantom (LRP) were that it should allow visual determination of intrinsic resolution to an accuracy of 0.5 mm in both x and y directions, it should permit measurements of line spread function to allow determination of full width half maximum FWHM and FWTM, and it should be usable on any type of gamma camera from the modem 50-60 cm field-of-view jumbo gamma cameras down to the 20-30 cm field-of-view mobile gamma cameras, the result shown that an image of the LRP obtained with a zoom factor of 2.0 on a 40 cm field-of-view gamma camera. The 3.5-mm slots are visible in both directions, but are better seen in the x direction compared to the y direction. These results are in good agreement with the line profile FWHM values of 3.3 mm and 3.7 mm in the x and y direction, respectively. Results were obtained from the. Evaluation on nine gamma cameras showed good agreement between results obtained with the LRP and measurement of resolution from the line spread function. The LRP is a simple and inexpensive test phantom which should find applications in quality control and acceptance testing.

Hassan (2001) Calculation of the Modulation Transfer Function from the Square Wave Response Function data with an interactive curve fitting software, The purpose of this article is to investigate aspects regarding the calculation of the MTF from the square wave response function SWRF data obtained from on site measurement in a hospital setting, using an interactive curve fitting software, they were using 19 groups of line pairs of 0.05 mm lead thickness was used for the measurement. Each line pair group has four line pairs, except the first which has two. The bar pattern was placed on screen-film, the exposures were made at 80 kVp with a 16 mm thick aluminum filter affixed to the X-ray tube window. The focus-to-film distance was 1.5 m. The image of the bar pattern was scanned with a microdensitometer (Photo scan System P-1000, Optronics International Inc., a computer program calculates the SWRF. The density values are converted to exposure values by the characteristic curve of the screen-film system. The modulation at each spatial frequency is determined, giving the SWRF. Finally, the SWRF is normalized by the square wave response factor at 0.25 line pairs/mm. An MTF calculator was constructed using a curve fitting software, The results from measured SWRF data a screen-film combination showed that the MTF of the first version was higher than the second by an average amount of 0.02 units for spatial frequency 0 3.5 cycles/mm, and on average the MTF of the first version was higher than the second by 10%. Both the SWRF data fitting and the MTF calculation were done within interactive curve fitting software which made the calculation relatively easy to perform.

Samartzis el al. (2010) The use of Modulation Transfer Function as an Overall Quality Control parameter in PET/CT, The objectives of this work were a) to prepare a film-based flood source, (i.e. a thin film with uniform distribution of a radioisotope) with a fast and low cost method, based on materials easily accessible at the hospital, b) to develop a new method form the Modulation Transfer Function (MTF) determination of a hybrid PET/CT system in three dimensions (3D) and c) to explore the possibility of using MTF as an overall quality control parameter in PET/CT. To develop a new method for MTF determination of PET/CT in three dimensions (3D), a novel and highly uniform, film based flood source using 18F-FDG has been prepared. The source was placed between PMMA blocks of various thicknesses, and imaged in a GE Discovery-ST, PET/CT system. MTF was then calculated from the line spread function (LSF) profile of the film. The result showed that iterative reconstructions are better than the Filtered Back Projection. A high MTF value in the low frequency range are needed to outline the coarse details of the image and is important for presentation and detection of relatively large but low contrast lesions. Consequently increased MTF values in the high frequency range are necessary to portray fine details and sharp edges. This is of obvious importance for small objects but also sometimes for larger objects be-cause of the importance of edges and sharp borders for detection of low contrast objects and for accurate assessment of their size and shape.

Chapter three

Methodology

3.1 Material:

X-ray: The X-ray units including TOSHIBA ROTANODE^{TM}, manufactured June2013 with a maximum voltage of 125Kv, focal spot 1.5/0.6, permanent filtration of 0.9AL/75.

Phantom: The designed phantom which was used to assess the diagnostic x-ray machine resolution was consisted of wires with different thickness (from 0.5L/mm to 5.0L/mm). The radiographic measurements were performed in conventional X-ray machines in Sudan University.

3.2 Design and sample type:

This is analytical study where the data collected from x-ray machine (for different Kv) using x-ray film and line bars phantom with a reference data.

3.3 Population of the study:

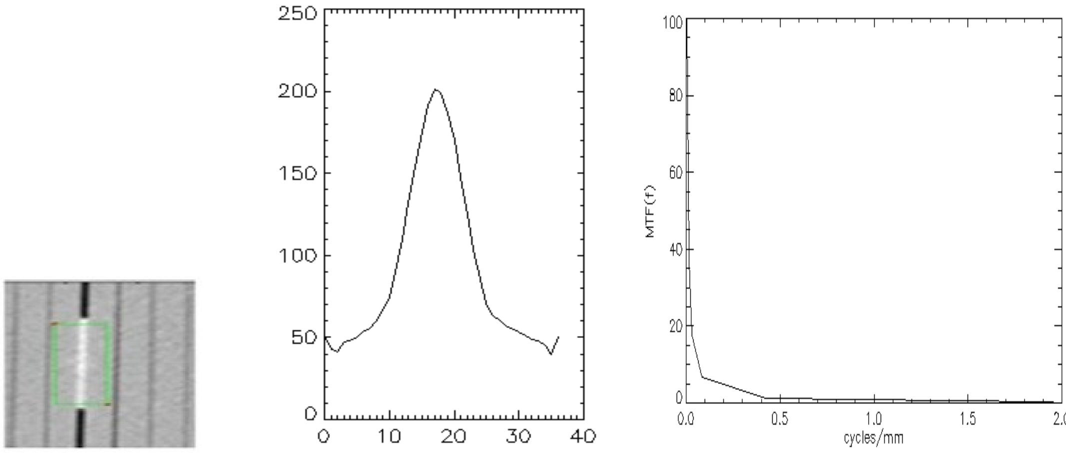
The inclusion criteria included x-ray units with a max tube voltage of 125KVp, with filtration of 0.9 AL at 75KV, with focal spot of 1.5/0.6 and the machines should have 3 phase generators.

3.4 Duration and place of the study:

This study conducted in the period from September 2014 to March 2015in Khartoum state Sudan University.

3.5 Method of data collection:

To determine the spatial resolution in order to find the optimum KV relative to machine type, the phantom is placed on the detector surface and source of radiation is placed above the hangar phantom that was the focus-to-film distance was 1m. An image is acquired, the units was set at 2mAs and 40kVp value. An X-ray exposure was made. This step was repeated at same constant mAs and different Kvp settings (40, 42 , 44 and 46kVp) and that was exposure of the x-ray machines. The choice of x-ray tube voltage (kV) affected the image contrast and is one of the adjustable factors of x-ray. The images of the phantom were scanned to a computer, and using Interactive Data Language IDL for generate a profile throw the lines in ordered to drown a curve and obtain the resolution, modulation transfer function and frequency of the lines with different Kv and thickness, Figure (3-1) shows a profile throw the line sinusoidal wave of line separate function and the spatial frequency of the image. Then calculation of the Fourier transform of the LTF to obtain the MTF an alternative is to use the Modulation Transfer Function (MTF) in order to describe the ability of the system to maintain the amplitudes of spatial frequencies passing through it and MTF is a plot of resolution, measured in percent, against spatial frequency measured in lp/mm. This graph is customarily normalized to a value of 1 at zero spatial frequency (all white or black).



(a1) (b1) (c1)

Fig (3-1) A Profile throws the line that (a1) coordinates of the line, (b1) the line separate function and (c1) the image spatial frequency that MTF is plotted on the y-axis, and the spatial frequency is plotted on the x-axis.

The spatial frequency (F) calculated by equation:

$$F = {}^{1/2}\mathbf{\Delta} \tag{3-1}$$

where$\mathbf{\Delta}$ is measured in millimeters.

Figure (3-2) shows the concept of spatial frequency, a single sine wave (bottom) with the width of one-half of the sine wave, which is equal to a distance Δ. The complete width of the sine wave (2Δ.) corresponds to one cycle. With Δ measured in millimeters, the corresponding spatial frequency is F $={}^{1/2}$Δ, Smaller objects (small Δ.) correspond to higher spatial frequencies, and larger objects (large Δ.) correspond to lower spatial frequencies. The sine wave corresponds to a single line.

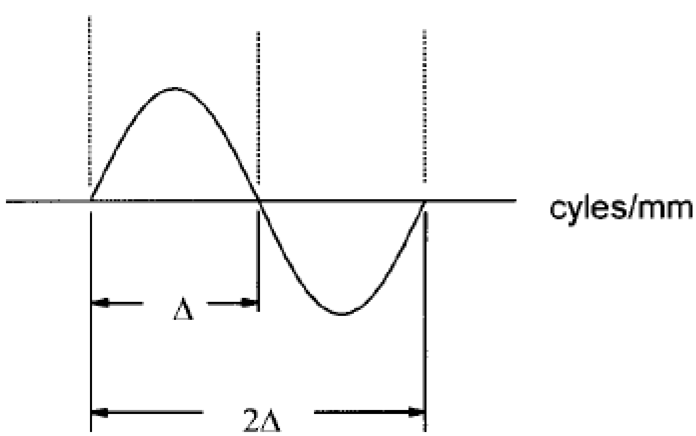


Fig (3-2).The concept of spatial frequency

Figure.3-3.Shows modulation transfer function *MTF*. When a spatial frequency v of an object is imaged, its amplitude may change. The ratio of the amplitude in the image of a spatial frequency to that in the object is known as modulation M. Measurement of M as a function of v yields the *MTF* of an imaging device. Ultimately, spatial resolution was defined by the 3% point of the modulation-transfer-function (MTF 3%), in units of line-pairs per mm (lp/mm).

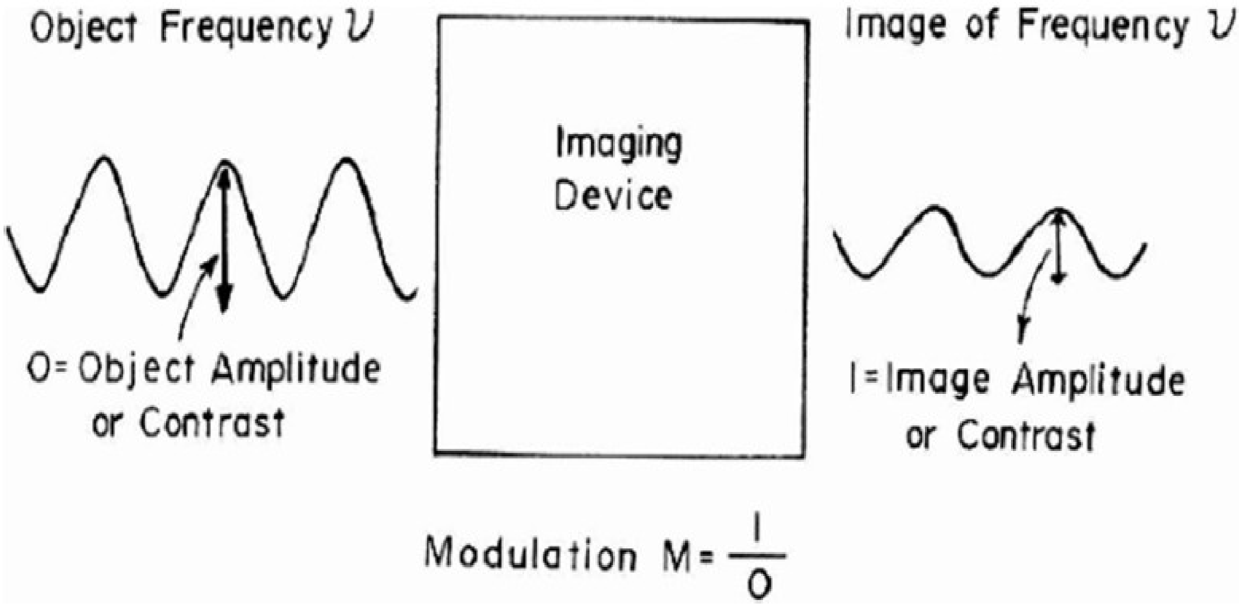


Fig (3-3).The ratio of the amplitude in the image of a spatial frequency to that in the object

The Modulation Transfer Function MTF calculated using Interactive Data Language IDL program. Modulation Transfer Function MTF gives the most complete characterization of the spatial resolution of an imaging device; Measure the degradation produced by an imaging device as a function of various spatial frequencies that were 1, 0.63, 0.89 and 0.79 cycles/mm, and these correspond (via Equation 3-1) to object sizes of 0.5,0.56 and 0.63mm.

Chapter four

Results

The results of this stud illustrated using tables, bar graphs, and line graphs for a phantom images consisted of wires with different object from 0.5 to 5.0 respectively which correspond to spatial frequency of 1 to 0.1cycles/mm respective. Each of the wire exposed to 40,42, 44 and 46 Kv.

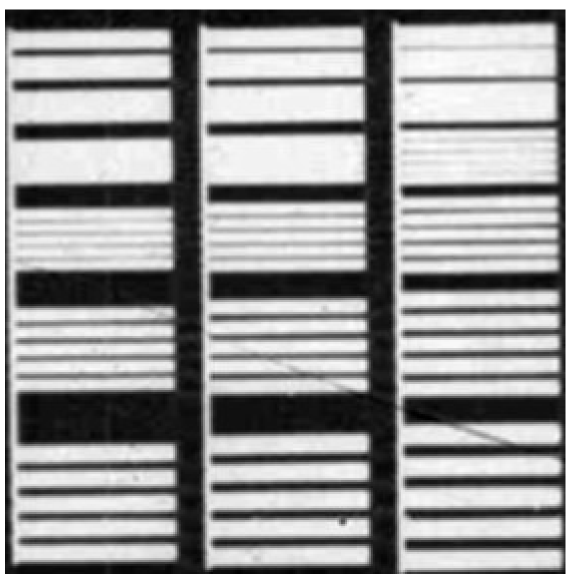


Figure 4-1 Hungar phantom image

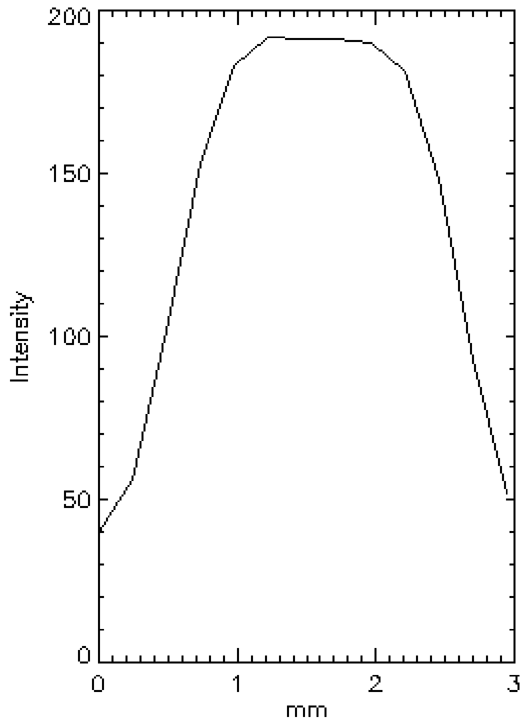


Figure 4-2 a line graph portrayed line transfer function (LTF) for the thickest line 0.5cycle/mm.

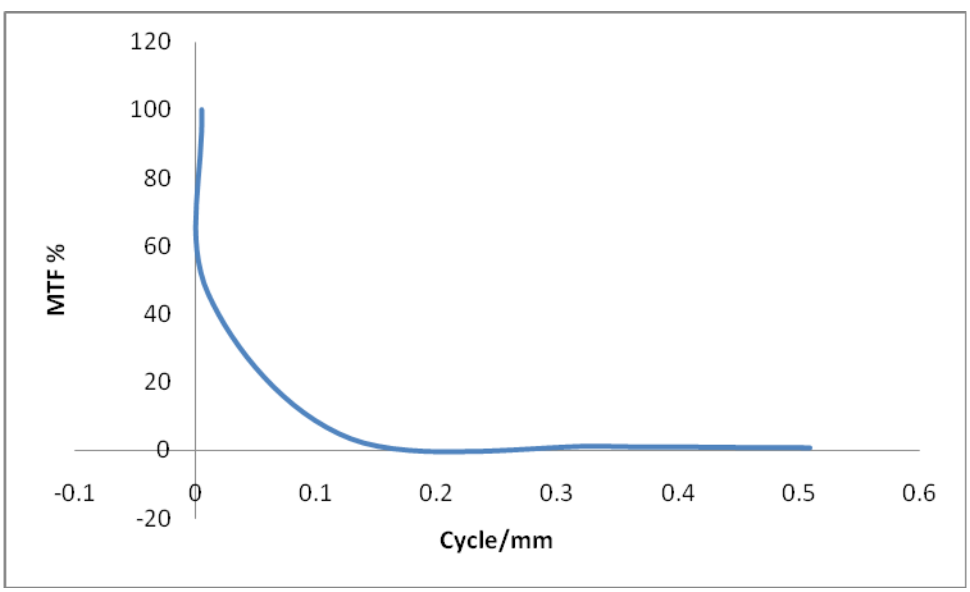
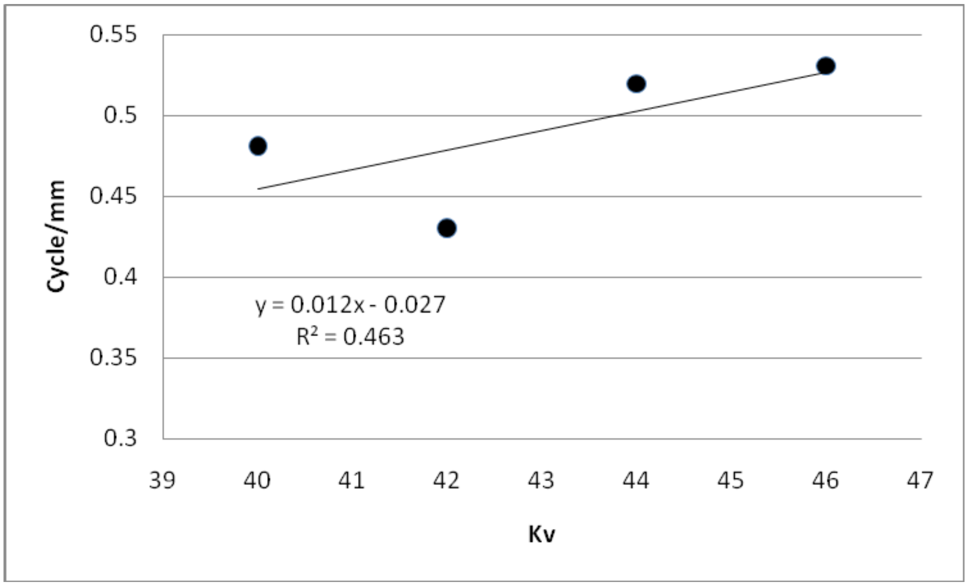


Figure 4-3 a line graph show the MTF percentage for the LTF showed in Figure 4-2.

Figure 4-4 scatter plot show frequencies of the 0.5LP/mm object in the x-ray image at different kv



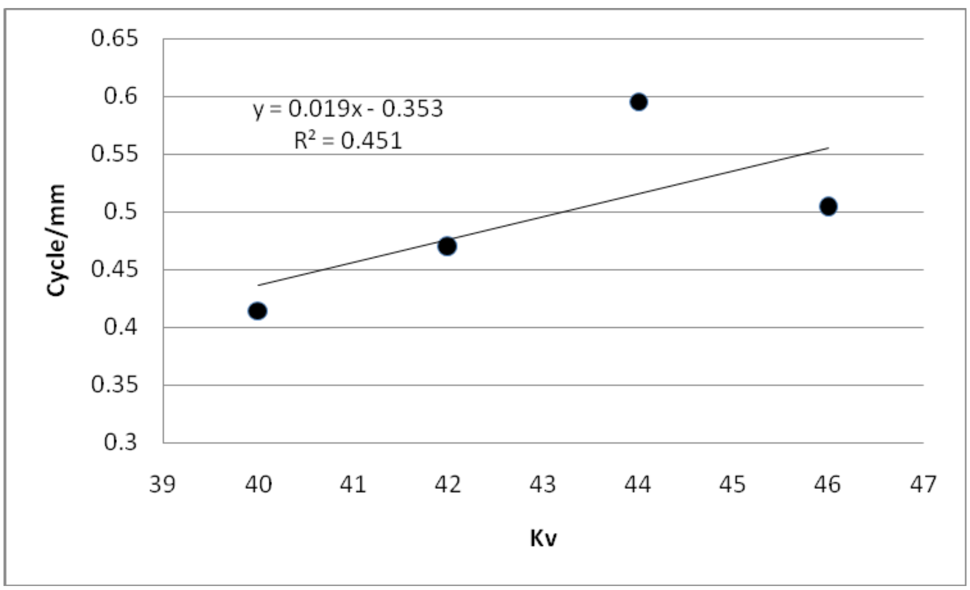


Figure 4-5 scatter plot show frequencies of the 0.56cycle/mm line in the x-ray image at different kv

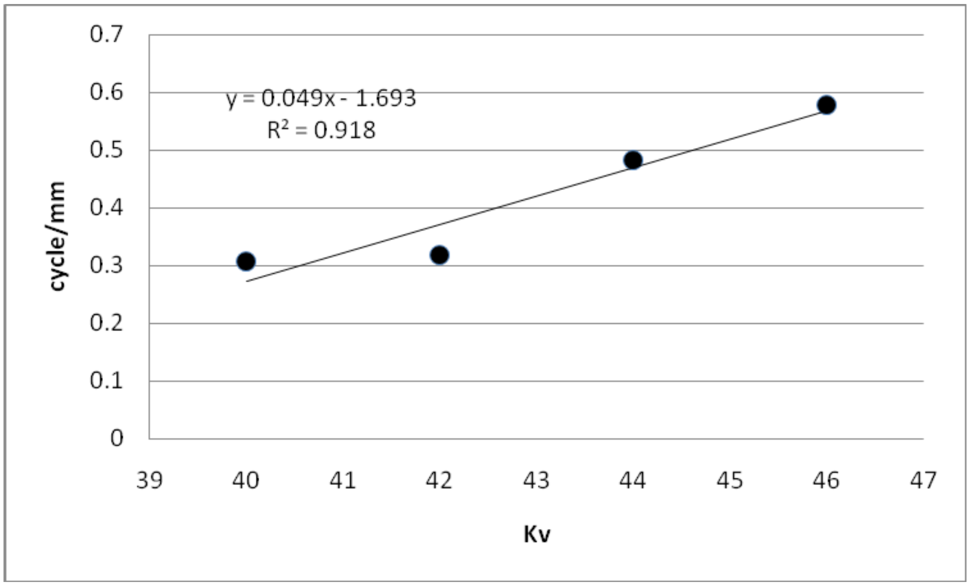


Figure 4-6 scatter plot show frequencies of the 0. 63cycle/mm line in the x-ray image at different kv

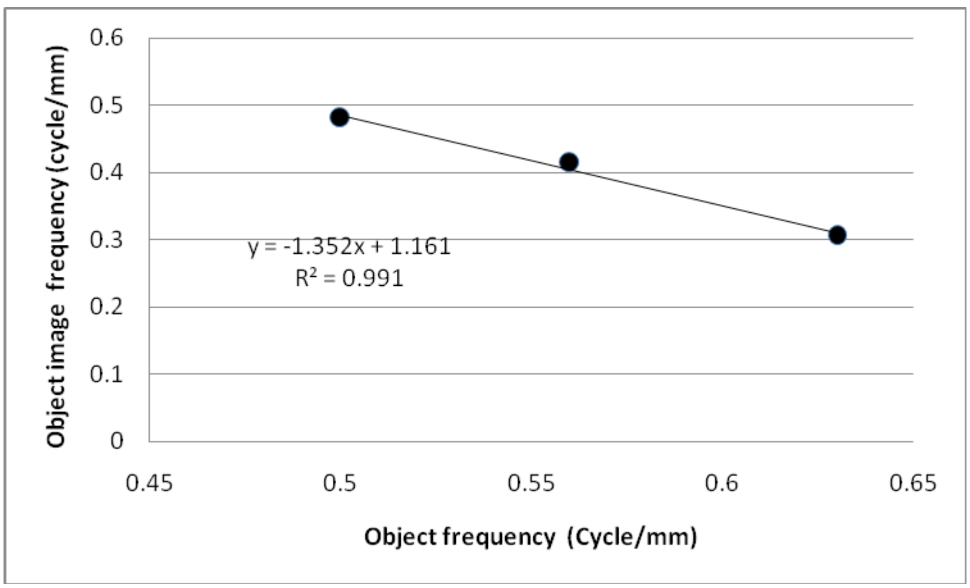


Figure 4-7 scatter plot of object frequencies (cycle/mm) with image object frequencies (cycle/mm) using 40kv

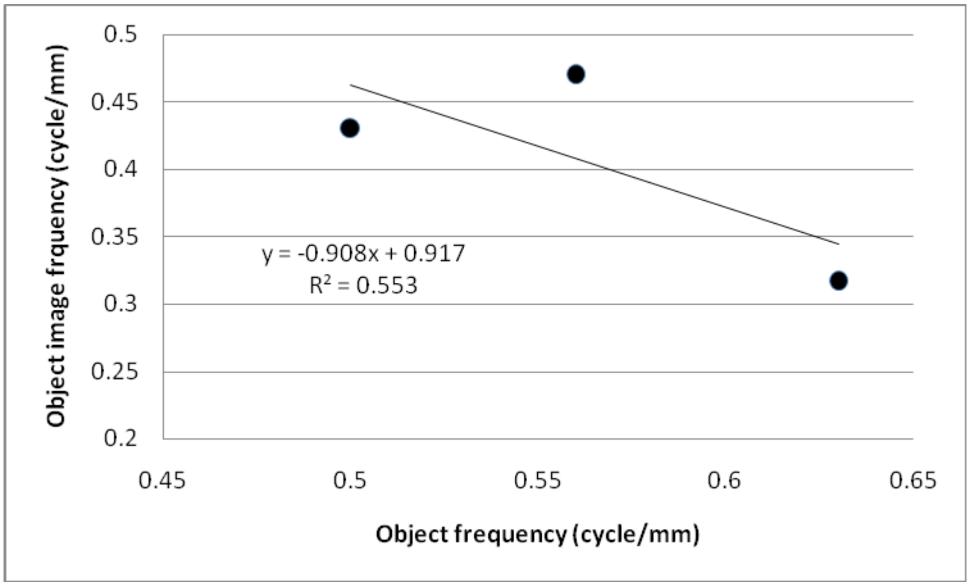


Figure 4-8 scatter plot of object frequencies (cycle/mm) with image object frequencies (cycle/mm) using 42kv

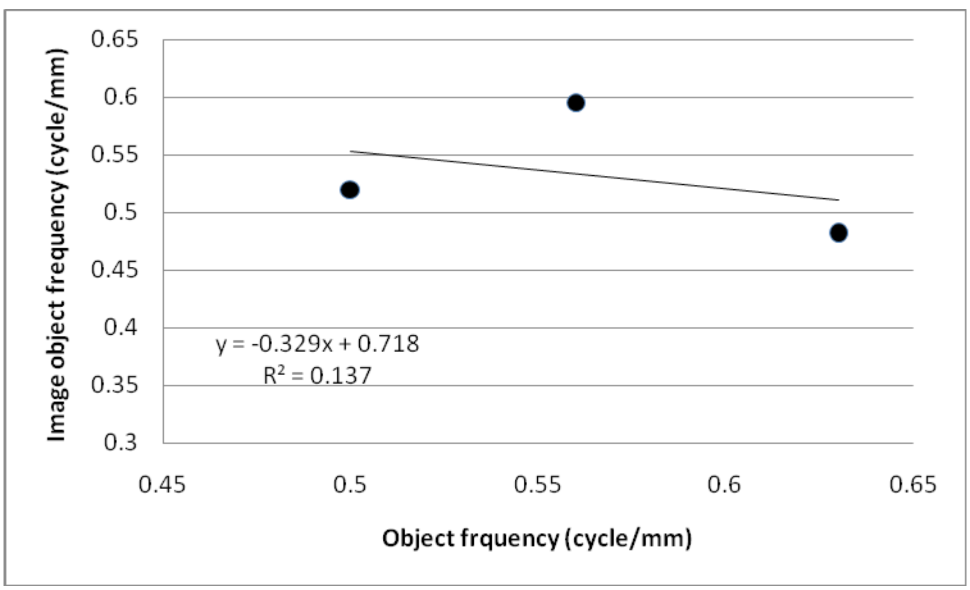


Figure 4-9 scatter plot of actual object frequencies (cycle/mm) with image object frequencies (cycle/mm) using 44kv

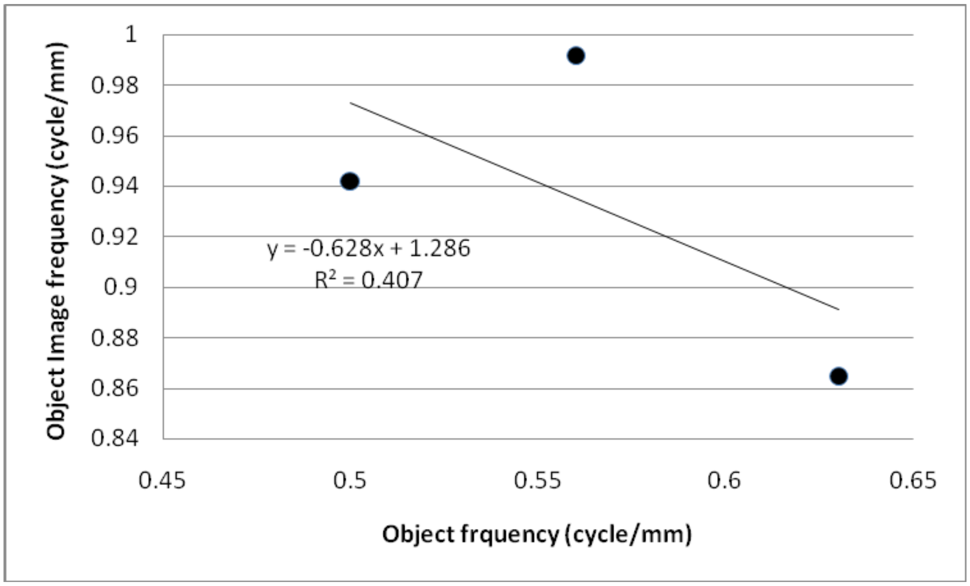


Figure 4-10 scatter plot of actual object frequencies (cycle/mm) with image object frequencies (cycle/mm) using 46kv

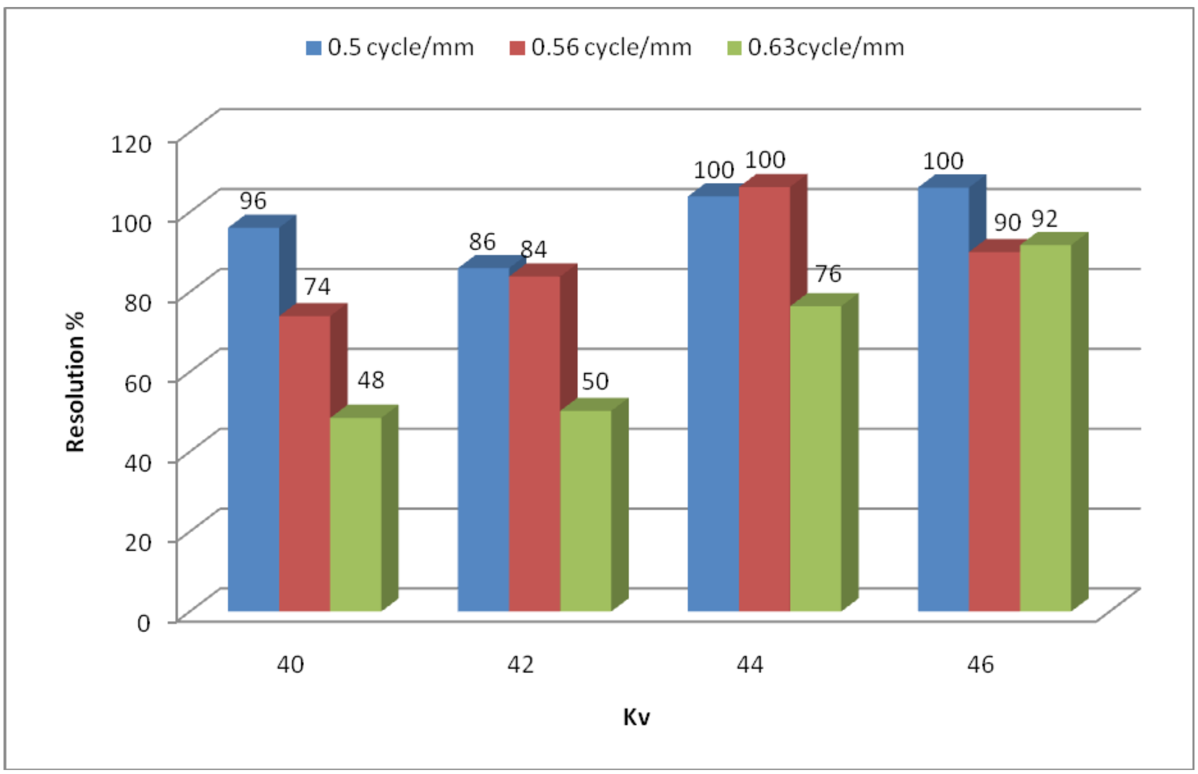


Figure 4-11 bar graph shows x-ray machine resolution for 40, 42, 44 and 46kv at different objects frequencies of 0.5, 0.56 and 0.63 cycle/mm.

Chapter five

Discussion, Conclusion and Recommendation

In This is a analytical study the researcher intended to assess the conventional diagnostic x-ray machine resolution using Modulation Transfer Function as an objective method of assessment; in order to find the optimum KV by hunger phantom consisted of different object (0.5,0.56 and 0.63 LP/mm) where images with differences KV (40,42, 44 and 46) were obtained and MTF were computed using line transfer function (LTF) by having the absolute values of Fast Fourier Transform (FFT) for the LTF.

5.1 Discussion:

The results of this study showed that the image object frequency increases linearly to match the actual object frequency as the KV increases from 40 to 46 for all object frequencies (0.5 – 63 cycle/mm). This increment was equal to 0.012 cycle/mm/KV for an object of 0.5 cycle/mm (Figure 4-4) and 0.02 cycle/mm/KV for an object of 0.56 cycle/mm (Figure 4-5) and 0.05 cycle/mm/KV for an object of 0.63 cycle/mm (Figure 4-6); this means as the frequency of the object increases the frequencies of the image increases as translated by the modulation function in respect to increases in the KV which increases the signal to noise ratio and hence decreases the degree of smearing of object outline.

As the object size decreases i.e. as the object frequency increase, the ability of the imaging devises to depict the same start to deteriorate. Figure 4-7 which illustrate the relationship between the frequencies of the object versus the frequency of the object image frequency using 40 kv. The object image decreases by a factor of 0.1cycle/cycle of actual object frequency

(Figure 4-7). Similarly for all KV used the frequency still going down even it is improve with increasing KV as shown in Figure 4-8 to 4-10 for 42, 44 and 46 KV respectively.

The resolution as shown in Figure 4-11 at 40 KV is better for the object image with low frequency 0.5 cycle/mm at 40 KV which is equal to 96% and reach 100% at 44 KV. The object with higher frequency 0.63 it is resolution increases from 48% at 40 KV progressively till it reach 92% at 46 KV.

In summary the resolution get better for object image with higher frequency as the x-ray quanta increases but objects with lower frequency approaches the optimum level before that considerably.

5.2 Conclusion:

The main objective of this study was to measure the x-ray machine resolution using MTF which gives a full analytical of the machine resolution. In this study conventional x-ray machines were investigated using hungar phantom which consisted of variable thicknesses used to test variable exposure factors. this study introduced the a more reliable method of measuring the resolution which is modulation transfer function (MTF) which gives a complete description of the resolution instead of using full width at half maximum (FWHM) or the visibility method which is more qualitative where MTF is a real quantitative method, by a prototype hunger phantom consisted of wires with different object and KVP for x-ray units and assessed the diagnostic x-ray machine resolution by found the optimum KV to machine type. This study showed that the best machine resolution was **TOSHIBA ROTANODE™ , June2013/2013-06 ,** for Sudan university that had high resolution 100% at 46Kv for object of 0.5mm and 0.56mm compared with 90% at 46Kvp in object 0.63 and . Also the result same exposure and the output decreased with age of x-ray unit, also the resolution reduced when decreased the distance between the wires.

5.3 Recommendation:

- The diagnostic x-ray machines should undergo QC test regularly.
- Evaluation of x-ray resolution should be done using objective method like MTF.
- Similar study can be done using variable of thicknesses from thinner wire thickness to thicker one as well as variable Kv and mAs using fine tuning.

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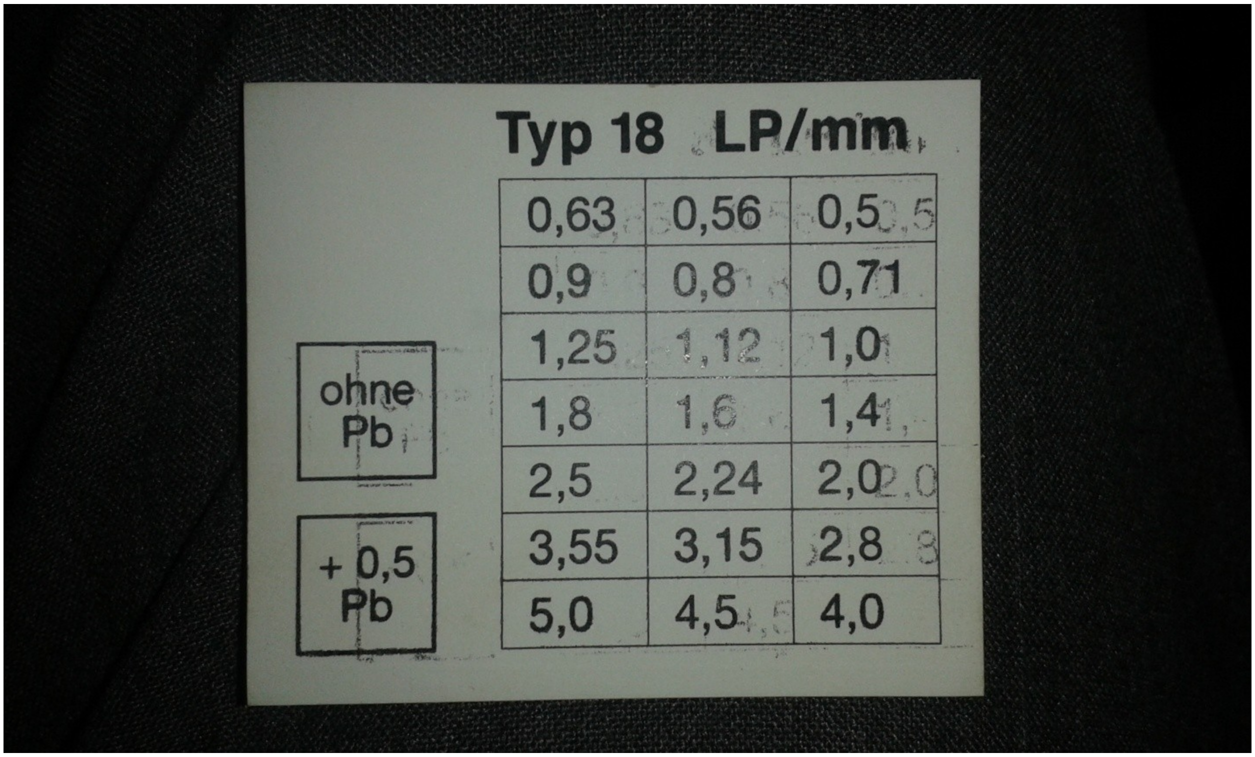
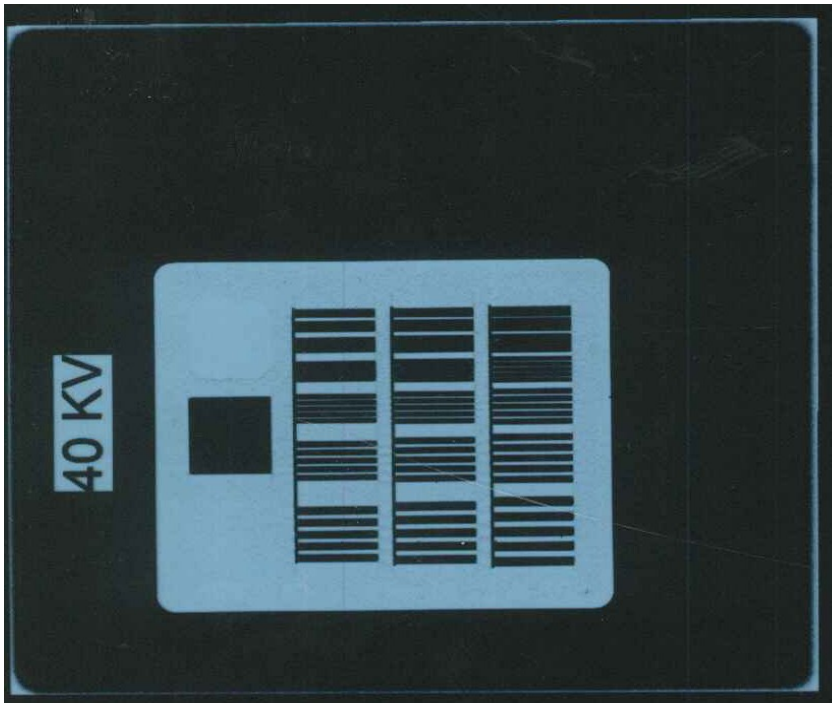
Paulette A. Peterson, M.Ed., R.T.(R)(M)(QM); Randy R. Prouty, B.S., R.T.(R);Andrew P. Woodward, M.A., R.T.(R)(CT)(QM); Teresa G. Odle, B.A., ELS, Best Practices in Digital Radiography 2014.

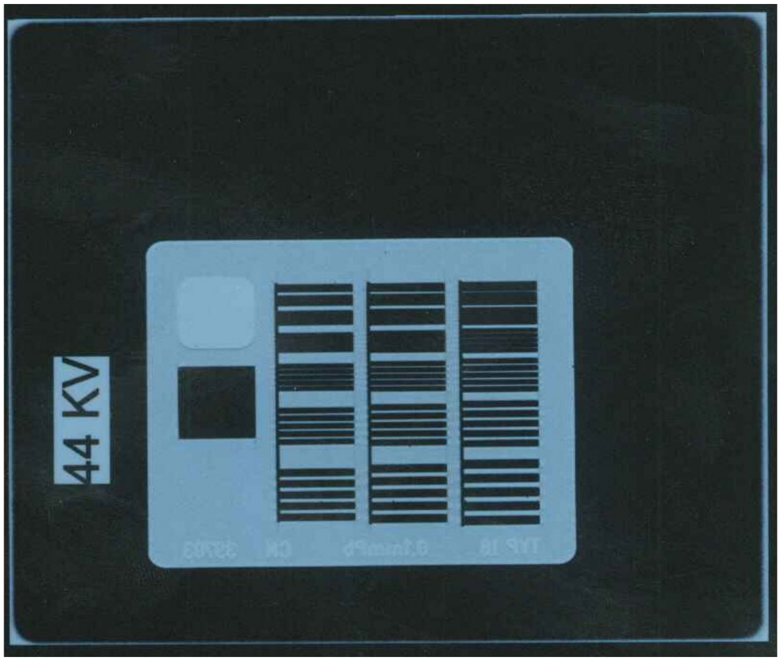
Appendix (A)

Phantom x-ray images




40 KV


42 KV


44 KV

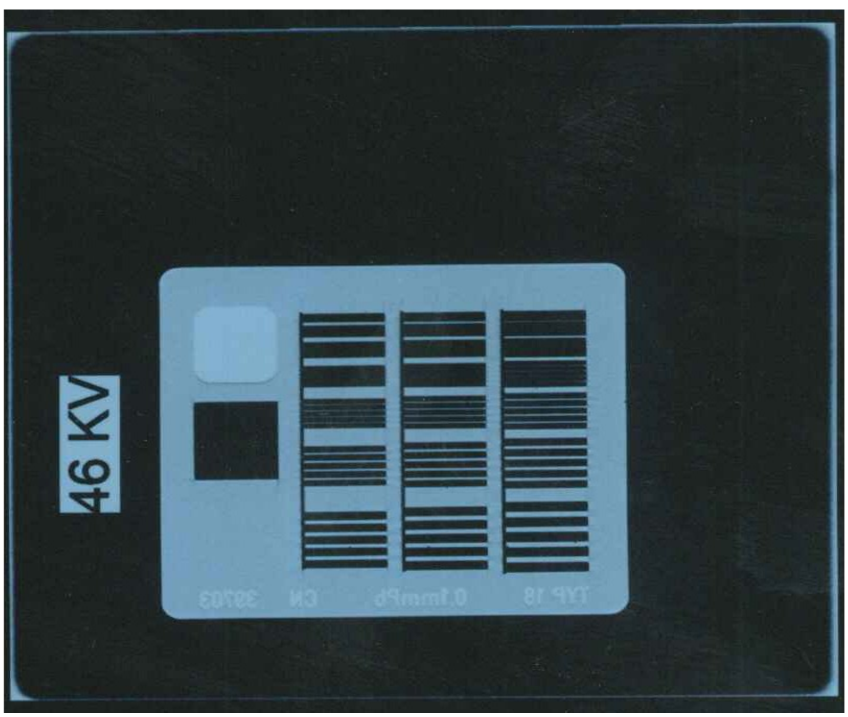

46 KV

Table :explaine kv with object frequency and imaged object frequency

Kv	original F	Frequency
40	0.5	0.480503
40	0.5	0.38078
40	0.5	0.392597
40	0.5	0.383936
40	0.5	0.371632
40	0.56	0.414248
40	0.56	0.337615
40	0.56	0.35137
40	0.56	0.340136
40	0.56	0.369276
40	0.63	0.297621
40	0.63	0.292398
40	0.63	0.291667
40	0.63	0.305449
42	0.5	0.436598
42	0.5	0.428741
42	0.5	0.429898
42	0.5	0.429673
42	0.5	0.411149
42	0.56	0.469669
42	0.56	0.36808
42	0.56	0.367345
42	0.56	0.371466
42	0.56	0.411174
42	0.63	0.301658
42	0.63	0.314218
42	0.63	0.303819
42	0.63	0.316545
44	0.5	0.610325
44	0.5	0.583569
44	0.5	0.565884
44	0.5	0.581515
44	0.5	0.519724
44	0.56	0.595243
44	0.56	0.479432
44	0.56	0.489776
44	0.56	0.489725
44	0.56	0.507644
44	0.63	0.481598
44	0.63	0.409836

44	0.63	0.408361
44	0.63	0.404624
44	0.63	0.424242
46	0.5	0.551745
46	0.5	0.546133
46	0.5	0.542947
46	0.5	0.546324
46	0.5	0.530749
46	0.56	0.690765
46	0.56	0.507837
46	0.56	0.504113
46	0.56	0.469478
46	0.56	0.582019
46	0.63	0.506586
46	0.63	0.439453
46	0.63	0.416173
46	0.63	0.578169

Table : The resolution in percentage for x-ray machine for 40, 42,44 and 46 Kv for Toshiba 2003 x-ray machine

Spatial frequency	40kv	42kv	44kv	46kv
0.5	85%	85%	100%	100%
0.56	70%	80%	100%	85%
0.63	45%	45%	70%	90%