Sudan University of Science and Technology

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Assessment of digital x-ray machine image quality using quantitative analysis

تقييم جودة صورة جهاز الاشعة السينية الرقمية باستخدام التحليل الكمي

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الآيـة

قال تعالى:

﴿يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ﴾

[المجادلة : 11]

صدق الله العظيم

Dedication

To my love

To my father & mother

To my little ones

Acknowledgements

I would like to send my deepest gratitude to Dr. **Mohamed Alfadil Mohamed** for his support and guidance. Without his help this work could not have been accomplished.

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My thanks also go to police Hospital,.

Deep thanks to my friend Finally, I would like to sincerely thank my family for their consistent mental support.

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Abbreviations

Symbols	Item
CAD	Computer-aided detection
DDR	Direct digital radiography
DICOM	Digital Imaging and Communications in Medicine
DIMS	Digital Image Management system
DQE	Detective quantum efficiency
DQE	Detective quantum efficiency
DR	Digital radiography
EDQE	Effective detective quantum efficiency
FSD	Focal to Skin Distance
IA	Image Amplifier
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IDR	Indirect digital radiography
KERMA	Kinetic Energy Released per unit Mass of Air
LPDF	Lock plate distal femur
LSA	Linear systems analysis
LSF	line spread function
MII	Mobile Image Intensifiers
MP	Megapixel
MRI	Magnetic Resonance Image
NPS	Noise power spectrum
PACS	Picture Archiving and Communications System
PSF	point-spread function
PTCA	Percutaneous Transluminal Coronary Angioplasty
QC	Quality control

RF	Radiofrequency
RIS	Radiology Information System
RP	Radiation Protection
SNR	Signal-to-noise ratio
TFT	Thin-film transistor
TIPS	Transjugular Intrahepatic Portosystemic Shunt
TR	Temporal resolution
UFE	Uterine Fibroid Embolization
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VIR	Vascular Intervention Radiology
XRII	X-ray image intensifier

Abstract:

Introduction**:** The physicians and radiography specialist are concern to image quality that reveals the pathology and hence the proper management of the patient condition and be satisfied; this situation mostly lead to high dose given to the patient where if the image quality was not suitable so repetition of the imaging process is mandatory. This study includes the significant increase of image quality and the new potential for dose reduction. It intends to assess digital x-ray machine image quality using quantitative analysis for five organs; Feet exam, breast exam, Pelvic exam, Spinal exam and chest exam in police Hospital in Sudan in Khartoum State. Statement of the problem**:** The evaluation of x-ray using quality mostly done subjectively, using visual perception which gives unreliable result these true of quantitative methods were applied more accurate results can be obtained and hence correlation of problem will be most accurate. Purpose**:** this study aimed to assessment of digital x-ray machine image quality using quantitative analysis. Material and method**:** A total of 100 patients from both male and female were randomly selected from whom exposed their Feet, breast, pelvic, spinal or chest to digital X-ray machine, from Neusoft in Police Hospital in Khartoum State. Region of interest (ROI) were selected from the image using 3×3 pixels in the high intensity and low intensity region on the same image then data were extracted from these region as signal, noise, signal to noise ratio, contrast before and after image enhancement using histogram equalization function; where distribution of image intensity histogram were redistributed for better image quality in respect to visual perception. In X- ray imaging the exposure parameters used are selected according to patient weight and organ size. The Standard (FFD) of 100 cm was used for all routine examination and the chest X- rays FFD of 180 cm are used for geometrical reason. The Interactive Data Language (IDL), Statistical Package for the Social Sciences(SPSS) and Microsoft Excel programs was used. Results**:** signal in high intensity region before and after enhancement, was 1409.66±532.08 and 1859.09±614.52; at $p = 0.05$ using t-test where p was <0.0001 and $t = 19.2$. While noise before and after enhancement did not show an increase in the high intensity area but barley it deceases it was 43.94±104.53 and 42.08±9.42 at $p = 0.05$ where $p = 0.8$ and t = 0.254 also Signal to noise ratio showed and improvement before enhancement since noises were not increases and the signal arbitrary were increased after enhancement as follows: 36.99±10.30 and 42.08±9.42. linear increased by 0.95 units per each units before the enhancement starting at 7.2 This increased were significance using t-test with $t = 9.717$ and $p < 0.0001$. The values of the signal and noise in low intensity areas before enhancement were 677.83±517.26 and, 41.01±142.41while after enhancement the signal and noise were 1104.65±71345 and 24.51±8.84; it increased by 0.99 unit per each unit before the enhancement starting at 6.7 units at $p < 0.0001$ and $t = 13.057$ Noise also follows the same pattern where it shown direct linear relationship it increased by 0.97 units per each units before enhancement starting at 6.9 at $t = 1.652$ and $p = 0.1$.

Conclusion**:** It concluded that the quantitative analysis is a valuable tool for digital X- Ray image estimation.

ملخص الدراسة:

مقدمة: ينصب اهتمام وتركيز الأطباء والمختصين في مجال التصوير الاشعاعي بجودة الصورة التي تبين علم الأمراض وبالتالي التعامل السليم مع حالة المريض ليكونوا مقتنعين بالتشخيص، وتؤدي هذه الحالة في الغالب إلى إعطاء المريض جرعة عالية وفي حال كانت جودة الصورة سيئة وغير مناسبة، يعد إجراء عملية التصوير عدة مرات إلزامي. تشتمل هذه الدراسة على تعزيز زيادة جودة الصورة وإمكانية تقليص الجرعة التي تعطى للمريض. أُعدت هذه الدراسة بغرض تقييم جودة صورة الجهاز الرقمي للأشعة السينية باستخدام التحليل الكمي لخمسة عناصر هي فحص الأقدام، وفحص الثدي، وفحص الحوض، وفحص العمود الفقري وفحص الصدر بمستشفى الشرطة بولاية الخرطوم في السودان.

بيان المشكلة البحثية: في الغالب يتم تقييم الأشعة السينية باستخدام الجودة ذاتياً، وذلك باستخدام الإدراك البصري الذي يقدم نتائج غير جديرة بالثقة. وفي حال تم تطبيق هذه الطرق الكمية بشكل صحيح، ففي هذه الحالة يمكن الحصول على نتائج أكثر دقة، وبالتالي، فإن ستكون علاقة المشكلة البحثية أكثر دقةً.

الغرض من الدراسة: تهدف هذه الدراسة إلى تقييم جودة صورة الجهاز الرقمي للأشعة السينية وذلك باستخدام التحليل الكمي.

المادة والطريقة: تم اختيار ما مجموعه 100 مريض من الجنسين (ذكور وإناث) عشوائياً، من المرضى الذين تعرضت أقدامهم، أو صدورهم، أو أحواضهم أو أعمدتهم الفقرية إلى الجهاز الرقمي للأشعة السينية من طراز (نيوسوفت) التابع لمستشفى الشرطة بولاية الخرطوم. وقد تم اختيار موضع الاهتمام (ROI) من الصورة باستخدام 3 × 3 بكسل بموضع الكثافة العالية والكثافة المنخفضة على نفس الصورة، ومن ثم تم استخلاص البيانات من هذا الموضع الإشارات، والأصوات، ونسبة الإشارة إلى الصوت، والتباين قبل وبعد تحسين الصورة التحسين باستخدام عملية تسوية المدرج التكراري، حيث تمت إعادة توزيع المدرج التكراري لكثافة الصورة وذلك لتحسين جودتها فيما يتعلق بالإدراك البصري.

في تصوير الأشعة السينية يتم اختيار معايير التعرض المستخدمة بحسب وزن لوزن المريض وحجم العضو المراد تصويره. تم استخدام المعيار (البعد البؤري للصورة) البالغ 100سم لجميع الفحوصات الروتينية، وتم استخدام البعد البؤري للأشعة السينية للصدر بمقاس 180 سم لأسباب هندسية. وتم استخدام لغة البيانات التفاعلية والحزمة الإحصائية للعلوم الاجتماعية وبرامج اكسل.

النتائج: كانت الإشارات في موضع الكثافة العالية قبل التحسين وبعده: 1409.66 ± 532.08 و1859.09 ± 614.52؛ عند $p = 0.05$ باستخدام اختبار t حيث كان $p < 0.0001$ و.. $t = 19.2$. في حين لم تبين الأصوات قبل وبعد التحسين زيادة في موضع الكثافة العالية ولكن كان هنالك تناقص بلغ: 43.94 ± 104.53 و42.08 ± 9.42 عند $p = 0.05$ حيث $p = 0.8$ و $t = 0.254$ كذلك بين معدل الإشارة إلى الصوت تحسناً بسبب عدم زيادة الصوت وزيادة إشارة تقديرية بعد التحسين كالتالي: 36.99 ± 10.30 و 42.08 ± 9.42. زاد الخطي بمقدار 0.95 وحدة لكل وحدة قبل بدء التحسين عند 7.2 وكانت هذه الزيادة كبيرة باستخدام اختبار t مع $t = 9.717$ و $p < 0.0001$. كانت قيم الإشارة والصوت في المواضع منخفضة الكثافة قبل التحسين 677.83 ± 517.26 و41.01 ± 142.41 بينما بعد تحسين الإشارة والصوت كانت 1104.65 ± 71345 و24.51 ± 8.84؛ وقد زادت بمقدار 0.99 وحدة لكل وحدة قبل التحسين الذي بدأ عند 6.7 وحدة عند $p < 0.0001$ و $t = 13.057$.

كما يتبع الصوت نفس النمط، حيث بين علاقة خطية مباشرة زادت بمقدار 0.97 وحدة لكل وحدة قبل التحسين الذي بدأ عند 6.9 عند $t = 1.652$ و $p = 0.1$.

خلاصة الدراسة:

وخلصت الدراسة إلى أن التحليل الكمي هو أداة ذات قيمة عالية لتقدير صورة الأشعة السينية الرقمية.

Chapter one: Introduction

1.1Background

Digital radiography (DR) systems are replacing analog systems in many clinical applications. Broadly speaking, DR can be defined as projection x-ray imaging in which the image data are sampled into discrete elements in the spatial and intensity dimensions. Initially, image data captured by the x-ray capture element of the detector, in a process similar to that used by analog (ie, screen-film) radiographic systems. The captured analog signal then transformed into digital form through the processes of sampling and quantization. The digital image data finally transferred to a computer and processed for display and distribution. DR detectors vary dramatically with respect to the technologies on which they based. However, these detectors all share three distinct components: the x-ray capture element, the coupling element, and the collection element. The performance of digital detectors and the quality of their acquired images directly related to various physical processes that take place in these elements during image formation. (Samei et al, 2001)

Digital radiographic systems are gaining widespread use in many clinical applications. Digital radiographic detectors vary dramatically with respect to the technologies that they use and the particular implementation. Their performance thus varies from system to system. It is often necessary to characterize the performance of a digital radiographic or mammographic detector for optimization, design, comparison, or quality assurance purposes. To do so, it is most useful to measure the performance of the detector in terms of common performance metrics, so that meaningful comparisons. The performance of a digital radiographic detector described in terms of a number of performance factors. Among them, sharpness and noise are two key characteristics that describe the intrinsic image quality performance of digital radiographic systems. Together, these two, along with an associated characteristic, the signal-to-noise ratio (SNR), define the intrinsic ability of an imaging system represent the anatomic features of the body part imaged. The quantification of sharpness, noise, and SNR in radiographic systems in terms of common performance metrics of the modulation transfer function (MTF), the noise power spectrum (NPS), and the detective quantum efficiency (DQE).(Samei et, al, 2001).

1.2 Problem of the study

The evaluation of x-ray using quality mostly done subjectively, using visual perception which gives unreliable result these true of quantitative methods were applied more accurate results can be obtained and hence correlation of problem will be most accurate.

1.3Objectives of the Study

1.3.1 General objective

To assessment of digital x-ray machine image quality using quantitative analysis.

1.3.2 Specific objectives

To find an image to x-ray (linearity and contrast),To measure the linearity and contrast and To calculate Signal to Noise Ratio SNR.

1.4Thesis outline

This thesis is concerned with the Assessment of Digital X-ray Machine Image Quality using Quantitative Analysis; it divided into the following chapters:

Chapter one is the introduction to this thesis. This chapter presents the historical background of image quality, in addition to study problem, objectives and scope of the work. It also provides an outlines of the thesis.

Chapter two contains the background material for the thesis. This chapter also includes a summary previous work performed in this field.

Chapter three describes the materials and methods that used to evaluate of image quality and explains in details the factor that affected of image quality.

Chapter four presents the results of this study.

Chapter five presents the discussion, conclusion and recommendations of this thesis and presents.

Chapter two:

Theoretical background & literature view

2.1The digital radiography system

Digital radiography is performed by a system consisting of the following functional components:

Interface to a patient information system, A digital image receptor, An image management system, A digital image processing unit, Image and data storage devices, A communications network, A display device with viewer operated controls. (Perry 2016).

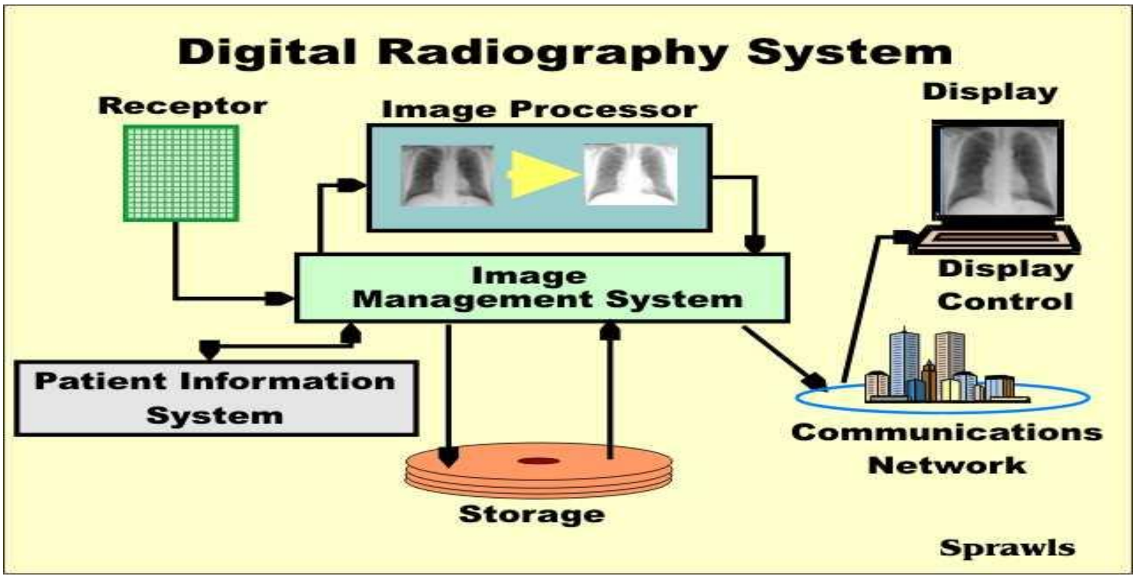

Figure 2.1 digital radiography system components (Sprawls.org).

2.1.1 Patient information system

The Patient Information System, perhaps known as the Radiology Information System (RIS), is an adjunct to the basic digital radiography system. Through the interface, information such as patient ID, scheduling, actual procedures performed, etc. (Perry 2016).

2.1.2 The digital receptor

The digital receptor is the device that intercepts the x-ray beam after it has passed through the patients body and produces an image in digital form, that is, a matrix of pixels, each with a numerical value. This replaces the cassette containing intensifying screens and film that is used in non-digital, film-screen radiography. There are several different types of digital radiography receptors. (Perry 2016).

2.1.2.1 The Direct Digital Radiographic Receptor

The direct digital radiographic receptor is as "a digital x-ray camera". The receptor is in the form of a matrix of many individual pixel elements.

They are based on a combination of several different technologies, but all have this common characteristic: when the pixel area is exposed by the x-ray beam (after passing through the patient's body), the x-ray photons are absorbed and the energy produces an electrical signal. This signal is a form of analog data that is then converted into a digital number and stored as one pixel in the image. (Perry 2016).

2.1.2.1.1 Digital Receptor Dynamic Range

One of the significant characteristics of most digital radiographic receptors is that they have a wide dynamic range. Which means that the receptors respond to x-ray exposure and produce digital data over a wide range of x-ray exposure values. (Perry 2016).

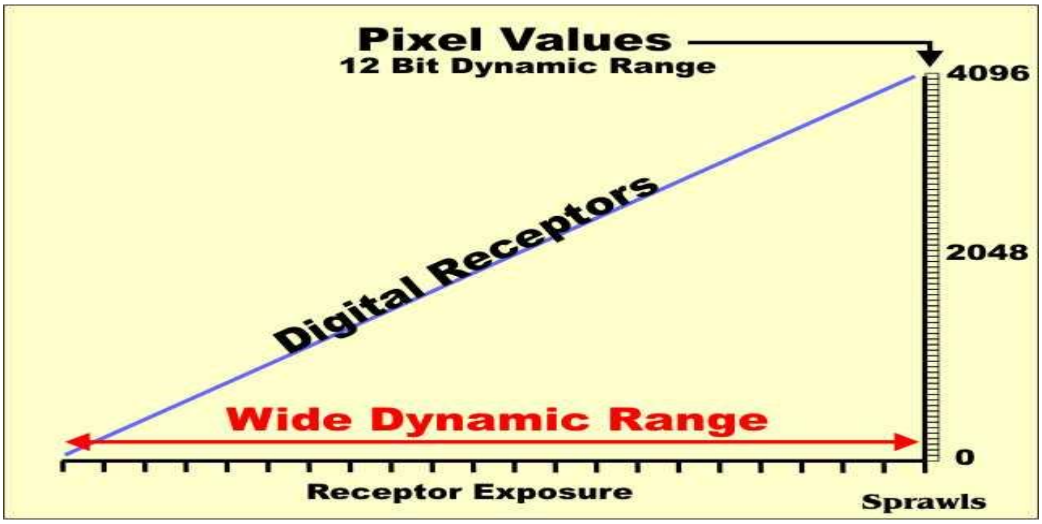

Figure2.2 dynamic range of digital receptor. (Sprawls.org).

2.1.2.1.1.1 The Advantage of a Wide Dynamic Range

One of the advantages of a digital receptor that has a wide dynamic range.

Even when there is a wide exposure range coming from the body (wide histogram) and exposures at different levels (because of exposure errors), that they still fit within the wide dynamic range of the digital receptor. This means that good image contrast can be formed over a wide range of exposure. (Perry 2016).

2.1.2.2 Stimualible Phosphor Radiographic Receptor

The stimualible phosphor receptor is as being like a conventional radiographic intensifying screen in that it absorbs the x-ray photons and then produces light. The difference is that there is a delay between the x-ray exposure and the production of the light. This is how it works: First, a receptor (cassette) containing only a stimualible phosphor screen is exposed to record an image. At this stage the image recorded by the screen is an invisible latent image. The next step is to process the receptor through the reader and processing unit. In this unit the screen is scanned by a very small laser beam. When the laser beam strikes a spot on the screen it causes light to be produced (the stimulation process). The light that is produced is proportional to the x-ray exposure to that specific spot. The result is that an image in the form of light is produced on the surface of the stimualible phosphor screen. A light detector measures the light and sends the data on to produce a digitized image. (Perry 2016).

2.1.2.2.1 Film Latitude (Dynamic Range)

Radiographic film has a somewhat limited dynamic range which is generally referred to as the film latitude. The latitude (or dynamic range) is the range of receptor exposures over which an image and contrast be formed. The relationship between receptor exposure and the resulting film density is usually described by the film characteristic (or H & D) curve. The latitude (or dynamic range) is associated with that part of the curve where there is some slope and contrast formed. In the region of the toe of the curve, there is no significant contrast formed, and this corresponds to under-exposed areas within an image. In the region of the shoulder of the curve there is no significant contrast formed and this corresponds to areas of overexposure. mages are formed with the silver halide crystals(fig 2.3).

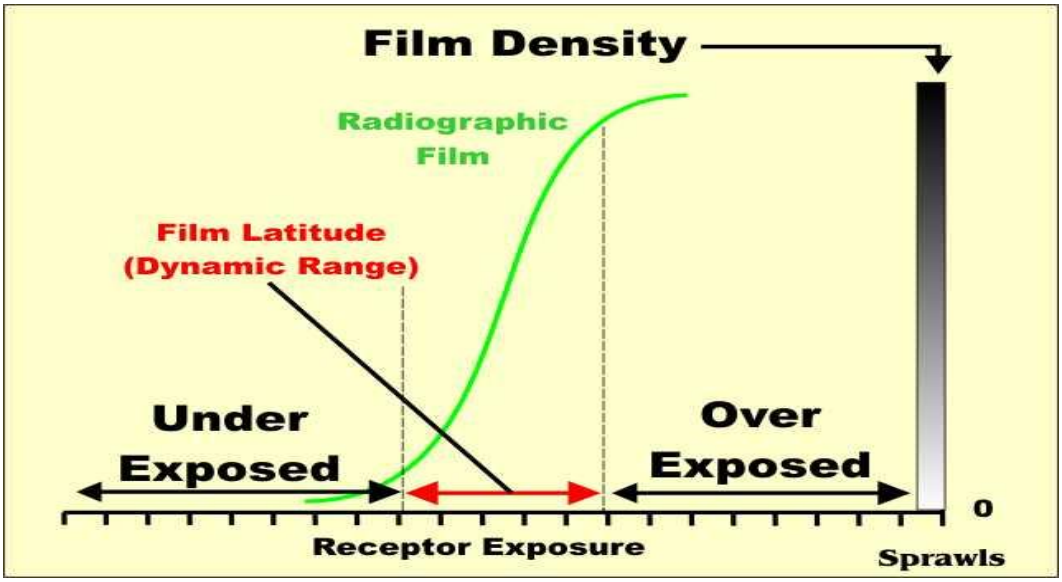

Figure2.3 dynamic range of Film Latitude. (Sprawls.org).

2.1.3 The Image Management System

Image management is a function performed by the computer system associated with the digital radiography process. These functions consist of controlling the movement of the images among the other components and associating other data and information with the images. Some of these functions might be performed by the computer component of a specific digital radiography device or by a more extensive Digital Image Management System (DIMS) that serves many imaging devices within a facility. Note: it is not unusual for the DIMS to be referred to by an older, and somewhat less appropriate name, PACS (Picture Archiving and Communications System). (Perry 2016).

2.1.4 Imaging Processing

One of the major advantages of digital radiography is the ability to process the images after they are recorded. Various forms of digital processing can be used to change the characteristics of the digital images.

For digital radiographs the ability to change and optimize the contrast is of great value. It is also possible to use digital processing to enhance visibility of detail in some radiographs.

The various processing methods are explored in much more detail in another module. (Perry 2016).

2.1.4.1 Image Formation

As the surface of the stimualible phosphor screen is scanned by the laser beam, the analog data representing the brightness of the light at each point is converted into digital values for each pixel and stored in the computer memory as a digital image. (Perry 2016).

2.1.5 Digital Image Storage

Digital radiographs, and other digital medical images, are stored as digital data.

2.1.5.1 Advantages (compared to images recorded on film) include

Rapid storage and retrieval, Less physical storage space required, Ability to copy and duplicate without loss of image quality and The digital image storage methods and process is explored in more detail in another module. (Perry 2016).

2.1.6 Communications Network

Another advantage of digital images is the ability to transfer them from one location to another very rapidly. This can be: Within the imaging facility to the storage and display devices, To other locations (Teleradiology), Anywhere in the world (by means of the internet)., The total network available for transferring digital images is made up of a variety of integrated systems as will be described in another module. (Perry 2016).

2.1.7 Digital Image Display and Display Control

Compared to radiographs recorded and displayed on film, i.e. "softcopy", there are advantages of "softcopy" displays. One major advantage is the ability of the viewer to adjust and optimize image characteristics such as contrast. Other advantages include the ability to zoom, compare multiple images, and perform a variety of analytical functions while viewing the images. (Perry 2016).

2.2The Exposure Histogram

X-ray images and image contrast are formed as the x-ray beam passes through the body and experiences different levels of attenuation through the various anatomical regions. In the example of the chest, the low-density lung areas produce a relatively high exposure to the receptor and dark areas in the image. The more dense areas, like the spine and below the diaphragm, produce relatively low exposure to the receptor and light areas in the image. The histogram (fig 2.4), shows the amount of image area (in a digital image this is the number of pixels) that receives the different levels of exposure that forms the image. At this time our primary interest is in the range of exposures (width of the histogram) that reaches the receptor. (Perry 2016).

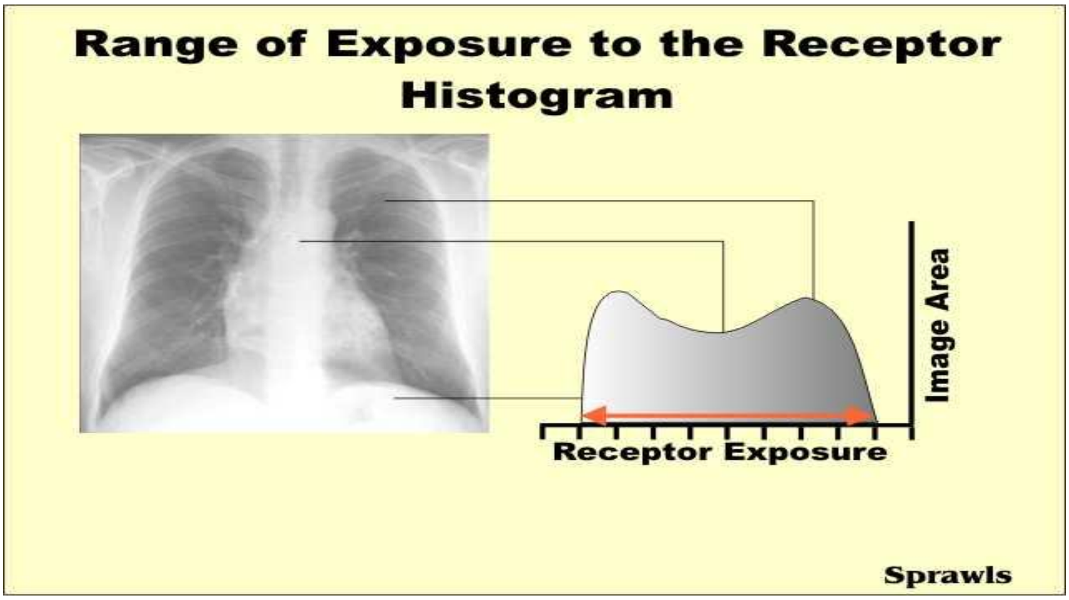

Figure2.4 the exposure histogram.

2.2.1 Imaging with Film

One of the challenges in doing film radiography is to get the range of exposures produce by the body (as described by the exposure histogram) fitted into the latitude or dynamic range of the film. If the exposure falls outside of the latitude, there will be little or no image contrast formed. There are generally two conditions that contribute to receptor exposure outside of a film's latitude: One is just an error in setting the correct exposureand The other is that some body regions, such as the chest, produce a relatively wide range of exposure (histogram) that exceeds the latitude of the film.

Using a film with a wide latitude, as is usually done for chest imaging, can reduce this problem but the tradeoff is that a film with a wide latitude generally produces less contrast than a so-called contrast film. (Perry 2016).

2.2.2 Digital Image Contrast

In a digital image contrast is represented by the different pixel values. A typical digital radiographic receptor has a linear relationship between exposure and the resulting pixel value as shown here. The relationship extends over a relatively wide range of exposures to produce the wide dynamic range.

This can be contrasted with the non-linear (curved) relationship between exposure and density, or image brightness, for film. Film also has a very limited latitude or "working range" of exposures. (Perry 2016).

2.2.3 Optimum Exposure in Digital Radiography

The wide dynamic range and linear response of the typical digital receptor is like a "two-edged sword".

The advantage is that a wide range of exposures, and exposure errors, will still produce good image contrast. That is, the loss of contrast with exposure error is not a limiting factor as it is with film.

So, what is the problem? It is that while images can be produced throughout the range (as far as contrast is concerned) there are two potential problems.

Even though images with good contrast can be produced with relatively low exposures, they will have a high level of quantum noise. In other modules that the level of image (quantum) noise depends on the exposure to the receptor. When a low exposure is used, the result can be excessive image noise.

The other problem is that excessively high and unnecessary exposures can be used to form images. While these images will have good quality (low noise) there will be unnecessary exposure to the patient. This problem does not exist with film radiography because the increased exposure will result in a visibly overexposed film.

In general, for a radiographic procedure there is an optimum exposure that produces a good balance between image noise and patient exposure. The challenge to the technologist is to make sure that the technique factors are set to produce this optimum exposure.

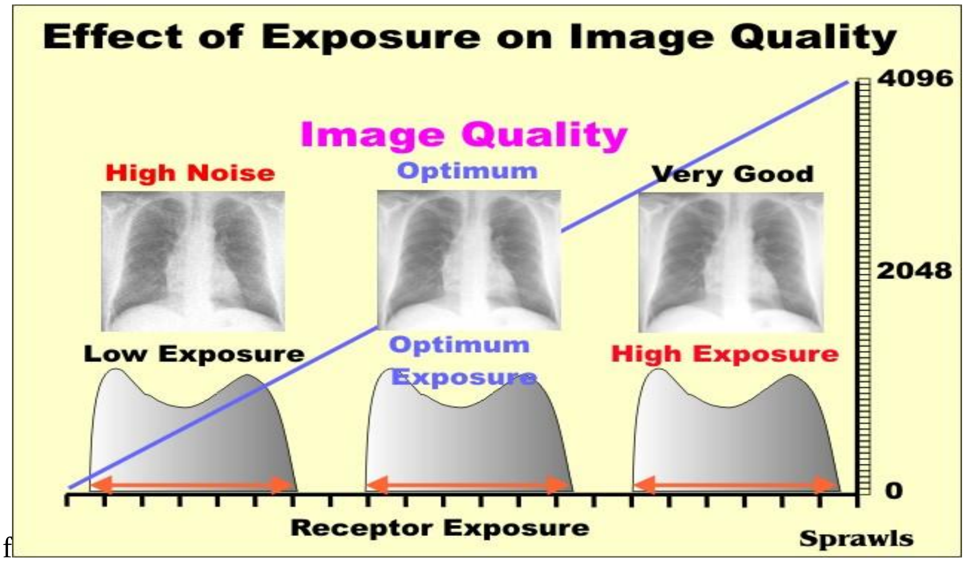

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Figure2.5 effect exposure on image. (Sprawls.org).

2.3Image quality parameters

There are several parameters which they characterize the quality of digital images.

2.3.1 Resolution

Describes the ability of medical imaging process to discriminate adjacent structures in organ tissues examined. Signal from detected photon should record with sufficient resolution in space, intensity and possibly time to produce a digital image that enables a medical interpretation of tissue structure and function. Therefore resolution is of three main categories, spatial resolution (space), contrast resolution (intensity) and temporal resolution (time). However, temporal resolution is more related to the digital radiography application of fluoroscopy.

2.3.1.1 Spatial resolution and/or blur Spatial resolution

Refers to the ability of imaging system to detect and discriminate small objects that are close together. The size of pixels and the spacing between them (the pitch) define the maximum spatial resolution.

The smaller the pixel sizes the higher the spatial resolution. However, this is not always true because the spatial resolution is influenced by other causes such as blur factors.

Image processing alters image spatial resolution however the image noise is excessively increased. Zooming or targeting and scanned field of view functions influence spatial resolution. Measurement methods including the point-spread function (PSF), line spread function (LSF) and the modular transfer function (MTF), are used to quantify and evaluate spatial resolution. Spatial resolution is affected by four blur factors, namely subject blur, geometric blur, motion blur, and receptor blur. Image blur refers to the element of blurring to boundaries in the object (patient). Sharp image describes the well-defined boundaries of the object (patient).Subject blur is caused by object shape or/and structure composition. This factor is also called object blur. Geometric blur results from the geometry of the image-construction procedures. The main influences of this factor are focal spot size of the x-ray tube, the distance between the x-ray source and patient and between the patient and image receptor. Border-blur increases with the increasing of focal spot size and with increases in the distance between patient and image receptor. Unequal magnification of different organ structures cause distortion in the radiographic images, which is called image distortion.

For example, tissues close to the image receptor are magnified less than those further away. When the distance between the patient and image receptor increases, blur factor decreases.

Motion blur is the most problematic blur factor. When motion occurs, the boundaries of patient structures will move from their actual position during image processing. Consequently, the boundaries are blurred in the image. This motion originates from anatomic region being imaged and it can be either voluntary action of the patient or involuntary physiologic process. Voluntary motion can mostly be controlled by applying short examinations, instructing the patient to remain still during the examination and in certain situation using physical restraints and an aesthetics. However, such techniques are sometimes ineffective.

Involuntary motion such as heart beats and bowel peristalsis cannot be stopped or minimized its influences on the images by using examinations of very short duration.

Receptor blur refers to the blur results from the image receptor. Image receptor gathers data produced during the imaging process and presents it as a visual image. Spatial resolution basically depends on physical detector characteristics. For example, the intrinsic spatial resolution of amorphous selenium utilized in direct conversion DR system is higher than that of structured cesium iodide utilized in indirect conversion systems. The detectors of structured cesium iodide has much higher intrinsic spatial resolution than that of unstructured scintillators. The thickness and material composition of the detector will determine its blur features. The factor of the blur increases with increasing thickness of receptor. The thickness also influences the sensitivity of the receptor which increases with increasing thickness. Receptor blur is also caused by scattering or photoelectric interactions within the image receptor when the photon energy dissipates. A part or all energy of the photon deposited somewhere in the detector other than the original point of entry causing the blur. The scattering and movement of the laser beam, that is used to stimulate storage plate in the CR system, are sources of blur. Scattering of the laser light beam during storage plate readout is the primary source of special resolution loss in CR. The thicker the phosphor plates, the greater the scattering depth and blur. Dual reader systems reduce scattering problems. The introduction of structured phosphor allowed the use of thicker plates and provided improved detection efficiency without much loss of spatial resolution.

In indirect conversion DR (IDR), the source of spatial resolution loss is the spread of light photons during the x-ray-to-light conversion process which results in blur. Utilizing structure phosphor increases detection efficiency and minimizes the scattering light. However, direct conversion DR (DDR) does not suffer from this effect; because of the limitation of the spread of the electrons within the photoconductor material as they are directed towards the thin-film transistor(TFT) array. Width of the detector, matrix size, pixel size, detectors pitch (spacing between detectors) are factors of spatial resolution loss in CR and DR systems. Locations of different x-ray absorptions within an element may be undistinguishable because all x-rays within an exposure contributes to a single quantity (the summed charge read from that element). So that, when the imaged structures of a patient are smaller than the size of a single element of the detector, they are smeared out and their contrast is reduced unless they are inherently high contrast objects. For example, when micro calcification is smaller than an element, it may be recognized as a calcification since its attenuation properties are so different from the other tissue in the element.

2.3.1.2 Contrast resolution

Contrast resolution refers to the ability of an imaging system to discriminate objects with small density differences and/or differentiate small attenuation variety on the image. Contrast resolution explains how well the image discriminates subtle structures in organs being exam. Contrast resolution can be inherited by recording the information of interest with sufficient intensity resolution to discriminate the contrast details of interest. While the first step of digitization, sampling in space, affects the spatial resolution, the second step, quantization in signal intensity, influences the contrast resolution or the gray-scale bit depth. Contrast resolution sometimes called tissue resolution. If there are two small objects with large difference in densities, the area between them considered as high frequency or high contrast region. Conversely, low contrast region refers to an area between two small objects; with small difference in densities.

Contrast resolution affected by tube collimation, number of photons, noise, scatter radiation, beam filtration, detector properties and algorithmic reconstruction used. Image contrast depends on subject contrast, detector contrast and displayed contrast.

2.3.1.2.1 Subject contrast

The anatomical and physiological characteristics of the region being imaged are considered to the intrinsic factors of image contrast, which are called intrinsic, subject, object, or patient contrast. Low intrinsic contrast tissues such as breast tissues have very subtle differences in composition. In radiography, the physical properties of atomic number, physical density differences among different tissues and patient thickness influence intrinsic or subject contrast.

Imaging methods and techniques are the second major factor which control image contrast. Selecting careful exposure techniques for specific tissues and for certain purposes greatly enhances image contrast to obtain the desired information. For example, low kVp and small amounts of beam filtration are preferable in mammography to discriminate subtle differences among tissues. In chest radiography, however, high kVp and large amounts of beam filtration are used to demonstrate the wide range of varying tissues densities (lung, bone tissues). This technique helps in detecting lesions of increased physical density in the under the ribs.

Introducing enhancement material or medium into the body improves image contrast by altering subject contrast. Contrast media changes photon attenuation properties from those of the surrounding tissues and therefore provide signal differences.

2.3.1.2.2 Detector (receptor) contrast

A detector's characteristics play an important role in producing contrast in the final image. Detector contrast determined principally by how the detector detects and converts the energy into the output signal.

The dynamic range of the detector influences the contrast resolution of image. The dynamic range of CR and DR, which is the ratio of the maximum to minimum input x-ray intensities incident on the detector surface, ranges from 1,000:1 to 10,000:1 compared with the dynamic range of film screen radiography which ranges from 10:1 to 100:1.

2.3.1.2.3 Displayed contrast

The attributes of image displaying that utilized to produce and demonstrate the final image influence the contrast of diagnostic images.

For example, displaying images on a video screen gives one the flexibility to alter and adjust image contrast, unlike film based images. Viewing diagnostic images digitally demonstrates the data of images in a wide range of grayscale images. It also allows use of a wide range of exposures for display image.

Consequently, image contrast is enhanced and radiation dose is reduced by utilizing digital system.8Therefore displaying process and devices of digital imaging systems (particularly for primary display or diagnostic interpretation) should be in compliance with the current Digital Imaging and Communications in Medicine (DICOM) standard of the American College of Radiology (ACR) and the National Electrical Manufacturers Association (particularly on grayscale displays).

There are two categories for displaying digital images, small matrix (for CT, digital fluorography, and digital angiography) and large matrix size (CR and DR and digital mammography). A monitor of 5 megapixel (MP) typically 2048 x 2560 pixels, is sufficient for viewing digital images particularly CR and DR images. It is important to utilize zooming and roaming display functions to achieve a correspondence between the display pixel matrix and the detector element matrix in order to avoid resolution limitations of the monitor for partially displayed images. Moreover, display luminance influences image quality and therefore appropriate luminance should be uniform over the entire display and at a level of at least 200 cd/m^2, especially for CR and DR. Bit depth resolution, which controls luminance quantification of soft copy display, is recommended to be large to prevent the loss of contrast details or the appearance of contour artefacts. Viewing environment and conditions also affect image display quality such room lighting and other display monitors light reflection.

2.3.1.3 Temporal resolution (TR)

Refers to the discrete resolution of a measurement with respect to time. Often there is a trade-off between the temporal resolution of a measurement and its spatial resolution, due to Heisenberg's uncertainty principle. In some contexts such as particle physics, this trade-off can be attributed to the finite speed of light and the fact that it takes a certain period of time for the photons carrying information to reach the observer. In this time, the system might have undergone changes itself. Thus, the longer the light has to travel, the lower the temporal resolution.

In another context, there is often a tradeoff between temporal resolution and computer storage. A transducer may be able to record data every millisecond, but available storage may not allow this, and in the case of 4D PET imaging the resolution may be limited to several minutes.

In some applications, temporal resolution may instead be equated to the sampling period, or its inverse, the refresh rate, or update frequency in Hertz, of a TV, for example.

The temporal resolution is distinct from temporal uncertainty. This would be analogous to conflating image resolution with optical resolution. One is discrete, the other, continuous.

The Temporal resolution is a resolution somewhat the 'time' dual to the 'space' resolution of an image. In a similar way, the sample rate is equivalent to the pixel pitch on a display screen, whereas the optical resolution of a display screen is equivalent to temporal uncertainty.

Note that both this form of image space and time resolutions are orthogonal to measurement resolution, even though space and time are also orthogonal to each other. Both an image or an oscilloscope capture can have a signal to noise ratio, since both also have measurement resolution.

An oscilloscope is the temporal equivalent of a microscope, and it is limited by temporal uncertainty the same way a microscope is limited by optical resolution. A digital sampling oscilloscope has also a limitation analogous to image resolution, which is the sample rate. A non-digital non-sampling oscilloscope is still limited by temporal uncertainty.

The temporal uncertainty can be related to the maximum frequency of continuous signal the oscilloscope could respond to, called the bandwidth and given in Hertz. But for oscilloscopes, this figure is not the temporal resolution. To reduce confusion, oscilloscope manufacturers use 'Sa/s' instead of 'Hz' to specify the temporal resolution.

Two cases for oscilloscopes exist: either the probe settling time is much shorter than the real time sampling rate, or it is much larger. The case where the settling time is the same as the sampling time is usually undesirable in an oscilloscope. It is more typical to prefer a larger ratio either way, or if not, to be somewhat longer than two sample periods.

In the case where it is much longer, the most typical case, it dominates the temporal resolution. The shape of the response during the settling time also has as strong effect on the temporal resolution. For this reason probe leads usually offer an arrangement to 'compensate' the leads to alter the trade off between minimal settling time, and minimal overshoot.

If it is much shorter, the oscilloscope may be prone to aliasing from radio frequency interference, but this can be removed by repeatedly sampling a repetitive signal and averaging the results together. If the relationship between the 'trigger' time and the sample clock can be controlled with greater accuracy than the sampling time, then it is possible to make a measurement of a repetitive waveform with much higher temporal resolution than the sample period by upsampling each record before averaging. In this case the temporal uncertainty may be limited by clock jitter. (http://ieeexplore.ieee.org/iel5/9356/29716/01352352.pdf 2019)

2.3.2 Noise

Noise is produced by the statistical fluctuation of value from pixel to pixel. Noise is recognized by a grainy appearance of the image. It is also characterized by a salt and pepper pattern on the image. Noise is un-useful information. The noise level is explained by the standard deviation, a measure of how spread out the pixel's values are. The lower the standard deviation, the higher the accuracy of the average pixel value.

Noise images relates to the number of x-ray photons that are logged in each pixel (for DDR) or in each small area of the image (for CR and IDR).

Goldman categorized the noise sources into three types, namely quantum noise, electronic or detector noise and computational or quantization noise.

2.3.2.1 Quantum noise

Quantum noise appears when too few photons, after being attenuated by organs, are received. The lower the number of attenuated photons at the detector the higher the image noise. The main factors of quantum noise are anatomical structure size, decreasing pixel size, and scatter radiation. The disturbing anatomic background variability is often called anatomical noise.

Figure 2.6 The parameters of image quality and the influence factors of each parameter.

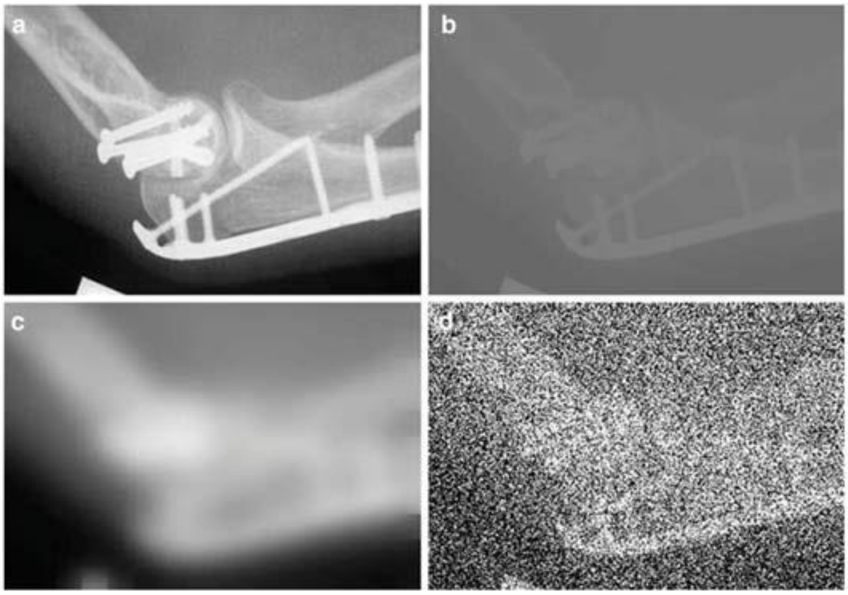


Figure 2.7 Optimum image quality has adequate resolution and contrast, and a low noise level, as demonstrated in image (a). Image (b) has high spatial resolution and low noise, but it has almost zero contrast. Image (c) has low noise and high contrast, but very poor spatial resolution. In image (d) has high spatial resolution but very high noise level which destroyed the image contrast. (Semantic scholar)

2.3.2.2 Detector noise

Noise originates from internal sources mainly image receptors whichcontain what is called electronic noise.2 Detector or receptor noise is produced because of non-uniform response to a uniform x-ray beam. This type of noise has fixed correlation to locations on the receptor, therefore it is called fixed pattern noise. Fixed pattern noise can be largely eliminated in digital imaging systems through post processing stages. Additionally, defects in the receptor's elements which may occur during the manufacturing process form unrelated structure in the image. Structured noise originates from different causes which creates unwanted signals or features on the image. Variations in pixel-to-pixel sensitivity and linearity, dead pixels and detector-response non-uniformities are the main causes of structure noise, particularly in DR.12

Conversion noise occurs because of the fluctuations of the generated energy per detected photons. Conversion noise which is also called instrumentation noise can be reduced by utilising higher-intensity scanning laser in CR detectors and brighter phosphor screens in indirect flat-panel detectors to collect and generate more secondary energy carriers and hence improve QDE. In addition, lowering the number of conversion stages of process can also reduce conversion noise.

2.3.2.3 Quantisation noise

Quantisation noise is another source of noise which occurs during the digitisation process, translating analogue output voltage of detectors to discrete pixel values (grayscale values). Th e range of these values is determined by bits, binary on-off channels. Detectors of 10 to 14 bits
(1024 to 16,384 digital values) are recommended to minimise quantisation noise in CR and DR systems.

Noise is also produced by scatter radiation which reduces subject contrast and decrease signal to noise ratio (SNR) and consequently degrades image quality. Using grid in CR and DR reduces scatter radiation and consequently reduces noise eff etc. However, the signal (incomplete transmission of the primary radiation by the grid) also reduces.

2.3.3 Artefacts

Features that occur on the image and mask or mimic clinical features called artefacts. Digital image artefacts cause by image acquisition or object artefacts, hardware or image receptor artefacts, and software artefacts.

2.3.3.1 Image acquisition/object artefacts

Radiographers usually perform image acquisition by using image receptor. Therefore, image acquisition artefacts are due to operator errors. These artefacts include inappropriate exposure factors, un-collimated images, improper grid usage, scatter radiation, delayed scanning, twin artefacts, exposed image receptors and handling carelessness.

Incorrect patient position, patient motion, improper x-ray beam collimation, and double exposure cause object artefacts. Inappropriate histogram selection can cause object artefacts. Errors of histogram analyses are associated with improper collimation of exposure field, leading to very noisy, very dark or very white images. Metal objects also cause artefacts.

2.3.3.1.1 Hardware/receptor artefacts

Digital image receptor artefacts can be caused by rough handling, dust, malfunction of pixels, faulty construction, and scratches and cracks on image detectors.18 Artefacts that results from faulty pixels cannot be treated and therefore the image receptor may need to be replaced.

Malfunction of rollers in digitizer of CR image plates causes defective scanning resulting in artefacts. Partial erasure of a previous image cause artefacts called ghost image, particularly on image plates of CR. Ghost artefacts can also be caused by environmental radiation.

2.3.3.1.2 Software artefacts

Dead pixels in image receptors cause artefacts during the image processing stage and are called soft ware artefacts. A few dead pixels may not interfere with diagnosis however many of these faults must be corrected. Radiation variation of x-ray beam over the image produce irregular configuration which again interfere with diagnosis. This can be corrected by equalizing the response of each pixel to a uniform x-ray beam by utilizing software pre-processing manipulation, namely flat fielding. Image compression is employed to facilitate transmitting and archiving of images. However, lossy compression techniques may cause redundancy of data and hence create soft ware artefacts. Artefacts may occur through inappropriate use of software filters of grid suppression, low pass spatial frequency filter, and blur masking.

2.3.4 Image transmission

(communication) errors or failures cause artefacts. Incorrect flat field corrections and a failing amplifier are other sources of artefacts.

The above discussed parameters are judged objectively (statically measurement) or/and subjectively (human observation) to determine image quality level.15 In order to improve the quality of image, image quality parameters are manipulated because they are not independent. There are trade-off s in manipulating these parameters individually.

Therefore image quality should be optimized for each specific purpose and specific region. For example, when spatial resolution is increased to get better image quality for bone tissue, the noise of image is also enhanced or hence increased visually.

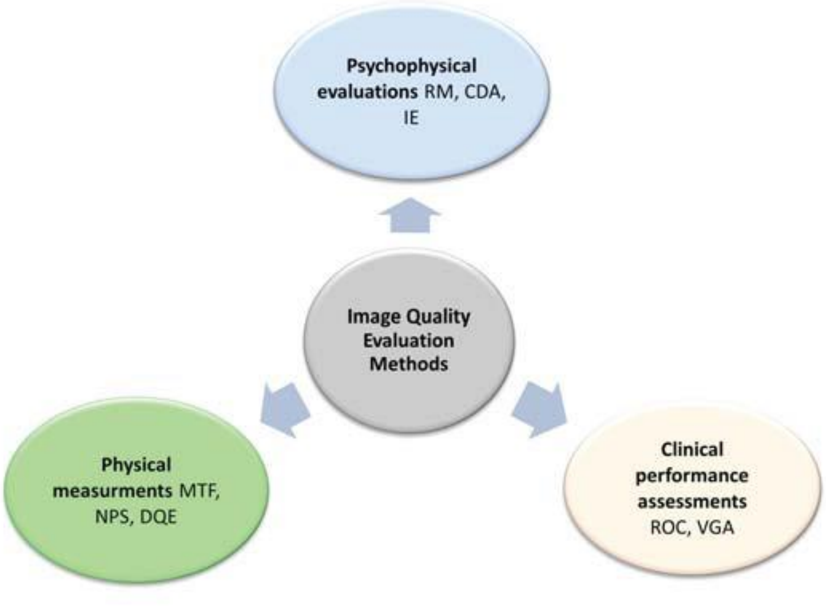
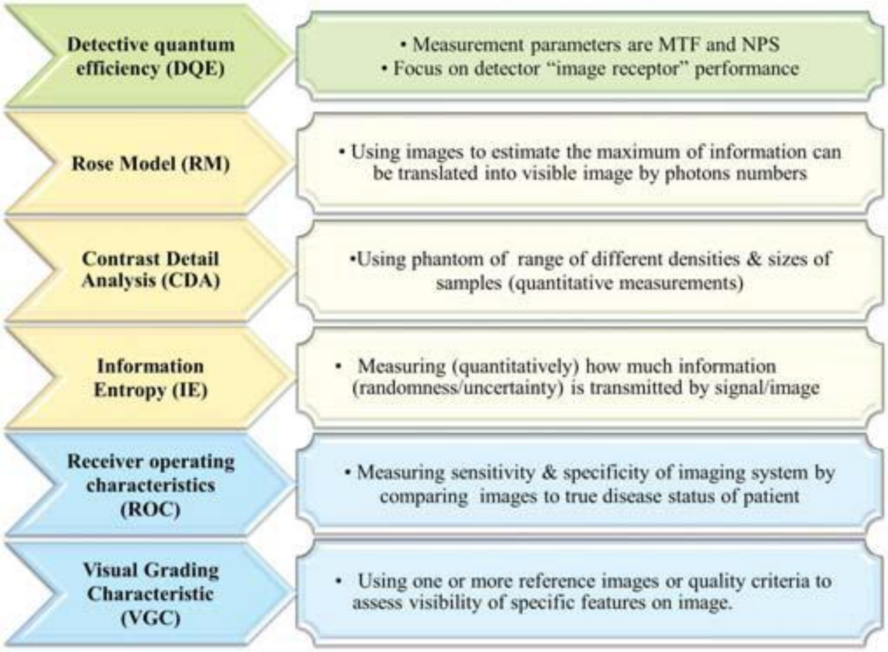


Figure 2.8 the types of evaluation methods of image quality. (Sprawls.org).


Detective quantum efficiency (DQE)
- Measurement parameters are MTF and NPS
- Focus on detector "image receptor" performance

Rose Model (RM)
- Using images to estimate the maximum of information can be translated into visible image by photons numbers

Contrast Detail Analysis (CDA)
- Using phantom of range of different densities & sizes of samples (quantitative measurements)

Information Entropy (IE)
- Measuring (quantitatively) how much information (randomness/uncertainty) is transmitted by signal/image

Receiver operating characteristics (ROC)
- Measuring sensitivity & specificity of imaging system by comparing images to true disease status of patient

Visual Grading Characteristic (VGC)
- Using one or more reference images or quality criteria to assess visibility of specific features on image.

Figure 2.9 Evaluation tools used to assess image quality and imaging system performance. (Sprawls.org).

However, there is a fundamental principle, radiation dose minimization, which should considered beside these parameters. Therefore, image quality is the balancing between image quality parameters and radiation dose.

Optimum image quality relies on the balancing of the image quality and patient dose and depends on the region being studied and case being examined. To optimise image quality, image quality parameters mentioned previously should be manipulated and altered according to the purpose of examination with respect to the patient dose. Moreover, eliminating or limiting the effects of image degradation factors are also essential in optimizing image quality.

2.4 Image quality and radiation dose

Optimal image quality is achieved at the lowest possible patient radiation dose. The high flexibility of CR and DR increases the opportunity of image quality optimizing and radiation dose lowering. The minimum level of image quality and radiation dose should be determined based on diagnostic purpose. It is essential to recognize the parameters that affect radiation dose and their influences on image quality. Exposure factors including mA, time and kVp are the most important factors that control the radiation dose to the patient. The other factors that also affect radiation dose are patient size and detector properties.

Reducing mAs decreases radiation dose and consequently decreases SNR as the noise is associated with lower radiation dose. Lower radiation dose deteriorates contrast resolution of the image. High noise level images increase the risk of diagnostic details loss.

Lowering the kVp is essential to increase x-ray attenuation and consequently the contrast resolution of structures is improved. Lower voltage increases DQE of the detectors of digital system. As a result, image quality can be improved. In CR and DR, Lower kVp techniques are more likely to improve SNR and hence the contrast resolution of image. However, low kVp techniques may increase radiation dose and image blur as a result of time increasing.

Different detector systems have different detection efficiency and radiation dose reduction ability and hence different image quality. For example, the detector of IDR can provide better image contrast resolution than that of CR.

Thicker detectors have better detection efficiency and hence higher ability of dose reduction. Spatial resolution of the image can improved with small detector elements however high radiation dose is required.

Therefore, good understanding of the influences of radiation dose factors on image quality is essential to obtain optimal image quality while maintaining lower radiation dose. Evaluation methods of image quality and imaging system performance. The utility of radiologic images and the accuracy of image interpretation depend on two main factors; the quality of images and the ability of the interpreter. Good image quality is a major factor that allows physicians to interpret the image most accurately, correctly and timely. Certain attributes are required for image quality evaluation tools and techniques to be used as quality control constancy examination. These tools should directly describe diagnostic performance, sensitively detect

2.4.1 Detective quantum efficiency

The evaluation method of detective quantum efficincy (DQE) focuses on detector “image receptor” performance to assess image quality of certain imaging systems. Assessing detector performance method bases on purely quantitative analyses by measuring objective parameters related to detector performance. Such methods are considered indirect methods of image quality evaluation. DQE has been commonly used as a tool for image quality assessment and medical imaging system performance in general. DQE based on linear-systems analysis (LSA) which is used to assess the ability of the system to transfer a signal and to characterize the noise associated with the system. The main measurement parameters of

DQE methods are the modulation transfer function (MTF) of the system and the noise power spectrum (NPS). The MTF describes a system with the ability to reproduce and preserve the information of spatial frequency contained in the incident x-ray signal. The NPS describes the frequency content of the noise in the spatial frequencies of the system image.

There are several ways to calculate MTF which alter DQE approach and quantities. In fact, MTF was used separately before as a tool of image quality assessment. However, the sharpness of the final image is not described by DQE. DQE quantifies signal-to-noise ratio to the number of incident x-ray photons and characterizes image quality.36 The main limitation of this method is that it ignores significant factors that affect image quality such as scatter radiation and image processing. Additionally, time consuming is considerable limitation of this method which makes it impractical in hospital basis environment.

Recently, DQE has been modified and improved to another method of image quality evaluation called effective detective quantum efficiency (eDQE). Some limitations of DQE are removed in eDQE. For example, factors that influence image quality such as scattering, magnification and image processing are now considered in eDQE. However, observers who are the second element in reliable radiology diagnosis are totally ignored in these methods. Moreover, they are difficult to implement as regular evaluation tools of image quality assessment due to the fact that they are time consuming and complex to some extent.

In general, the main limitations of the DQE method and its relative approaches have two drawbacks. Firstly, they do not provide description of all components in the imaging process. They give limited information about the characteristics of the produced image. Factors such as dose level and display characteristics which influence final appearance of the image are not considered in these methods and relative approaches. Secondly, they do not consider the anatomical background which limits the observer performance in detecting pathology. Anatomical background is considered as a factor of hindering detection of pathology.The ability of observers to detect details is reduced by anatomical details, even though the mechanism of this effect is not clear and is not really understood.

Therefore, the reliability and validity of recent approach of DQE and relative approaches are high in providing accurate measurement of the ability of information transfer. However, their validity is low in assessing the entire imaging system.

2.4.2 The Rose model

The method of RM, SNR based method, is another tool used to evaluate image quality of digital radiographic images. Rose, in 1953, used images to estimate the maximum amount of information that can be translated into visible image by numbers of photons. Quantum efficiency (absolute scale) is used in this method to evaluate the performance of imaging systems by utilizing a simple model of signals detect ability which is assessed by human observation. Later, Rose’s quantum signal detection model is based on SNR. It gives a description of visibility of an object in an image.39 Phantom of a number of disc-like objects of different size (0.3–8.0 mm diameters) and diverse contrast, represented by sample depth (0.3– 8.0 mm), is utilized as well. SNR is calculated to measure image quality in this method based on linking the mathematically calculated SNR to the results of detection examinations. SNR describes noise and resolution characteristics of image and human visual system.

There are some problems with this method which influence its validity and reliability in evaluating image quality. First, the size of the objects are not considered in SNR measurements in this method. Second, the noise description used in SNR is overly simplistic for observers who are sensitive to the noise characteristics. Third, to offer the same imaging conditions, a larger number of photons for the image are used with smaller pixels. Meanwhile, the observers are mostly not interested in single pixel values and are not affected by the pixel-to-pixel variations. Fourth, observers are not often affected by pure noise from the anatomical background. Hence, the validity of using SNR methods is very low to measure image quality. Therefore, it is not recommended that using SNR methods to compare different imaging systems or various image processing procedures.

2.4.3 Information entropy

A new evaluation method of image quality, IE, which is a quantitative measure of the information transmitted by the image. The concept of information entropy describes how much information (randomness/uncertainty) is provided by the signal or image. It is a simple and straightforward method based on single parameter, transmitted information.41 Step wedge phantoms of varying thicknesses are used in this method. Images of phantoms are detected, for example, by storage phosphoric plate for CR. Several images are taken with a variety of exposure times. Because of the variety of thickness of step wedge phantom, the images demonstrate a gradual scale of grey level with diverse values. The more information conveyed the better the image quality.

The authors found that IE is a useful method for the evaluation of physical image quality in medical imaging system. The results of their study demonstrated that there was a correlation between the transmitted information and both image noise and image blurring.

The main advantage of this method over DQE is that the final image is considered in the evaluation procedure. Other advantages of this method which include simplicity of computation and experimentation and the combined assessment of image noise and spatial resolution. However, its validity still low as human observers are not used in this method. In addition, the simplicity of the used phantom reduces the reliability of this method. Step wedge phantom is limited by several different thicknesses without considering sample sizes. demonstrate the effects of different noise sources such as the electronic noise and structural noise.

2.5Previous Studies:

There are many authors target this field; for example Jacquelyn S, et, al, Investigation of the Variability in the Assessment of Digital Chest X-ray Image Quality, April 2013, they had developed technology for the purpose of reducing the inherent subjectivity in performing visual QA assessments. Their methodology has the potential to produce supplemental data that can be incorporated into an overall image QA program. The approach utilizes a series of computer-based, reject-detection algorithms. The concept is similar to computer-aided detection (CAD) for digital mammography, but instead of detecting and classifying potential cancer sites for the radiologist, the algorithms detect and classify QA deficiencies for the technologist. The algorithms can be applied at the point of capture, and they have the potential for providing additional information on the presence of QA deficiencies at the reject decision point. The goal is to provide ancillary information at the point of image capture to assist the technologist in cases where the quality deficiency is less obvious and to provide collateral data that, over time, may prove useful in performing reject analyses. They concluded that Radiographic technologists agreed only moderately in their assessments of image quality deficiencies. This leads to an intrinsic variability in reject rates among technologists and, further, leads to variability in the quality of images delivered to the PACS. When compared against each other, radiologist and technologist groups were found to have less agreement than the inter-reader agreement within each group. Radiologists were found to be more accepting of limited quality studies than technologists. Evidence from this study suggests that technologists weigh their reject decisions more heavily on objective technical attributes, while radiologists weigh their decisions more heavily on diagnostic interpretability relative to the image indication. Objective technical criteria tend to be more stringent to satisfy, which explains, in part, why the technologist reject rates were found to be consistently higher than that of the radiologists. Having the reject-detection algorithm results available to the technologist did not improve inter-reader agreement in terms of the technologist’s decisions about whether to accept or reject. However, if the algorithms were optimized based on the opinion of the radiologists, the technologist might be able to better utilize the software to improve consistency, and they could potentially reduce repeats by not accepting cases that were rejected by the algorithm and by having the option to reject an image that is accepted by the algorithm. Over time, the algorithms could be refined with information learned from radiologists’ review, and when the algorithms were optimized sufficiently to be in high correlation with the radiologists’ opinions, the software could be introduced into the operational environment. The algorithms were shown to detect a small percentage of QA-accepted images that should have been rejected, and thus, the algorithms do provide information that could be captured within a reject-tracking database and leveraged as part of a site-wide QA program.

Also N W Marshall, et, al, Quality control measurements for digital x-ray in Jan 2011, they published paper described a digital radiography (DR) quality control protocol for DR detectors from the forthcoming report from the Institute of Physics and Engineering in Medicine (IPEM). The protocol was applied to a group of six identical caesium iodide (CsI) digital x-ray detectors to assess reproducibility of methods, while four further detectors were assessed to examine the wider applicability. Twelve images with minimal spatial frequency processing were required, from which the detector response, lag, modulation transfer function (MTF), normalized noise power spectrum (NNPS) and threshold contrast-detail (c-d) detectability were calculated. The x-ray spectrum used was 70 kV and 1 mm added copper filtration, with a target detector air kerma of 2.5 µGy for the NNPS and c-d results. In order to compare detector performance with previous imaging technology, c-d data from four screen/film systems were also acquired, at a target optical density of 1.5 and an average detector air kerma of 2.56 µGy. The DR detector images were typically acquired in 20 min, with a further 45 min required for image transfer and analysis. The average spatial frequency for the 50% point of the MTF for six identical detectors was 1.29 mm−1 ± 0.05 (3.9% coefficient of variation (cov)). The air kerma set for the six systems was 2.57 µGy ± 0.13 (5.0% cov) and the NNPS at this air kerma was 1.42 × 10−5 mm2 (6.5% cov). The detective quantum efficiency (DQE) measured for the six identical detectors was 0.60 at 0.5 mm−1, with a maximum cov of 10% at 2.9 mm−1, while the average DQE was 0.56 at 0.5 mm−1 for three CsI detectors from three different manufacturers. Comparable c-d performance was found for these detectors (5.9% cov) with an average threshold contrast of 0.46% for 11 mm circular discs. The average threshold contrast for the S/F systems was 0.70% at 11 mm, indicating superior imaging performance for the digital systems. The protocol was found to be quick, reproducible and gave an in-depth assessment of performance for a range of digital x-ray detectors.

Also Alain Berthel, et, al, Digital Radiography: Description and User's Guide, June 2007, they aimed to analyze the quality parameters of digital images influencing the answer and the diagnosis brought to a given industrial problem. They concluded that document is a first version of a user's guide intended for the potential users of the digital radiography. The domain of the digital sensors evolving very quickly, a regular update will be made by the COFREND workgroup. Therefore, the characteristics indicated in this document are to be considered as a rough guide. The short-term continuation of the workgroup is the addition of practical appendices handling various types of examination and the monitoring in the time of the installations. That document could serve as base for the elaboration of one or several standards.

The next authors Ehsan Samei, et, al, talk about Performance of Digital Radiographic Detectors: Quantification and Assessment Methods, in 2003 they summarized that The performance of a digital radiographic detector can be described in terms of various performance metrics. Among them, sharpness and noise are most commonly equated with the intrinsic performance of digital radiographic detectors. The MTF, the NPS, the NEQ, and the Figure 9. Contrast-enhanced uncorrected uniform image from a flat-panel digital detector, illustrating various structured noise patterns. Detector Performance: Quantification and Assessment 47 DQE are meaningful measures of sharpness and noise for digital radiographic detectors. Extensive methods have been developed to measure these quantities. The measurements can readily be used for the design of new detectors and for optimization, testing, and comparison of existing ones.

Also H Alsleem1, et, al, Quality parameters and assessment methods of digital radiography images, 2012, they abstracted that article reviewed the parameters that characterized the image quality of digital radiography and the available evaluation methods that are used to measure these parameters. The article also discussed the factors that affect each parameter of image quality. Digital imaging systems are the most commonly utilized technology in the field of radiology. Screen-film radiography systems are almost replaced by digital radiography. The data acquisition and image processing principles of digital radiography differ from that of conventional radiography. The required exposure factors for each digital radiography system are not the same. Therefore, the image quality should be optimized while lower radiation dose is maintained according to the properties of the specific imaging system. Distinguishing image quality parameters and understanding the factors that control each image quality parameter are essential to optimize and maintain image quality and to reduce radiation dose to the patient. The degree of factors effects on the images of different digital radiography types and systems are not exactly same. There were different methods and approaches that are used to evaluate the quality of medical images and to assess the performance of imaging systems and each has its own rewards and limits. Therefore, these methods should be utilized and employed according to their aptitudes to improve imaging process.

They concluded that the relationship between the quality parameters of digital radiographic images including resolution (spatial resolution and contrast resolution), noise, and artifacts is complicated, meaning that there is a trade-off between them, improving one parameter may deteriorate another. Hence, optimizing these parameters is not a simple task. Optimizing image quality parameters in regard to radiation dose make it a more complicated task. Additionally, the effect levels of these parameters on image quality of different digital radiography systems and units are not exactly the same even though they share the principles of image quality parameters. The only way to optimize image quality parameters while maintaining low radiation dose is to deeply understand the effects of these parameters on each other, the influence factors and their impact on the radiation dose for each different digital radiographic systems. Each of the available evaluation methods has its own advantages and limitations. Therefore each evaluation method should be utilized and employed according to its aptitudes to improve image quality and imaging process.

Also Jin-Soo Lee's, et, al, Quantitative Evaluation of Image Quality using Automatic Exposure Control & Sensitivity in the Digital Chest Image, Aug 2017, they abstracted that The patient radiation dose is different depending on selection of Ion chamber when taking Chest PA which using AEC. In this paper, we studied acquiring the best diagnostic images according to selection of Ion chamber on AEC mode as well as minimizing patient radiation dose. Experimental methods were selection of Ion chamber and change of sensitivity under the same conditions as Chest PA projection. At AEC mode, two upper ion chambers sensors and one lower ion chamber sensor were divided into 7 cases according to selection of on/off. after measuring five times respectively, we obtained average value and calculated exposure dose. Image assessment was done with measured Modulation Transfer Function, Peak Signal to Noise Ratio, Root Mean Square, Signal to Noise Ratio, Contrast to Noise Ratio, Mean to Standard deviation Ratio respectively. In exposure assessment results, selection of two upper chambers was the lowest. In resolution assessment results, image of two upper chambers had the second high spatial frequency at sensitivity at 625(High) was 1.343 lp/mm. RMS value of image selecting two upper chambers was low secondly. SNR, CNR, MSR were the high value secondly. As the sensitivity was increased, radiation dose was decreased but better image could be obtained on image quality. In order to obtain the best medical images while minimizing the dose, usage of two upper ion chambers is considered to be clinically useful at sensitivity 625(High).

Also C Morea, et. Al, Quantitative analysis of bone density in direct digital radiographs evaluated by means of computerized analysis of digital images, Sep 2010, their objectives Minimal density variations of mineralized tissues can be reliably detected with quantitative image subtraction analysis. The aim of this study was to evaluate quantitative variations of *in vitro* mineral density by varying the exposure time of direct digital radiographs using a computer assisted densitometric image analysis (CADIA) program.

Their method was in a human mandibular segment a three-wall periodontal defect was created mesial to a molar. Bone chips were created from the marrowbone of the same mandible with masses of 1 to 5 mg. A triplicate radiograph of the defect was taken as a baseline for seven different exposure times. The bone chips were inserted into the defect and another triplicate series of radiographs for the seven exposure times were taken as follow-up images. The images were analysed using CADIA software to detect variations in bone density.

They resulted of CADIA revealed increased density when the size of the inserted bone chip increased. The 2 mg chip was underestimated owing to mass reduction during insertion. The regression line of the CADIA values was consistent with the weight of the bone chips of 1, 3, 4 and 5 mg. The exposure time f6 (0.178 s) showed the best correlation with the bone chip weight. Loss of information in the images occurred when the exposure time exceeded the sensor's latitude.

They concluded that CADIA analysis is a reliable and sensitive tool for detecting subtle bone density variations. More reliable results are obtained with increased exposure time; however, excessive exposure should be avoided.

Chapter three

Materials & Methods

3.1Material

3.1.1 X-ray Machines

In the present study, digital X-ray machine, from Neusoft which made in china in June 2015 manufacture was used.

3.2Design of the study and population

This study intends to assess digital x-ray machine image quality using quantitative analysis by research. The thesis submitted in fulfillment for the requirements of master degree in Medical Physics

3.3 Sample size and type

A total of 100 patients from both male and female were randomly selected from whom exposed their Feet, breast, pelvic, spinal or chest in Police Hospital in Khartoum State.

3.4 Place and duration of study

This study was carried out in police hospital in Khartoum state from September 2016 till September 2019.

3.5 Method of data collection (technique)

Region of interest (ROI) were selected from the image using 3×3 pixels in the high intensity and low intensity region on the same image then data were extracted from these region as signal, noise, signal to noise ratio, contrast before and after image enhancement using histogram equalization function; where distribution of image intensity histogram were redistributed for better image quality in respect to visual perception. In X- ray imaging the exposure parameters used are selected according to patient weight and organ size. The

Standard (FFD) of 100 cm was used for all routine examination and the chest X- rays FFD of 180 cm are used for geometrical reason.

3.6 Method of data analysis

3.6.1 IDL program

The Interactive Data Language (IDL) which used here in the study is a proprietary software system distributed by Exelis Visual Information Solutions, originally Research Systems, Inc. IDL grew out of programs written for analysis of data from NASA missions such as Mariner and the International Ultraviolet Explorer. It is therefore oriented toward use by scientists and engineers in the analysis of one-, two-, or three-dimensional data sets. Exelis claims over 150,000 users.

IDL is currently available in LINUX, UNIX/Solaris, Windows, and Macintosh versions. IDL device drivers are available for most standard hardware (terminals, image displays, printers) for interactive display of image or graphics data.

IDL is not simply a package of task-oriented routines in the style of astronomical software systems such as IRAF or CIAO. Instead, it is genuinely a computer *language*, readily understandable by any computer-literate user. It offers all the power, versatility, and programmability of high level languages like FORTRAN and C. But it incorporates three special capabilities that are essential for modern data analysis:

interactivity, graphics display, and array-oriented operation. (IDL is array-oriented in the sense that arrays can be referenced without the use of subscripts or do-loops and that code is automatically vectorized for fast array computations.)

Users who are conversant with FORTRAN, C, C++, or other high level languages will have little trouble understanding IDL. Its syntax and operation are clear, sensible, and convenient (most similar to FORTRAN's). Because it is interactive, learning IDL through on-line trial-and-error is rapid.

IDL provides the scientist better understanding of and control over computations and data analysis by virtue of a large number of special features:

rapid response and iteration, immediate access to all variables (stored in RAM), immediate access to all source code (except Exelis-written proprietary routines), optimized array operations, dynamic variable typing and memory allocation, on-demand compilation and linking of routines, versatile built-in plotting and graphics routines, interactive session journal-keeping, command recall/edit, command scripts, data structures, flexible parameter specification in subroutine calls, and

structured syntax, full integration with windows systems, support for all common scientific I/O protocols, widgit (GUI) and object-oriented programming, anda large suite of mathematical, data analysis, & special interactive utility routines. (http://en.wikipedia.org/wiki/IDL_(programming_language). 18/10/2018).

3.6.2 SPSS program

SPSS (Statistical Package for the Social Sciences) which used in this study is a versatile and responsive program designed to undertake a range of statistical procedures. SPSS software is widely used in a range of disciplines and is available for all computer.

3.6.3 Microsoft Excel

is a spreadsheet developed by Microsoft for all devices. It features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications.

Chapter Four

Results

4.1 Results

Table 4.1 the mean and stander deviation of the variables calculated from high and low intensity region before and after enhancement

Signal	Mean ± Std.	
	Before enhancement	**After enhancement**
Signal high intensity region	1409.7±532.1	1859.1±614.5
Noise high intensity region	43.9±104.5	42.08±9.4
Signal to Noise high intensity region	36.9±10.3	42.08±9.4
Signal low intensity region	677.8±517.3	1104.7±713.5
Noise low intensity region	41.01±142.4	24.5±8.8
Signal Noise low intensity region	24.5±8.8	31.05±11.9
Contrast Before	0.57±0.1	0.94±0.1

Table 4.2 Paired Samples Correlations

Paired samples	Correlation	Sig.
Signal White & Signal White Enhancement	0.844	.000
Noise White & Noise White Enhancement	0.105	.141
Signal Noise White & Signal Noise White Enhancement	0.722	.000
Signal Black & Signal Before	0.763	.000
Noise Black & Noise Before	0.154	.029
Signal Noise Black & Signal Noise Before	0.741	.000
Contrast Before & Contrast After	0.111	.117

Table 4.3 Paired Samples t-test for significance differences of the signal before and after enhancement

Paired Samples Test (before and after enhancement)	***t***	**Sig. (2-tailed)**
Signal High intensity	19.241	.000
Noise high intensity	.254	.800
Signal to Noise Ratio high intensity	9.717	.000
Signal low intensity	13.057	.000
Noise low intensity	1.652	.100
Signal to Noise Ratio low intensity	11.585	.000
Contrast	1.041	.299

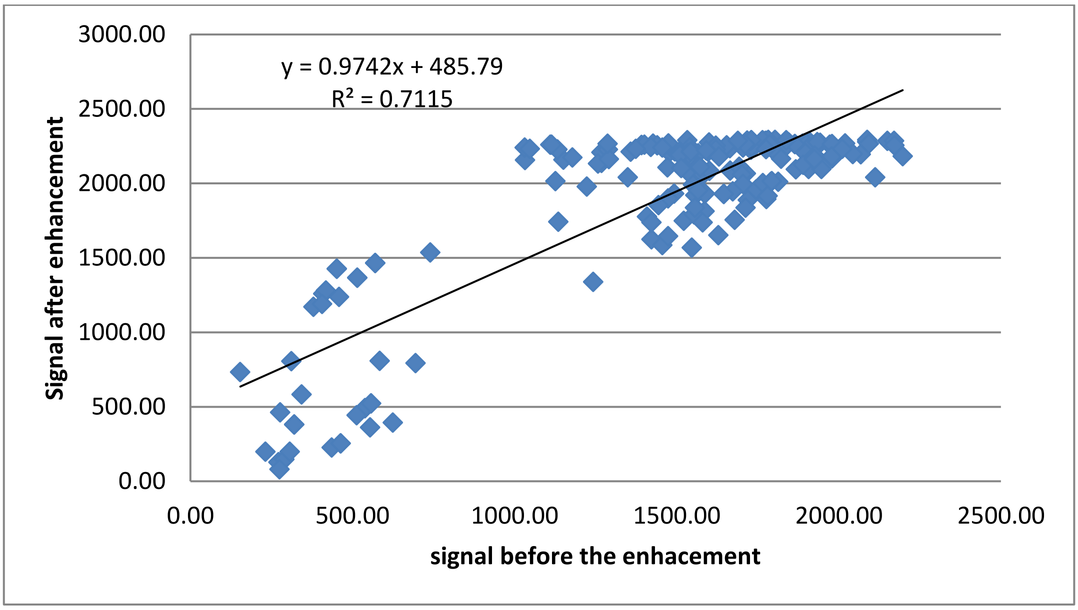


Figure 4.1 Scatter plot show a direct linear relationship of Signal in high intensity region before and after enhancement.

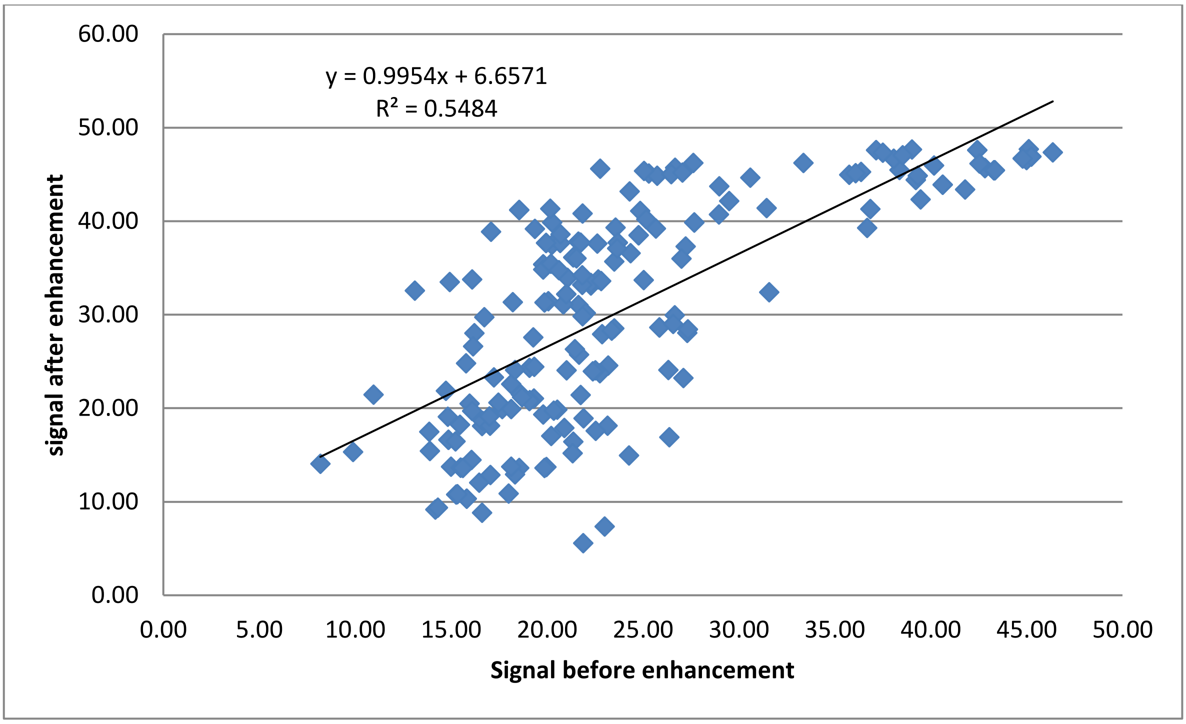


Figure 4-2 Scatter plot show a direct linear relationship of Signal in low intensity region before and after enhancement.

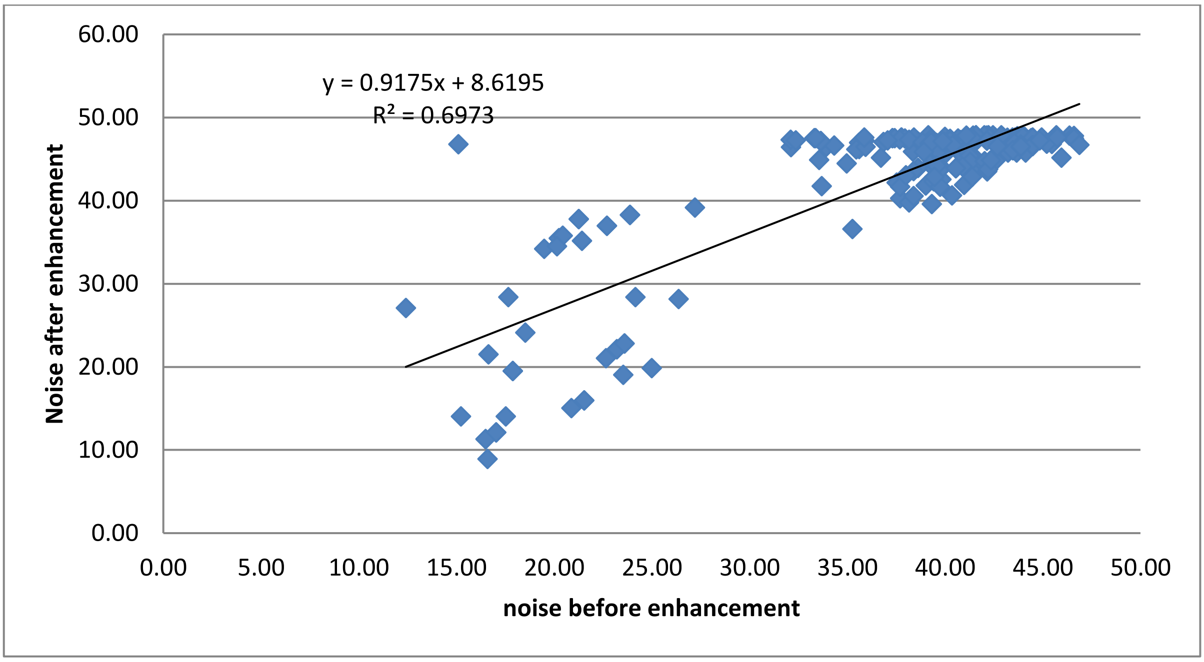


Figure 4.3 Scatter plot show a direct linear relationship of Noise in high intensity region before and after enhancement

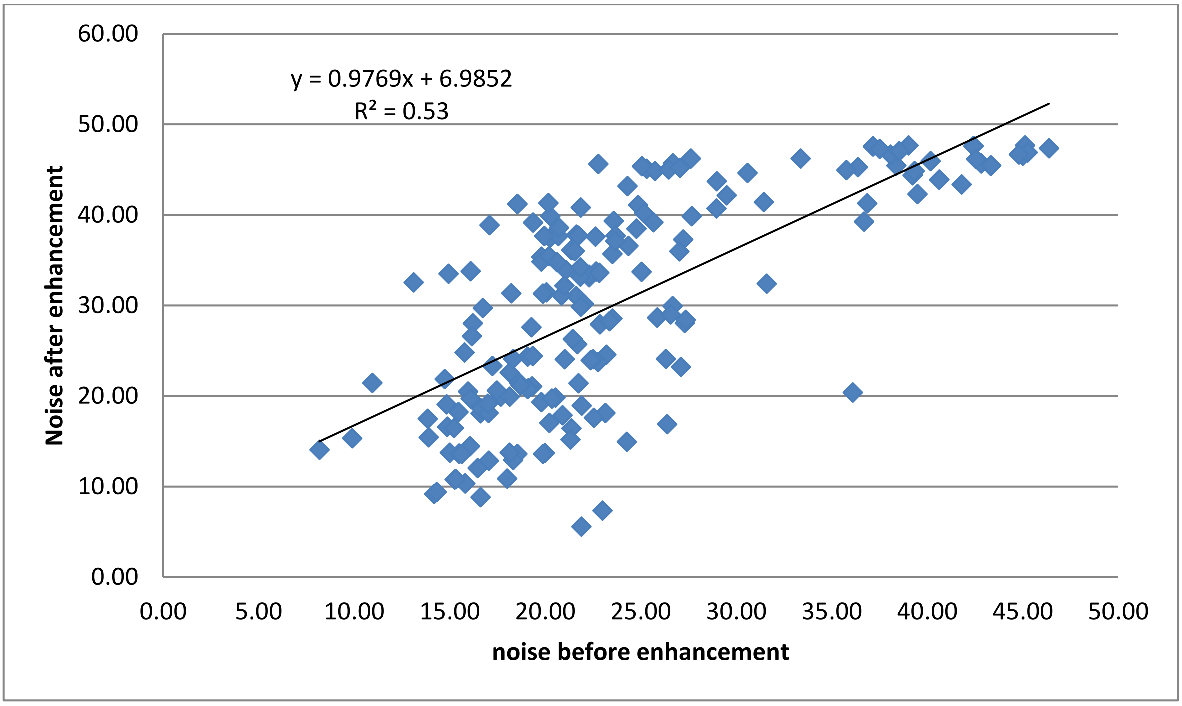


Figure 4.4 Scatter plot show a direct linear relationship of noise in low intensity region before and after enhancement

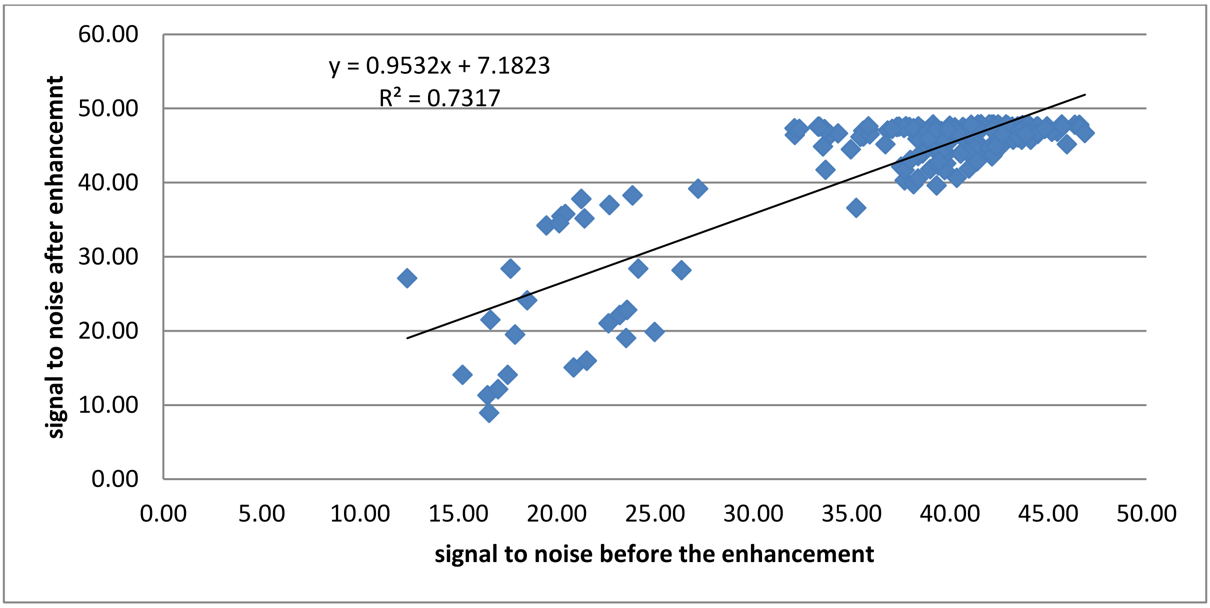


Figure 4.5 Scatter plot show a direct linear relationship of Signal to Noise in high intensity region before and after enhancement

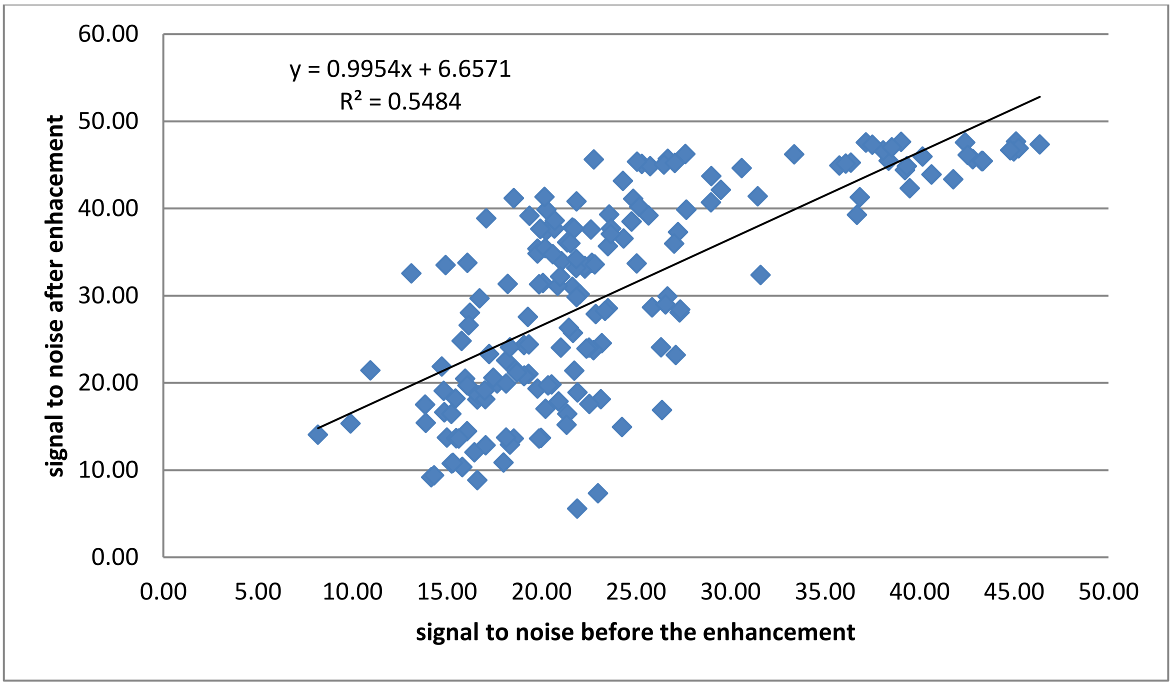


Figure 4.6 Scatter plot show a direct linear relationship of Signal to Noise in low intensity region before and after enhancement.

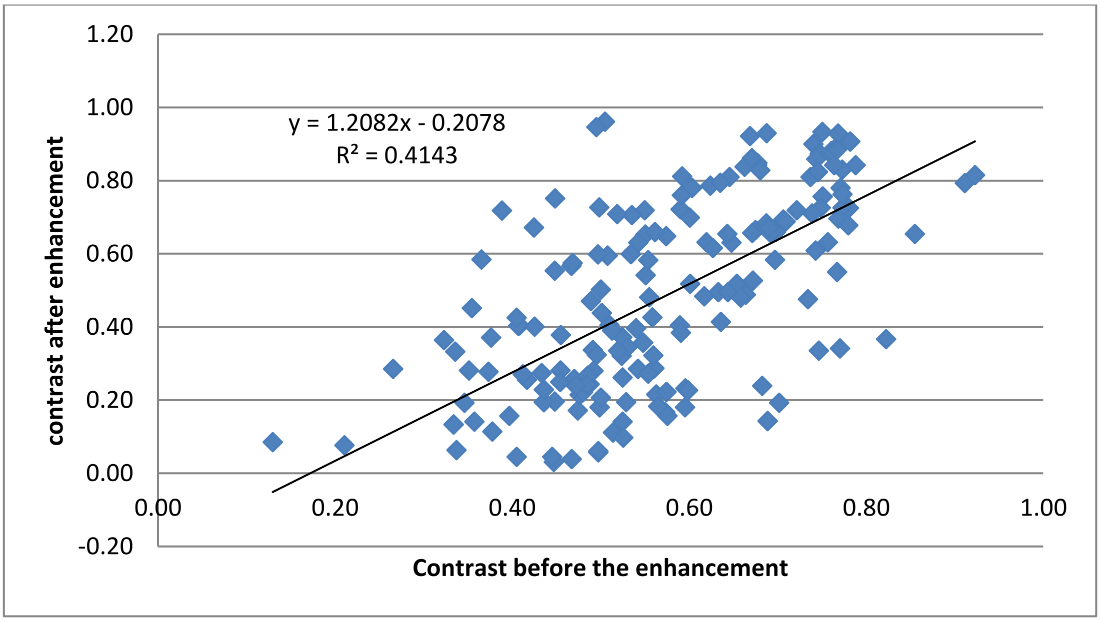


Figure 4.7 Scatter plot show a direct linear relationship of contrast before and after enhancement.

Chapter Five

Discussion, conclusion and Recommendations

5.1 Discussion

The physicians and radiography specialist are concern to image quality that reveals the pathology and hence the proper management of the patient condition and be satisfied; this situation mostly lead to high dose given to the patient where if the image quality was not suitable so repetition of the imaging process is mandatory. This study includes the significant increase of image quality and the new potential for dose reduction. It intends to assess digital x-ray machine image quality using quantitative analysis for five organs; Feet exam, breast exam, Pelvic exam, Spinal exam and chest exam in police Hospital in Sudan in Khartoum State.

A total of 100 adults patients were exposed to DR device their images were used to study signal, noise and contrast before and after in high and low intensity regions. The mean and standard deviation for the variable above and the linear relationships between them were shown in Tables (4.1), (4.2) and (4.3) .

A comparative status were shown in Table (4.1) using mean ± standard deviation for the signal in high intensity region before and after enhancement, it was 1409.66±532.08 and 1859.09±614.52; which indicate and increases of signal after enhancement. The signal was increased linearly as a result of enhancement by 0.9742 per each unit before the enhancement starting at 486 units (Figure 4.1); this increases and differences between the two form of the intensity was significance at $p = 0.05$ using t-test where p was <0.0001 and $t = 19.2$ (table (4-3).

While noise before and after enhancement did not show an increase in the high intensity area but barley it deceases it was 43.94±104.53 and 42.08±9.42 (Table 4-1). As shown in (Figure 4-3) there is a direct linear relationship between the noise values before and after enhancement where it increase relatively by 0.92 units versus each units before enhancement starting at 9 units this increases were inconclusive using *t*-test at $p = 0.05$ where $p = 0.8$ and $t = 0.254$ (Table 4-3)

Signal to noise ratio showed and improvement after enhancement since noises were not increases and the signal arbitrary were increased after enhancement as follows: 36.99±10.30 and 42.08±9.42. This increase was direct linear increase by 0.95 units per each units before the enhancement starting at 7.2 (Figure 4-5). This increased were significance using t-test with $t = 9.717$ and $p < 0.0001$ (Table 4-3).

The values of the signal and noise in low intensity areas before enhancement were 677.83±517.26 and, 41.01±142.41while after enhancement the signal and noise were 1104.65±71345 and 24.51±8.84; this result also show that the signal in the low intensity areas were increased as a result of histogram equalization which broaden the high intensity in the low intensity area as well noise were decreased as a result of the increases of the image signal adaptively. The increases of signal were linearly i.e. it increase by 0.99 unit per each unit before the enhancement starting at 6.7 units this increases were significance at $p < 0.0001$ and $t = 13.057$ (Table 4-3). Noise also follows the same pattern where it shows a direct linear relationship it increases by 0.97 units per each units before enhancement starting at 6.9 (Figure 4-4) this results were inconclusive using t-test with $t = 1.652$ and $p = 0.1$ (Table 4-3).

Therefore signal to noise in low intensity region before enhancement was 24.51±8.84 and increase as a result of enhancement to 31.05±11.89. This result supported by a direct linear relationship where the SNR increases by 0.99 units for each unit before the enhancement starting at 6.7 units (Figure 4-6), this increase were significance using t-test with $t = 11.6$ and $p < 0.0001$ (Table 4-3). Similarly contrast was increased as a result of enhancement because contrast represent the differences between high and low intensity areas where enhancement increases the signal in the high intensity areas relative to the low intensity area; therefore contrast before enhancement was 0.57±0.14 and after enhancement was 0.94±0.1 in average. The contrast were increased linearly by 1.21 per each unit before enhancement and start at 0.2078 unit (Figure 4-6). But this increase were inconclusive using *t*-test with $t = 1.041$ and $p = 0.299$ (Table 4-3).

5.2 Conclusions

This study intended to assessment of digital x-ray machine image quality using quantitative analysis. It was done in police hospital in Khartoum state from September 2016 till

September 2019 for five organs; Feet exam, breast exam, Pelvic exam, Spinal exam and chest exam ; it aimed to measure the signal, noise, signal to noise ratio and contrast; in high and low intensity regions for to minimize the dose to patients, wrong diagnostic, rejections images and repeat images.

The signal was increased linearly as a result of enhancement by 0.9742 per each unit before the enhancement starting at 486 units; this increases and differences between the two form of the intensity was significance at $p = 0.05$ using t-test where p was <0.0001 and $t = 19.2$ While in noise before and after enhancement there is a direct linear relationship between the noise values before and after enhancement where it increase relatively by 0.92 units versus each units before enhancement starting at 9 units this increases were inconclusive using t-test at $p = 0.05$ where $p = 0.8$ and t = 0.254 Signal to noise ratio showed direct linear increase by 0.95 units per each units before the enhancement starting at 7.2 . This increased were significance using t-test with $t = 9.717$ and $p < 0.0001$. The result of the signal and noise in low intensity areas before enhancement showed that the signal in the low intensity areas were increased as a result of histogram equalization which broaden the high intensity in the low intensity area as well noise were decreased as a result of the increases of the image signal adaptively. The increases of signal were linearly i.e. it increase by 0.99 unit per each unit before the enhancement starting at 6.7 units this increases were significance at $p < 0.0001$ and $t = 13.057$. Noise also follows the same pattern where it shows a direct linear relationship it increases by 0.97 units per each units before enhancement starting at 6.9 this results were inconclusive using t-test with $t = 1.652$ and $p = 0.1$. Therefore signal to noise in low intensity region before enhancement was supported by a direct linear relationship where the SNR increases by 0.99 units for each unit before the enhancement starting at 6.7 units , this increase were significance using t-test with $t = 11.6$ and $p < 0.0001$ (Table 4-3). Similarly the contrast were increased linearly by 1.21 per each unit before enhancement and start at 0.2078 unit. But this increase were inconclusive using t-test with $t = 1.041$ and $p = 0.299$.

It concluded that the quantitative analysis is a valuable tool for digital X- Ray image estimation.

5.3 Recommendations :

- Advices the physician and technician to not decided to repeat or reject an image before to use all available methods to make the best image quality.

- Must use contrast, signal to noise ratio etc .. in different regions to modify the image quality.
- More cases, more patients and more types of exams can be used to reach more accuracy.
- More exams must be used.
- More regulatory quality control test can be done for equipment and machines.
- More regulatory training can be done to staff in order to reduction the rejection and repeat images.
- We can minimize the use of high parameters that caused high radiation doses when possible by using image quality methods.
- An experience one in any field can be found in the digital radiology to minimize the radiation dose parameters.
- More studies in this field can be done to reach to best result and best expected.
- This study consider as starting print for continuo research in this subject am highly recommended.

5.4 References

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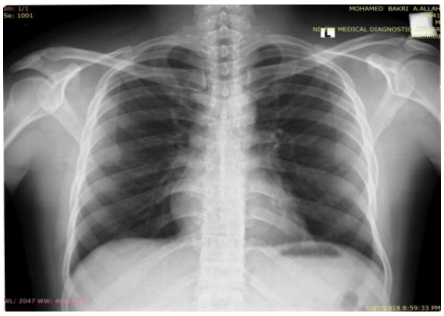
5.5 Appendices:

1. Feet exam .

2. Pelvice exam

3.Breast exam.

4. Spinal exam



5.Chest exam.

Table 1:

Signal	**Before enhancement**	**After enhancement**
Signal high intensity region		
Noise high intensity region		
Signal to Noise high intensity region		
Signal low intensity region		
Noise low intensity region		
Signal Noise low intensity region		
Contrast Before		

Table2:

Paired samples	**Correlation**	**Sig.**
Signal White & Signal White Enhancement		
Noise White & Noise White Enhancement		
Signal Noise White & Signal Noise White Enhancement		
Signal Black & Signal Before		
Noise Black & Noise Before		
Signal Noise Black & Signal Noise Before		
Contrast Before & Contrast After		

Table 3:

Paired Samples Test (before and after enhancement)		
Signal High intensity		
Noise high intensity		
Signal to Noise Ratio high intensity		
Signal low intensity		
Noise low intensity		
Signal to Noise Ratio low intensity		
Contrast		