

Chapter One

1.1 Introduction:

Medical imaging has experienced significant change in both technologic and clinical areas. Innovations have become common in the Radiology Department, and today the introduction of new ideas and methods refinement in existing techniques are apparent (NAGEL, 2002)..

The goal of these developments is the acquisition of optimal diagnostic information while the quality of care afforded to patient is improved. One such development that is revolutionary tool of medicine, particularly in medical imaging, is computed tomography “CT”.

Tomography is old word mean section; conventional tomography is an image of a section of the patient that is oriented parallel to the film.

Later they develop another tomographic technique in which the sections were transverse section (cross section); this technique was referred transverse axial tomography (NAGEL, 2002).

The primary purpose of quality control (QC) is to maintain a standard of image quality for the benefits of patient, physician, medical imaging department, and the institution.

For CT scanners, QC may be defined as a program that periodically tests the performance of a CT scanner and compare its performance with some standard, the goal of quality control program is to insure that every image created by CT scanner is a good image.

1.2 Research problems:

The reasons for low computed tomography image quality in Khartoum state hospital.

1.3 Hypothesis:

The evidence of quality control protocol in diagnostic CT scan improves the quality of diagnosis and reduces the cost of maintenance, and due to the absence of QC program for CT equipment the performance will be affected.

1.4 Research objectives:

1.4.1 General objectives:

To determine reasons of low image quality in Khartoum state hospital.

1.4.2 Specific objectives

To evaluation of CT image quality in Khartoum state hospital.

1. 5 Research Overview

Chapter one: introduction to this thesis.

Chapter two: literature review

Chapter three: materials and a method.

Chapter four: results of the study.

Chapter five: discussion, conclusion and recommendations of the thesis and References and appendix.

Chapter two

Literate review

2.1 Theoretical background:

Computed tomography (CT) scanners create cross-sectional images of high radiographic contrast. This is particularly important for diagnosis involving soft tissue (that is, organs not including lung or bone) as the contrast available from CT images is vastly superior to that gained from projection radiography. Therefore, this type of imaging is medically very useful and increasingly the technique of choice for a growing number of examinations. On the other hand, the dose to the patient may be significantly higher than with alternative imaging modalities. This is of particular importance if the examination involves a pregnant patient or child. The cause of excessively high patient dose can usually be attributed to poor optimization of scanner radiographic protocols, but can also be due to poor equipment condition. CT scanners are under continual technical development, resulting in increasing clinical application which in turn highlights the need for continual professional education (NAGEL, 2002).

The increasing complexity of scanner operation and application requires careful monitoring by the medical physicist in conjunction with the radiologist and radiographer to ensure that appropriate examination conditions exist and that procedures are optimized for diagnostic quality and patient dose. To achieve this, it is essential to promote and facilitate the implementation of a quality assurance (QA) program. This includes appropriate training of radiographers and radiologists, use of well-designed equipment that is in proper operating condition, suitable examination protocols and adequate viewing conditions for image interpretation. The involvement of a medical physicist is a key element in the QA process. It should be further noted that CT scanners are being increasingly utilized by radiotherapy

departments for image acquisition for treatment planning purposes in addition to the traditional roles of patient diagnosis and cancer staging, placing further important demands on scanner performance requirements and QA processes. CT scanners are usually found in diagnostic radiology departments and might be accessed by the therapy department by arrangement .However, once the need for CT based treatment planning increases, as is the case when a significant number of treatment units are utilized in a department, and most importantly, when the percentage of therapy patients receiving curative rather than palliative treatment increases, the use of a dedicated CT simulation unit situated within the therapy department becomes a high priority (Mutic, s., et al., 2003).

There currently exist a small number of established quality assurance (QA) publications, including several on acceptance and quality control (QC) testing for CT (IPEM, York 2003) .These publications form a comprehensive available resource in this area. The IAEA recognizes the different resources and needs of Member States. This publication has been compiled in the light of existing publications and has incorporated the principal components of the existing programs in a harmonized manner to create a useful handbook for the broad range of Member States. It has been developed with the philosophy that CT imaging must be of the highest quality in order to fulfil the diagnostic tasks expected of it. This publication addresses topics such as the special requirements for scanners used for radiotherapy treatment planning and how to ensure adequate performance in shared diagnostic and radiotherapy scanner utilization and in radiotherapy-only use. In some areas, resources, both technological and human, are limited and therefore this publication was developed with the concept of practical application in mind (IEC, Geneva 2004).

2.2 Basic CT Technology:

CT is a mature diagnostic modality that is still undergoing rapid Development.

CT is a radiographic process that produces a photon attenuation map of the patient based on the variable attenuation of a beam of X rays as it passes through a patient. In order to obtain a cross-sectional image, the beam is restricted to form a thin fan across the patient (in the x–y direction) of between 0.5 mm and 10 mm in thickness, in the case of single slice scanners, to produce a single imaged slice in the axial (z) direction. Many hundreds of attenuation profiles are created in each revolution of the x ray tube around the patient (KALENDER, W.A., 2005). These profiles are then reconstructed to form the required transverse image (Fig. 2.1).

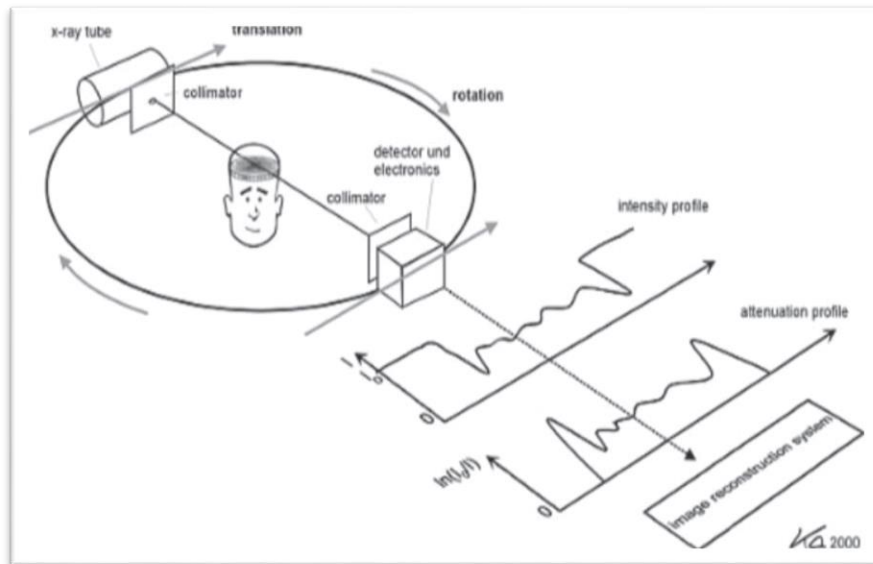


Fig (2.1) Simplified diagram of the creation of an attenuation profile in a CT scan. Note that modern scanners use a fan beam to acquire the attenuation profile in one exposure.

2.2.1 CT gantry: Tube, collimator, filters and detector:

The large x-ray tube located within the gantry (Fig. 2) operates at between 80 kV and 140 kV. This tube can generate over 10⁹ photons per mm² per second at 75 cm from the tube focus for typical CT radiographic settings of tube voltage (120 kV) and current (300 mA). The x-ray tube is typically operated at high voltage and high tube current values for long periods of time, which requires the rapid dissipation of heat to avoid tube failure. The tube cooling system is designed to deal with this.

However, it is essential that the ambient temperature around the scanner or heat exchanger be controlled by effective air conditioning to allow optimal operation. The x-ray beam, after leaving the tube, passes through filter material to remove low energy photons. Typically, specially shaped filters are then applied to compensate for attenuation differences in a patient's head or body. It is essential to use the correct filter for the correct body part. The slice width collimator, positioned at the filter exit, determines the width of the x-ray beam. In modern scanners, multiple slices (currently up to 320) are acquired simultaneously. These scanners are known as multidetector, multislice or multirow CT scanners. The width of the beams for these acquisitions is the product of the individual slice width and the number of slices acquired simultaneously (KALENDER, W.A., 2005).

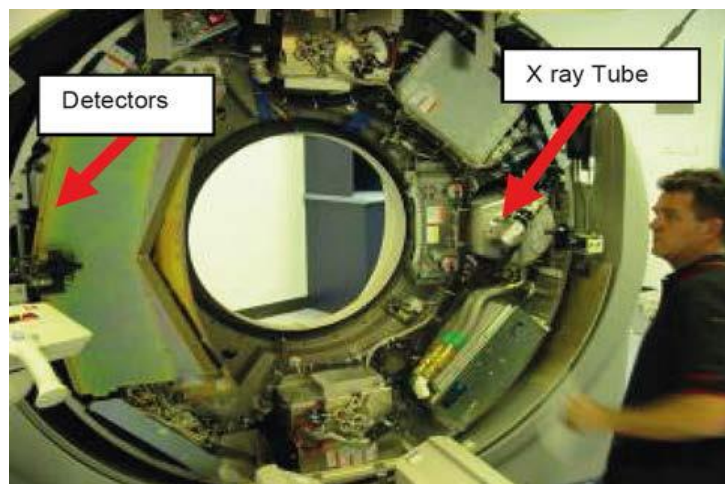


Fig (2.2) CT scanner with gantry cover removed. Note the x-ray tube on the right hand side with collimator and filters facing towards the scan aperture. Detectors are on the left hand side.

The x-ray detector element is typically an ionization chamber using high pressure xenon or a scintillation detector. Early scanners used scintillation detectors such as sodium iodide (NaI) or cadmium tungstate (CdWO_4); later high pressure xenon generally replaced these early materials and in later years scintillator doped ceramics have been used, such as gadolinium oxysulphide ($\text{Gd}_2\text{O}_2\text{S}$) or yttrium gadolinium oxide (YGdO). Important specifications for such detector elements, and factors in

their development, include a high dynamic range, high quantum absorption efficiency and a fast temporal response with low afterglow. For a single slice axial scanner, the detector unit will have over 700 elements arranged along an arc to intersect the exit beam of the tomographic plane. This is known as 3rd generation scan geometry (see Figs 2.3 and 2.4) and is the basic design for modern CT scanners. In multidetector CT scanners, the detector typically has additional adjoining arcs, or rows, of detector elements. Such multirow detectors may have up to 64 rows, allowing a total acquisition width of 32–40 mm (measured at the isocentre). This type of acquisition can produce slice thicknesses varying from 0.5 mm to 10 mm. With such a detector, the acquisition time is reduced and the occurrence of motion artefacts is considerably reduced (KALENDER, W.A., 2005).

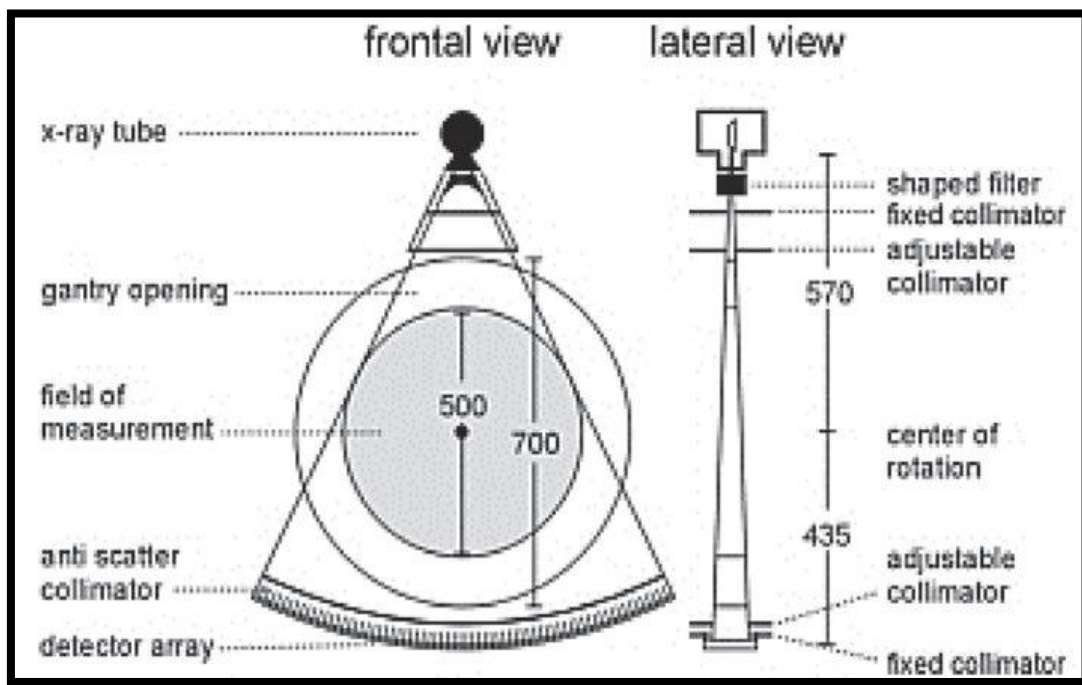


Fig (2.3) Schematic representation of the scanning geometry and important components of the CT measurement system in frontal view (x-y plane) and in lateral view (y-z plane).

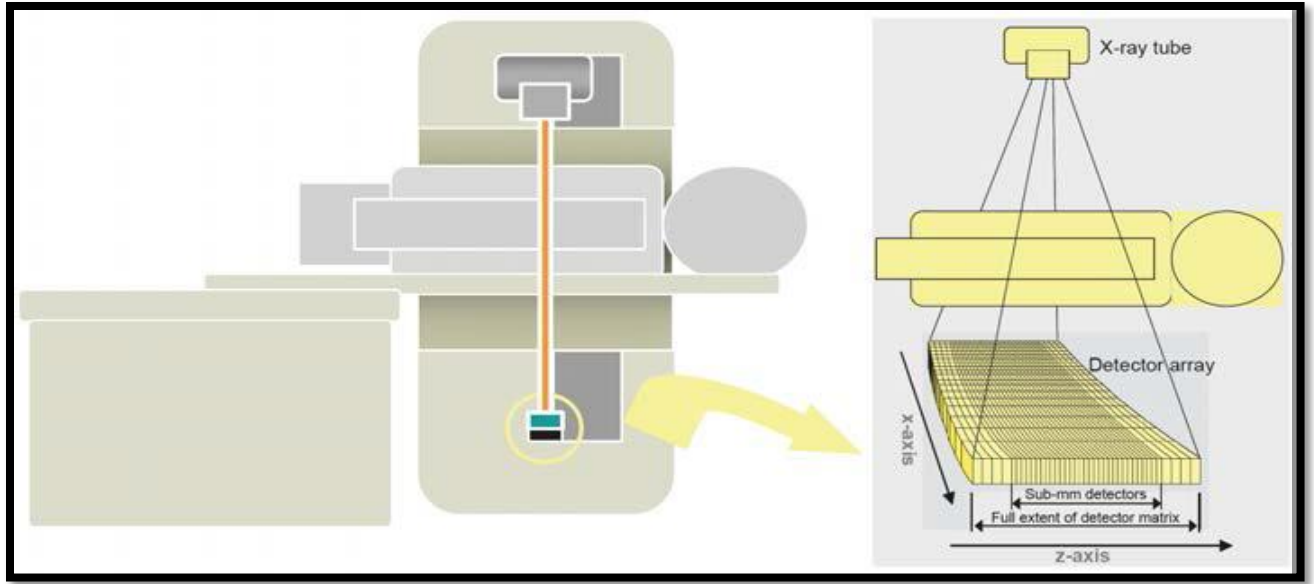


Fig (2.4). Schematic representation of the scanning geometry in the lateral view (y-z plane) for a multidetector scanner, demonstrating the multiple detector rows along the z axis.

2.2.2 Image reconstruction:

Typically, the reconstruction of an axial image uses projection profiles acquired from a 360° rotation of the tube and detector around the patient. However, reconstruction is possible with projections of as little as 180° of rotation, while in helical (spiral) CT scanners, variable reconstruction angles are used. The reconstruction is primarily achieved by a filtered back projection method (Fig. 2.5) that allows almost real time reconstruction, although iterative reconstruction methods are also increasingly being considered now (KALENDER, W.A., 2005).

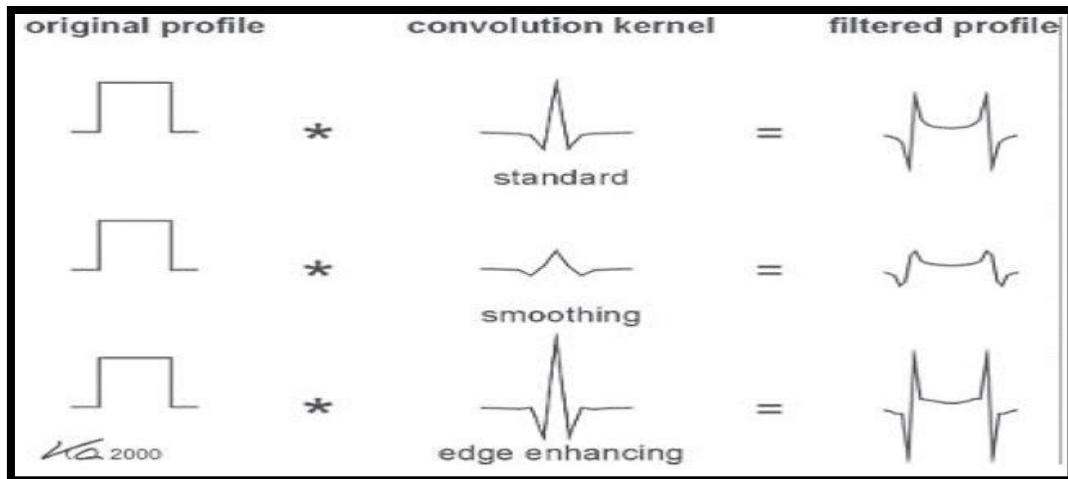


Fig (2.5) Image characteristics can be influenced by the choice of convolution kernel, whereby increasing spatial resolution or edge enhancement also means increasing image noise.

2.3 Performance Requirements in CT:

2.3.1 Scan and Patient Positioning Accuracy:

2.3.1.1 CT alignment lights, SPR accuracy:

All scanners have patient positioning lights which identify the tomographic plane. These are often referred to as the 'internal lights'. There are often other lights that identify the sagittal and coronal planes, as well as a further set of lights identifying a transaxial plane, set at a fixed distance from the tomographic plane. These are usually called the 'external' lights. Once a patient or phantom is aligned to the external lights, the tomographic plane, as defined by the internal lights, can usually be reached by a single button press. Testing the quality of the scanner involves establishing a level of certainty in the position of the scanner lights and their accuracy against requirements. The lights are either tungsten or laser. (Where laser lights are used, safety aspects need to be considered. Generally, the lights are classified as safe for use where the blink reflex is used as the body's natural protection. Care is needed for unconscious or anaesthetized patients). In clinical practice, the lights are usually used as a rough guide for setting up the patient. The patient is first aligned on the scanner couch using the scanner tomographic plane

lights, in order to establish which region of the body to scan, to center the patient to the isocentre for best image quality and sometimes to avoid irradiating the eyes in brain scanning (IAEA, Vienna NO 19 2012).

Precise preparation for cross-sectional CT scanning is taken from the scan projection radiograph (SPR) also known as a Scoutview, Scanogram, Surview or Topogram, depending on the manufacturer, and this is used to define the beginning and the ends of the required scanned volume. When carrying out a number of tests on a scanner, it can be helpful to perform the light alignment checks first, in order that the lights can be used to assist in setting up the phantoms. Clinically accurate light positioning is required in diagnostic imaging for biopsy location and for avoiding radiosensitive organs such as the eyes in brain scanning (IAEA, Vienna NO 19 2012).

2.3.2. Image Quality:

2.3.2.1 CT number:

The CT number (H_s) of a sample of materials is defined by the expression:

$$H_s = K \frac{\mu_s(E) - \mu_w(E)}{\mu_w(E)} \quad (1)$$

Where $\mu_s(E)$ and $\mu_w(E)$ are the linear attenuation coefficients at the energy of the X ray beam for water and the scanned sample, respectively and K is a constant, which has a value of 1000 if the CT value scale is in Hounsfield units. The Hounsfield unit scale is the accepted scale on all modern CT units. The exceptions were for very early scanners and for a very few modern scanners where the K factor is halved in the application of certain high resolution convolution kernels. From Eq. (1), the CT number for water is zero and, since the attenuation is negligible for air, the CT number (Hounsfield unit) for air is -1000 . The attenuation process for CT is dominated by Compton interactions for soft tissue, with some photoelectric interactions for materials of higher atomic number (Z). Compton interactions are independent of atomic number, proportional to electron density and inversely

proportional to the energy, E . The photoelectric effect is approximately proportional to $(Z/E)^3$. In radiotherapy treatment planning, in order to compute the treatment dose distribution from a CT image, the relationship between relative electron density and CT number needs to be established, since the Compton Effect is the predominant X ray interaction at radiotherapy energies (IAEA, Vienna NO 19 2012).

2.3.2.2 Image noise:

When a uniform material is imaged on a CT scanner, examination of the CT values for individual pixels in a localized area shows that the CT numbers are not all the same, but fluctuate around a mean value (Fig.2.6). This random variation is known as image noise and is due primarily to the statistical nature of x-ray production and interaction with matter. It is also known as quantum noise.

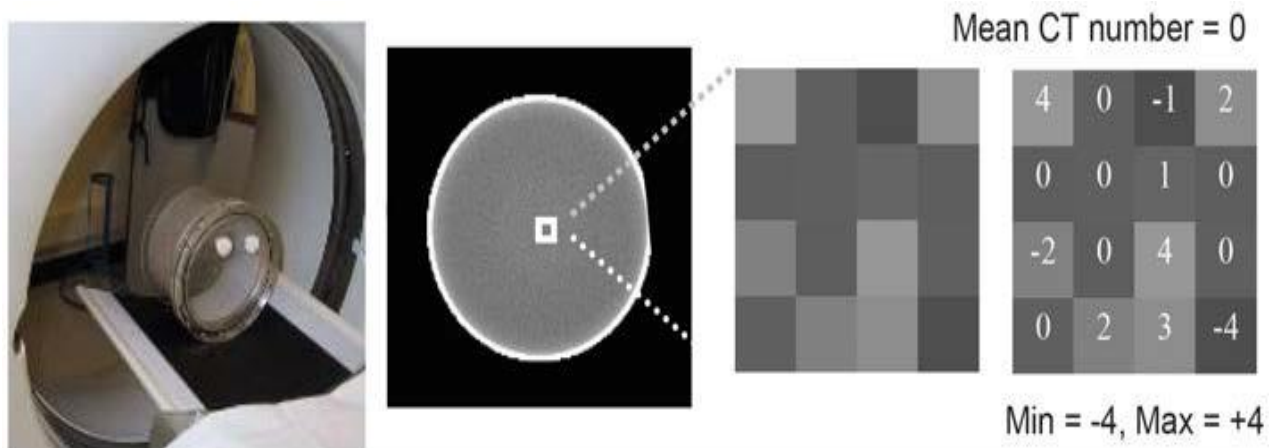


Fig (2.6) Variation in grey level from a water phantom (CT number).

In addition, other sources of noise may include structured noise or artefacts and Electronic noise (IAEA, Vienna NO 19 2012).

2.3.2.3 Contrast to noise ratio (CNR):

CT scanning utilizes a large photon flux in acquisition in order to achieve low noise images. However, this results in higher patient doses. These images allow the identification of low contrast structures, reflecting very small differences in photon attenuation in the tissue due to composition or density differences. While the image

noise in a uniform material is usually a good indicator of the ability to visualize small contrasts in diagnostic images, a more versatile measure is that of CNR. To measure CNR, the contrast of two objects is determined by the difference of the mean CT numbers within selected ROIs. And is divided by the average noise for these two ROIs (IAEA, Vienna NO 19 2012).

2.3.2.4 Uniformity of image noise and CT number:

A scan of a water filled phantom should give a CT image with similar pixel values, and similar amounts of noise, across the whole field of view. However, in practice, scans of uniform phantoms often show gradual variations of CT number and noise values across the image. These variations may be particularly noticeable when the uniform phantom is surrounded by a high contrast material, such as cortical bone substitute material. Variation is also noticeable at the extremities of large phantoms, particularly when an exceptionally large phantom is used to investigate the extended fields of view used on the large bore scanners that are sold for radiotherapy use. If a phantom, or patient, is not centered at the isocentre, a more pronounced variation of CT number and image noise is also likely to be observed. The uniformity of CT number is of importance when the scanner is used for quantitative assessment of CT values, particularly for radiotherapy (IAEA, Vienna NO 19 2012).

2.3.2.5 Image artifacts:

Artifacts are features on the image which do not represent true tissue structure. At best they are a nuisance to the radiologist trying to interpret the image; at worst they are misleading and give rise to false or missed diagnoses. There are a number of causes of image artefacts. To avoid them, as much as possible, it is essential to have a good installation process, give attention to electronic components and servicing, and conduct regular calibration. At installation, it is essential that room preparation be carefully considered. The room must be stable, level and able to withstand the weight of the scanner. During assembly, the alignment of components is critical and

scans must be carefully examined during the acceptance and early clinical phase to check for any indication in phantom images. Electronic component failure or poor board connections can give rise to artefacts. Regular calibration by the servicing engineer and daily calibration by the radiographer will avoid certain artefacts occurring. Visual artefacts may appear due to the quality of the image monitor. The image display monitor, therefore, needs to be included in the whole QA/QC program. Image artifacts in CT are generally separated into four descriptive categories; streaking, shading, rings and aliasing. They generally have a variety of causes (BARRETT, J.F et al 2004).

Streaking artifacts tend to be caused by inconsistencies in neighboring projections, either by a high attenuating region such as a metallic implant, or by patient movement. These can also be caused by scanner movement or misalignment of the equipment. Shading artifacts tend to be due to inappropriate beam hardening corrections, giving a gradual change in accurate CT numbers across a phantom or patient. It is normal practice for calibrations to be carried out by the installation engineer for every scanning factor or combination that will be used in clinical protocols (e.g. voltage (kV), current (mA), slice thickness), to ensure that the correct beam hardening factors are implemented.

Ring artifacts are very common and are generated by detectors that have differing sensitivities relative to each other. The easiest way to avoid most of these is to ensure that the 'air calibrations' are run whenever required by the scanner manufacturer; this is usually once a day, or sometimes more frequently or when flagged by the system.

Aliasing artifacts generally appear with high resolution algorithms and merely show the mismatch of the physical aperture to the mathematical filter applied to the projections.

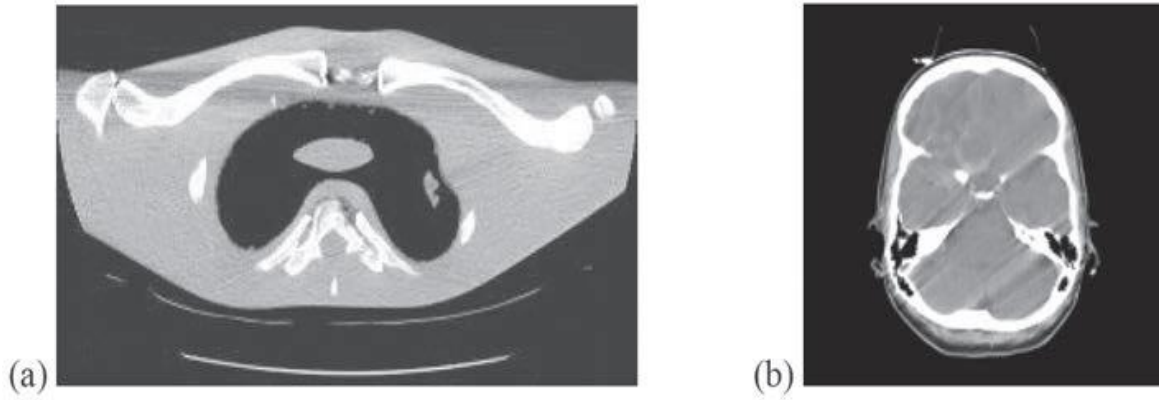


Fig (2.7) Examples of streaking artefacts caused by (a) highly attenuated projections through the lateral view of the thorax and (b) patient movement.

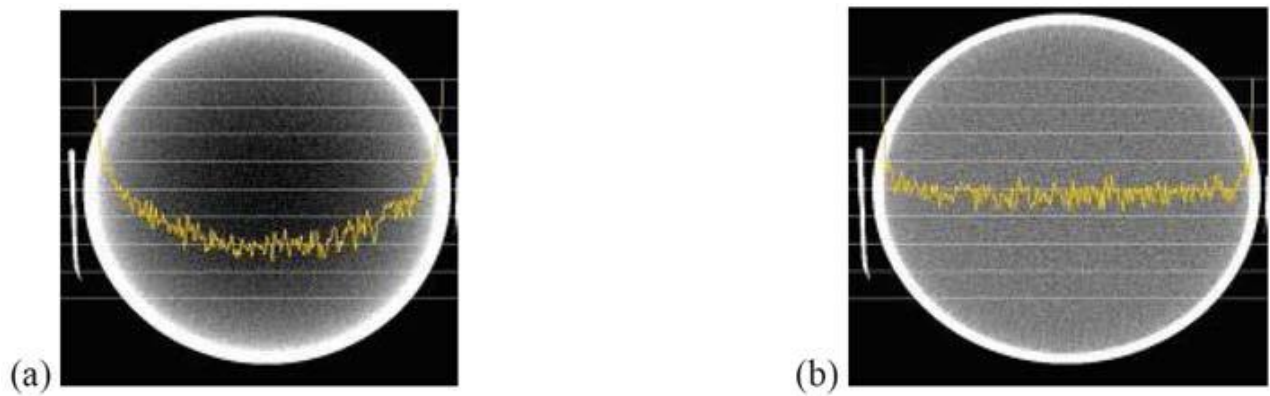


Fig (2.8) Example of (a) beam hardening artefact through a water filled phantom and (b) after beam hardening correction applied.

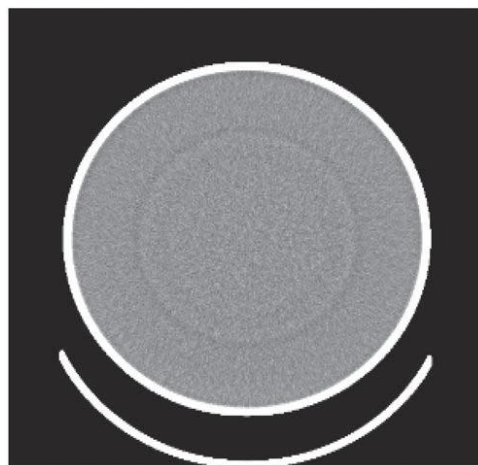


Fig (2.9) Example of ring artefacts in a water filled phantom.

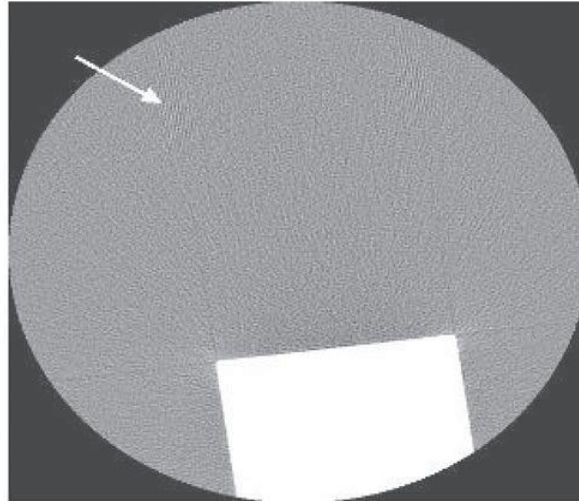


Fig (2.10) Example of aliasing artifact.

3.2.2.5 Spatial resolution:

Spatial resolution is the ability of the CT system to create an image of an object without loss of spatial information or ‘blurring’. It usually refers to high contrast objects and is defined in the tomographic plane, although 3-D scan reconstruction allows spatial resolution to be considered more generally. The determination of spatial resolution can be made through the use of a high contrast test object through visual inspection or computation to compute the modulation transfer function (MTF) or with the use of an appropriate test object to compute the MTF. The MTF is commonly derived from the image of a bead or wire to give a point spread function (or of an edge to give an edge spread function) (DROEGE, R.T., 1982).

Standard methods are then used to compute the MTF from either the point spread function or the edge spread function. Comparisons can then be made of the frequencies at which the MTF curve falls to the 50% and 10% levels. If a high contrast test object is used, the resulting quantity is line pairs per millimetre (lp/cm), and if MTF is determined, the quantity is cycles per centimetre (c/cm). Calculating the MTF is critically dependent on the ability to access the numerical data and the scanner, as well as having a suitable analysis program (IPEM, York 2003). This has become less of a problem in recent years with the advent of the DICOM image

transfer standard and the availability of functional software on personal computers. Only one or two manufacturers calculate the MTF as a standard facility on their QC software packages (DROEGE, R.T., 1982).

2.3.2.6 Partial volume effects:

The partial volume effect, often mentioned in relation to the artefact that it creates, is a consequence of the finite thickness of a CT slice or can be considered as a type of blurring in the z axis. This effect is prominent when viewing objects that are only partially within the image slice, or that are smaller than the image slice thickness. For example, a small blood vessel filled with iodine will have a reduced contrast in a thick slice compared with a thin slice, owing to the overlying tissue of the thick slice ‘averaging’ the density over the full voxel. Consequently, the use of thin slices reduces this effect considerably, although it comes at the cost of either higher noise or higher patient dose. The spatial resolution in a CT image is currently limited to approximately 0.5 mm, which is inferior to most other radiological procedures but better than that possible with radioisotope imaging. CT scanners can also acquire slices of thin tissue thickness (minimum 0.5 mm), which allows very precise cross-sectional delineation of structures without interference from partial volume effects (BARRETT, J.F et al 2004).

2.3.3 CT Dose:

Dosimetry for CT has recently been specified by the International Commission on Radiation Units and Measurements (Bethesda, 2006) with a complementary code of practice recently published by the IAEA. In these publications, the use of a dose index is formulated that can be a powerful tool in the optimization of CT examinations.

2.3.3.1 Understanding the concepts of CT dosimetry indices:

The CT air kerma index (or CTDI) is calculated from a measurement made with a pencil ion chamber, irradiated by a single rotation of the x-ray beam, at the central

position along the chamber's length. The integration length in the definition of C (or CTDI) matches the length of the pencil ion chamber (100 mm). The interpretation of this measurement is that it gives an equivalent value to the z average dose at the central slice position, as though a 100 mm length had been scanned with contiguous X ray slices. The weighted value (C_w) looks at the CT air kerma value in a phantom, and takes into account the variation in dose over the cross-section of the phantom. So it represents an averaged x – y plane (scan plane) dose, averaged along the z axis at the central slice position, as though a 100 mm length had been scanned with contiguous X ray slices. The volume CT air kerma index ($CVOL$) goes further, considering the CT air kerma value in a phantom, but in this instance taking into account non-contiguous irradiations along the z axis, i.e. pitch. It therefore represents the average of the dose in the x – y plane and the z average dose at the central slice position as though a 100 mm length had been scanned at a given pitch.

2.3.3.2 Dosimetry for CT scanners with large collimation beam widths:

The early development of the CTDI started when the slice width of a CT scanner was typically 10 mm or less. It was originally developed for head scans and the integration length was selected to be similar to the length of a head examination. It was subsequently changed to 100 mm with the development of the 100 mm pencil ion chamber. The contribution of radiation falling outside the active length of the pencil chamber was considered negligible for beam widths up to about 20 mm. However, with the advent of MDCT scanners with collimation beam widths of up to 40 mm, there was concern that there would be more scatter not included in this measurement and calculation. However, it has since become apparent that beam widths up to about 80 mm are equivalent in the proportion of radiation that is excluded (BOONE, J., 2007). In addition, for all these beam widths there is a significant amount of radiation not included in the measurement of CPMMA, 100 and this leads to a systematic difference in dose compared with a long integration length. This

underestimate is of the order of 30–40% for a body phantom and 10–20% for a head phantom (BOONE, J., 2007). The maximum dose values are reached at the equivalent irradiation lengths of 300 mm for the body phantom and 160 mm for the head phantom. In concept, the CT air kerma index (or the CTDI in other terminology) represents the average dose in the central slice of a 100 mm scanned volume. The CT air kerma index does not represent the average dose in the central slice region for a longer scanned volume. The current use of cone beam scanner technology with collimation beam widths of 160 mm, for example, clearly demonstrates the deficiencies of the standard CT dosimetry methodology (BOONE, J., 2007).

2.3.3.3 Calculation of organ doses from CT scanners:

It must be remembered that measures such as CVOL are indicators of dose only. They are measured within a standard sized PMMA phantom, and represent the dose as though a 100 mm length of the phantom had been scanned. Although they are not measures of the dose to organs or tissue received by the patient, or even a population of patients, they do, however, have a use in comparison of doses delivered by different scanners and protocols. While organ doses can be measured for specific patient categories with the use of thermoluminescent dosimeters and appropriate anthropomorphic phantoms, the use of Monte Carlo modelling is a more usual approach. To date, a number of centers have used mathematical models to simulate typical patients and determine conversion factors that allow organ dose to be calculated from a reference dosimetry index, such as $C_{a, 100}$ or C_w for a given set of scanner factors, patient position variables and scan length parameters. This process has been described in the literature and has been applied to a variety of patient models and includes pediatric dose estimation. A number of calculation engines are available, as listed in Appendix IV. As mentioned above, the viability of these conversion factors is currently problematic for some MDCT scanners owing to the wide beam widths, variability of peripheral dose patterns and use of

modulating tube current under the control of automatic exposure systems (KALENDER, W.A., 1999).

2.3.3.4 Dose calculations for CT scanners using some form of AEC:

Dose calculations are necessarily more complicated when AEC systems are in place. Dose distribution within a slice will change with rotational aspects of AEC systems and will change along the patient with the z axis modulated tube current. Detailed analysis can be undertaken by investigating the average tube current for each slice, which is often given. However, this can be time consuming. Also, the information on the rotational variation of the tube current is often not available or accessible. Depending on the requirement, some pragmatic approaches can be taken. For example, either the average tube current can be used or, since the maximum and minimum current values are often given, best case and worst-case calculations can be undertaken. This is usually sufficient for most purposes (KALENDER, W.A., 1999).

2.4 Basic Principles of QA in CT:

2.4.1 QA Activities:

A QA program in diagnostic radiology, as defined by the World Health Organization, is an organized effort by the staff operating a facility to ensure that the diagnostic images produced are of a sufficiently high quality that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation. Registrants and licensees must establish a comprehensive QA program for medical diagnosis with the participation of appropriate medical physicists. (WHO, Geneva 1982).

QA programs for medical exposures should include:

- (a) Measurement of the physical parameters of the radiation generators and imaging devices at the time of commissioning and periodically thereafter.
- (b) Verification of the appropriate physical and clinical factors used in patient diagnosis (or treatment).

(c) Written records of relevant procedures and results. This includes a manual that defines clear lines of responsibility, outlines the individual QC tests performed, stipulates the test frequencies, aids staff training, facilitates audit of a service and helps to keep information within the service.

(d) Verification of the appropriate calibration and conditions of operation of dosimetry and monitoring equipment.

(e) Optimization of clinical protocols and equipment operation to achieve the aims of QA as stated above.

(f) Regular and independent quality audit reviews of the QA program. QA programs are designed to ensure that the radiology equipment and staff procedures can yield the desired information. They include:

(a) Administrative procedures or management actions designed to verify that:

- The QC tests are performed properly and according to a planned timetable;
- The results of these tests are evaluated promptly and accurately;
- The necessary corrective measures are taken in response to these results;
- The assignment of responsibility for QA actions is made;
- Standards of quality for equipment in the facility are established;
- Adequate training is provided;
- The appropriate equipment for each examination is selected, including the writing of adequate equipment specifications.

(b) Acceptance testing and commissioning (see Fig. 2.11):

Acceptance tests are those performed to verify that the purchase specifications have been met by the vendor. These are often performed by the company installing the equipment under the supervision of the medical physicist (IAEA, Vienna 2006) or alternatively, performed independently by the medical physicist. Commissioning tests are those undertaken at the time the equipment is put

into service and are used to establish baseline levels of performance, including measurements which may be helpful in optimization of protocols. These are performed by the medical physicist. To a large extent, acceptance and commissioning tests overlap. This publication primarily describes the tests that form a comprehensive ongoing QC program for CT, but it is recognized that it is necessary to ensure that the equipment, as delivered, conforms to specified standards and that appropriate initial baseline values are established and used to ensure the maintenance of the quality of the equipment throughout its working life. These acceptance and commissioning tests are included in this publication and are indicated as such. During acceptance testing, a qualified person should check the electrical and mechanical safety of any new installation.

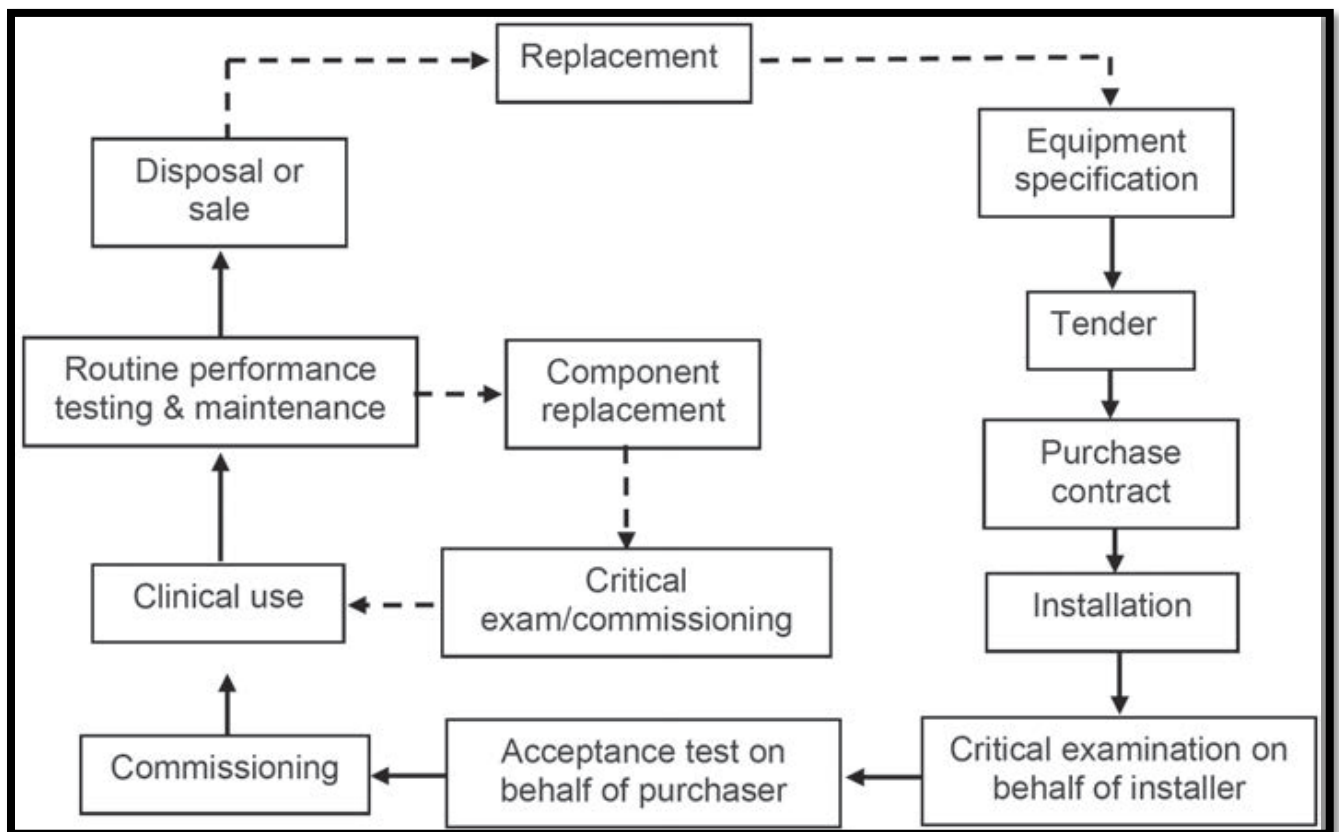


Fig (2.11) Life cycle of a piece of equipment

(c) QC tests (also classified as either constancy or status tests by the IEC) are used to test the components of the radiological system and to verify that the equipment is operating satisfactorily.

(d) Verification of QC equipment and material.

(e) Follow-up of any corrective actions proposed:

It is important that routine QC testing be properly performed in the CT facility and that results be documented thoroughly and carefully. It is equally important that problems and potential problems be clearly documented and communicated to the facility in a timely manner and that the medical physicist be assured that the receiving party has received and understood the supplied information. This is especially the case when safety concerns are raised.

The reporting structure in the facility should be understood by the medical physicist, who should ideally report problems to an individual who is empowered to call in service personnel and, if necessary, who can ensure that the equipment is not used until the problems are corrected.

The medical physicist may be asked to explain the problems to service personnel and to share test results with them. The medical physicist and the representative from the facility should work together to ensure that the problems have been appropriately corrected.

(f) Education and training of the staff, including radiologist, radiographer and medical physicist. Each must meet a minimum level of competency.

(g) Continuing education. Each team member must undertake sufficient continuing education to ensure that they are up-to-date on new techniques and that they are ‘refreshed’ relative to their basic knowledge, e.g. radiation safety.

(h) Experience. To ensure proficiency, the radiologist must read a sufficient number of cases, the radiographer must undertake a minimum number of cases a year and

the medical physicist must conduct a sufficient number of CT unit surveys under American College of Radiology guidelines [70].

2.4.2 Roles and Responsibilities:

The licensee or registrant has specific responsibilities to ensure that all regulatory or licensing requirements are met. Further, the licensee or registrant must ensure that all radiologists, radiographers, medical physicists and other personnel who work at the facility are appropriately qualified and trained and meet all continuing education and experience requirements. It is the responsibility of the licensee or registrant to ensure that a QA program is in place that encompasses all aspects of the imaging process. The specific tasks within that program may be delegated to appropriate staff Who already have expertise in carrying out those tasks. Notwithstanding the above delegation of authority, it remains the ultimate responsibility of the licensee or registrant that the elements of the QA program are fulfilled.

2.4.2.1 Roles and Responsibilities of the Radiologist

Should be identified by the facility to have the specific Responsibility of ensuring that all required QA activities are performed.

The radiologist although it is recognized that the radiologist will delegate many of the following tasks, they still have responsibility for the following tasks:

- (a) Ensuring that medical physicists and radiographers have adequate training and continuous education courses in CT.
- (b) Ensuring that all equipment is appropriately maintained.
- (c) Motivating, supervising and managing all aspects related to the QA program in the area of CT.
- (d) Providing an orientation program for radiographers based on a carefully established procedures manual.

- (e) Designating a single radiographer to be the primary QC radiographer to perform the prescribed QC tests and oversee those that have been delegated to other individuals.
- (f) Ensuring availability of the equipment and the necessary materials for the Implementation of the QC tests.
- (g) Arranging staffing and scheduling so that adequate time is available to carry out the QC tests and to record and interpret the results.
- (h) Ensuring that a medical physicist is available to oversee the equipment related QC program and to perform the medical physicist's tests.
- (i) Reviewing the radiographer's test results at least every 3 months, or more frequently if consistency has not yet been achieved, and reviewing the medical physicist's test results annually, or more frequently as needed.
- (j) Designating an individual to oversee the radiation protection program for employees, patients and other individuals in the surrounding area.
- (k) Ensuring that records of employee qualifications, mammography technique and procedures, infection control procedures, QC, safety and protection are properly maintained and updated in the CT QC procedures manual.
- (l) Providing feedback continually, both positive and negative, to radiographers on image quality and QC procedures.

2.4.2.2 Roles and Responsibilities of The radiographer:

The responsibilities of the radiographer include:

- (a) Ensuring that the appropriate protocol and technique factors are used for the requested examination.
- (b) Ensuring that the QC tests are performed, interpreted and recorded appropriately. This is best achieved when one radiographer assumes overall responsibility for QC matters and is able to train others to assist in QC activities.
- (c) Recording imaging problems.

(d) Undertaking additional continuous education courses.

2.4.2.3 Roles and Responsibilities of The medical physicist:

The medical physicist is a person trained in medical physics and certified as a medical physicist according to the applicable program in the State, if such a program exists. The medical physicist should be specialized in diagnostic radiology.

The responsibilities of the medical physicist include:

- (a) Advising the facility on CT image quality and on radiation protection of the patient, staff and members of the public.
- (b) Advising the facility on acquisition, installation and shielding for CT.
- (c) Conducting tests to ensure the safety and proper performance of equipment used in CT. These include acceptance, commissioning and routine QC tests.
- (d) Advising the radiologist and radiographer on optimization.
- (e) Providing oversight and advice to the radiographer who carries out the Radiographer's component of the QC program.

2.5 Optimization of Clinical Practice:

2.5.1 General principles of radiation protection:

All potential diagnostic and interventional radiology exposures must be subject to the principles of justification and optimization which are common to all practices dealing with exposures to ionizing radiation (IAEA, Vienna (1996). This may be stated as follows, the principal aim of medical exposures is to do more good than harm to the patient, subsidiary account being taken of the radiation detriment from the exposure of the radiological staff and of other individuals.” For patients undergoing medical diagnosis or treatment, there are two levels of justification. Firstly, the practice involving exposure to radiation must be justified in principle through the endorsement of relevant professional societies, as matters of effective medical practice will be central to this judgment. Secondly, each procedure should be subject to a further, case-by-case justification by both the referrer, who is responsible for the

management of the individual patient and who determines that the exposure is necessary for diagnostic purposes, and the radiologist and other practitioner who may direct the radiological procedure (IAEA, Vienna 2002).

2.5.2 General principles of optimization:

Once clinically justified, each examination should be conducted so that the dose to the patient is the lowest necessary to achieve the clinical aim. The optimization process necessarily requires a balance between patient dose and image quality along with other clinical considerations, including the use of a contrast agent. Dose reductions must not be achieved without regard to any loss of diagnostic quality in the image that may accompany the dose reduction, as previously noted by the IAEA “The objective of the diagnostic radiology process as a whole is to obtain the requested diagnostic information with the minimum patient exposure within prevailing resource limitations.” The requirement for image quality should be tailored to the clinical problem and lower levels may be acceptable in some circumstances. Certainly, the size and shape of the patient will influence the level of dose required. Accordingly, the equipment operators should minimize patient dose while maintaining acceptable image quality for the diagnostic information required. It must be recognized that optimization is a multidisciplinary task involving the radiologist, radiographer and medical physicist (ICRP 2007).

Dose surveys for CT procedures indicate wide variations in patient dose and indicate the need for optimization with the use of established diagnostic reference levels (DRLs) to aid in this process.

2.5.3 Factors Affecting Image Quality and Dose:

A large number of factors in a CT examination can affect the dose and image quality, collectively described by the image noise and spatial resolution.

These factors can be generally categorized as radiographic protocol or scan parameter, equipment, image reading condition and patient related factors. Patient

related factors can usually be controlled through adjustments in the scan parameters, therefore leaving three main groups of factors. Of these, the equipment factors are often set by the scanner configuration at manufacture and are beyond the control of the operator ().

Controllable factors affecting patient dose in CT include:

- Radiographic protocol or scan parameters
- kV and mAs for manual operation
- Pitch
- Reconstruction filter
- Scan length and number of scan series
- Patient size variation, usually requiring changes in examination protocol
- AEC (correct dose modulation techniques)
- Collimation selection including MDCT considerations of over-beaming
- Helical acquisition considerations of over-ranging
- Scan mode (axial, helical or MDCT)
- Use of external filters for body part shielding.

The relationship between scan parameters, image quality and dose is complex. To some extent this depends on whether the scanner is single slice or multislice and whether scanning is axial ('step and shoot') or helical.

2.5.4 The Optimization Process:

To optimize a CT examination, a process involving 14 steps can be followed:

Initial preparation

Establish agreement for an optimization process with the radiology department, including a schedule of achievable targets.

(2) Determine the priority for examinations to be optimized for a particular modality in conjunction with clinicians and radiographers, considering such factors as examination risk and frequency.

- (3) Check QA status of equipment used for the procedure.
- (4) Establish clinically appropriate image quality requirements in collaboration with clinicians.

Dose, image quality and clinical acceptability assessment

- (5) Determine patient doses (preferably from a patient audit or possibly from phantom based measurements (see Section 9.6)).
- (6) Determine image quality (preferably with the assistance of radiologists; the assessment should include a measure of noise and resolution).
- (7) Review scan protocol, examining the purpose of the examination and the adequacy of technical factors to account for patient size, with special consideration being given to any paediatric protocols.

Review of current status of procedure

- (8) Compare examination dose with appropriate benchmarks, such as the DRL, as available [98].
- (9) Compare examination image quality with appropriate benchmarks, if available.
- (10) In conjunction with the radiologist and radiographer, review examination related data including: Radiographic protocol, Equipment configuration and Image reading conditions.
- (11) Investigate the effect on image quality and dose of varying the parameters in the above list.

Intervention

- (12) Recommend changes to the radiographic protocol, equipment configuration and/or viewing conditions, on the basis of the review of the procedure.

Verify effect of optimization process

- (13) After an agreed period of clinical introduction, repeat the dose and image quality analysis to determine the effectiveness of the optimization intervention.

(14) Record the results of the optimization procedure in such a way that they are accessible to all interested parties, particularly radiographers and clinicians.

2.6 Outline of Performance Tests:

These tests are intended to verify the performance of the CT scanner. They include tests for CT acceptance and commissioning as well as tests of the operational stability of the equipment or equipment elements used to acquire, process and display the CT images. The tests have been classified into two types, essential and desirable, according to their importance in influencing image quality and radiation dose. The performance of the first category of tests is considered indispensable; however, it is recommended that the tests in the second category be carried out only if adequate human resources and equipment can be made available.

2.6.1 Test priority:

Desirable describes the test procedures that should be performed, if feasible.

Essential refers to tests that *must* be carried out in a facility. Some of the QC tests need to be performed frequently (daily or monthly). Therefore, it is recommended that these tests be performed by local personnel who are present daily in the installation (technical personnel, normally radiographers). The lower frequency tests have been assigned in the majority of cases to medical physicists and radiologists.

Suggested frequency Acceptance:

These tests are carried out to ensure the scanner delivered is operating in accordance with the manufacturer's specification. These tests are also carried out at any major software or hardware upgrade.

Commissioning: These tests are carried out to provide a baseline for ongoing QC tests and for future optimization. They may use different phantoms and scan protocols, depending on availability of phantoms and typical scan protocols. These tests are also carried out at any major software or hardware upgrade.

Annual: QC tests that are not likely to alter within a shorter time scale.

Monthly: QC tests that need more frequent monitoring. Each test in the QC program has a specified tolerance level for ‘acceptable’ and ‘achievable’ results as applicable. Should the results of a test fall outside the specified tolerance, the test should usually be repeated to confirm the result before action is taken. In some cases, only the ‘acceptable’ level has been defined.

Performance standards

Acceptable indicates that performance must be within certain tolerances, and if it is not, the equipment should not be used.

Achievable indicates the level of performance that should be attained under favourable circumstances, which is the level at which a facility should work, if feasible. A facility should strive to ensure that equipment operates at the achievable level of performance (as specified in appropriate tables when defined), as this will produce the highest image quality and the most appropriate dose performance. It is recognized, however, that limited resources and other factors may occasionally prevent the achievable levels from being obtained. Suitable minimum specifications for test equipment and phantoms are provided in Appendix I. Table 5 lists all the tests that need to be carried out by radiographers and medical physicists for diagnostic installations (with additional tests for therapy applications also included).

Table (2.1) Summary of CT Performance Test

Test number	Test name	Test personnel ^a	Diagnostic facility	Radiotherapy facility
8.2	CT alignment lights	R	✓	✓
8.3	SPR accuracy	R	✓	
8.4	CT number, image noise, image uniformity and image artefacts	R	✓	✓
8.5	Image display and printing	R	✓	✓
10.2	External CT positioning lasers	R		✓
10.3	Couch top alignment and positional accuracy	R		✓
10.4	CT number of multiple materials	R		✓
9.2	Visual inspection and review of programme	P	✓	✓
9.3	CT alignment lights	P	✓	✓
9.4	SPR accuracy	P	✓	✓
9.5	kV and half-value layer (HVL)	P	✓	✓
9.6	Radiation dose	P	✓	✓
9.7	CT number accuracy, image noise, image uniformity and image artefacts	P	✓	✓
9.8	Image display and printing	P	✓	✓
9.9	Imaged slice width	P	✓	✓
9.10	X ray beam width	P	✓	✓
9.11	Spatial resolution (MTF or modulation)	P	✓	✓
10.6	External CT positioning lasers	P		✓
10.7	Couch top alignment and index accuracy	P		✓
10.8	Gantry tilt	P		✓
10.9	CT number accuracy	P		✓

2.7 Previses Studies

Barrett JF in 2004 studied the Artifacts in CT: recognition and avoidance. And he found to optimize image quality, it is necessary to understand why artifacts occur and how they can be prevented or suppressed.

Ashish Kumar Jha et al in 2013 studied the Identification of a unique cause of ring artifact seen in computed tomography trans-axial images and the study found the ring artifact seen in trans-axial image was caused by contrast contamination of CT tube aperture. Proper fitting of Mylar window and avoidance of contrast leakage can avoid this occurrence. And if ring artifact appears in the CT image this cause needs to be ruled out.

Sad A. Tam et al in 1998 Imaging Artifacts: A Comparative Study In X-Ray CT & Medical Ultrasound and he found most predominant artifact is due to " high differential metal brain artifact streak "represents 80% the second one is detectors artifact and it represents 60% the lowest contribution came from " high differential brain vat artifact overshoot " and indexing error artifact represent 10%.

Chapter three

Materials and methods

3.1 Materials:

This study intended to quality of computed tomography image in Khartoum state hospital.

The data used in this study was collected from three hospitals in Khartoum state: al-Zytoun Specialist Hospital, Al-Ribat teaching hospital and modern medical center. The data collected from October 2015 to March 2016.

3.1.1 CT Machine:

Three CT machines were used to collect data during this study. This machines are installed in three radiological departments.

Hospital	Manufacture	Detector type
Al-Zytouna Hospital	Toshiba	64 Rows
Modern medical center	GE	2 Rows
Al-Ribat teaching hospital	neosoft	16 Rows

3.2 Methods:

The present descriptive and cross-sectional study has evaluated a population including 10 radiology technicians working in health care institutions.

Data collection was performed through a module questionnaire. The module included nine questions and table for evaluation the quality control program.

Then used as input to statistical software (SPSS) and Microsoft excel for analysis.

Chapter Four Results

Results:

Table (4.1) demonstrate population and the distribution of gander of this study

Male	Female
37	16

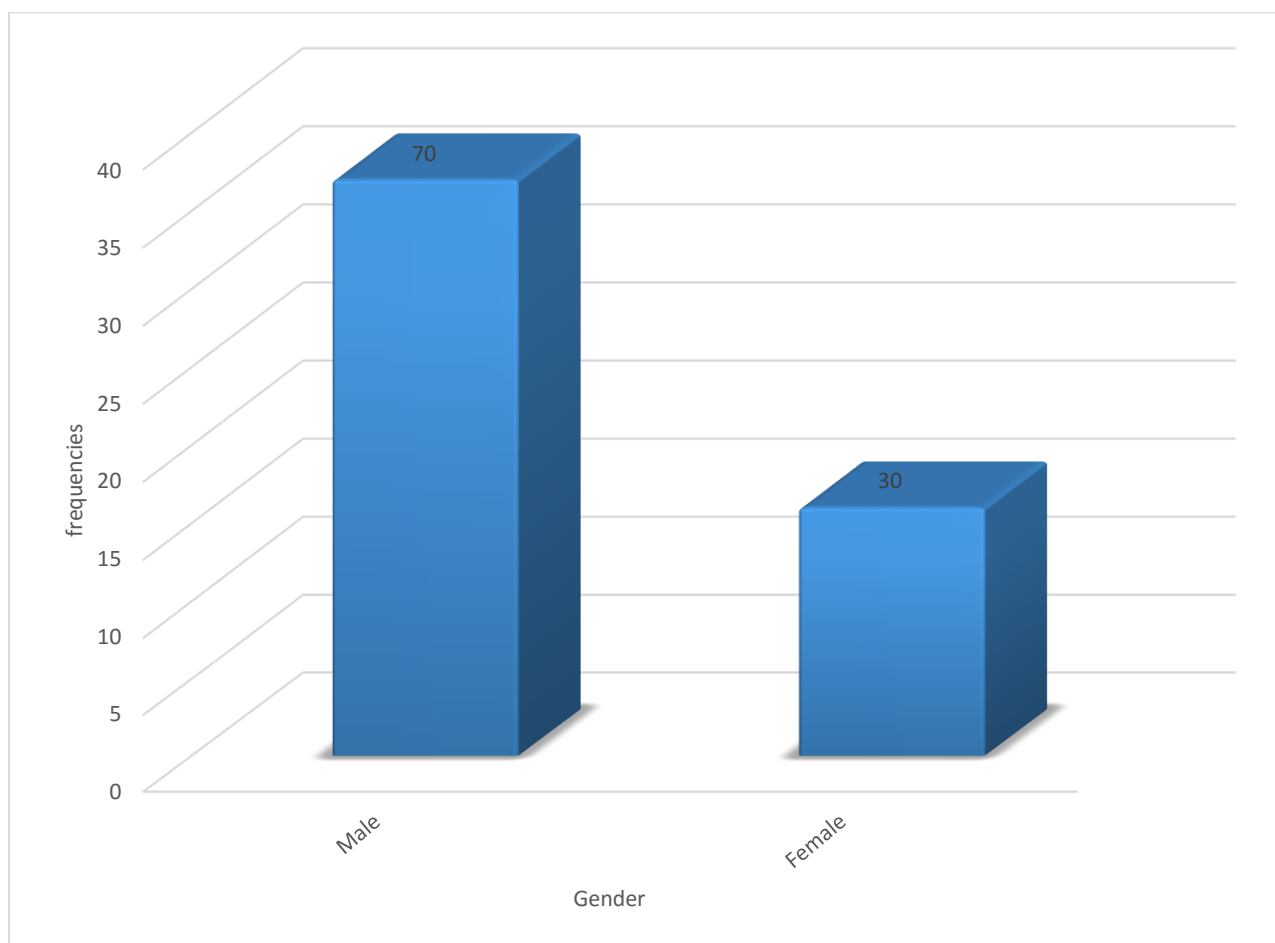


Fig (4.1) shows the population and the distribution of gender in this study

Table (4.2) demonstrate frequencies of artifacts in this study

	Metallic artifact	Motion artifact	Beam hardening artifact	Ring artifact
Frequencies	19	16	16	2

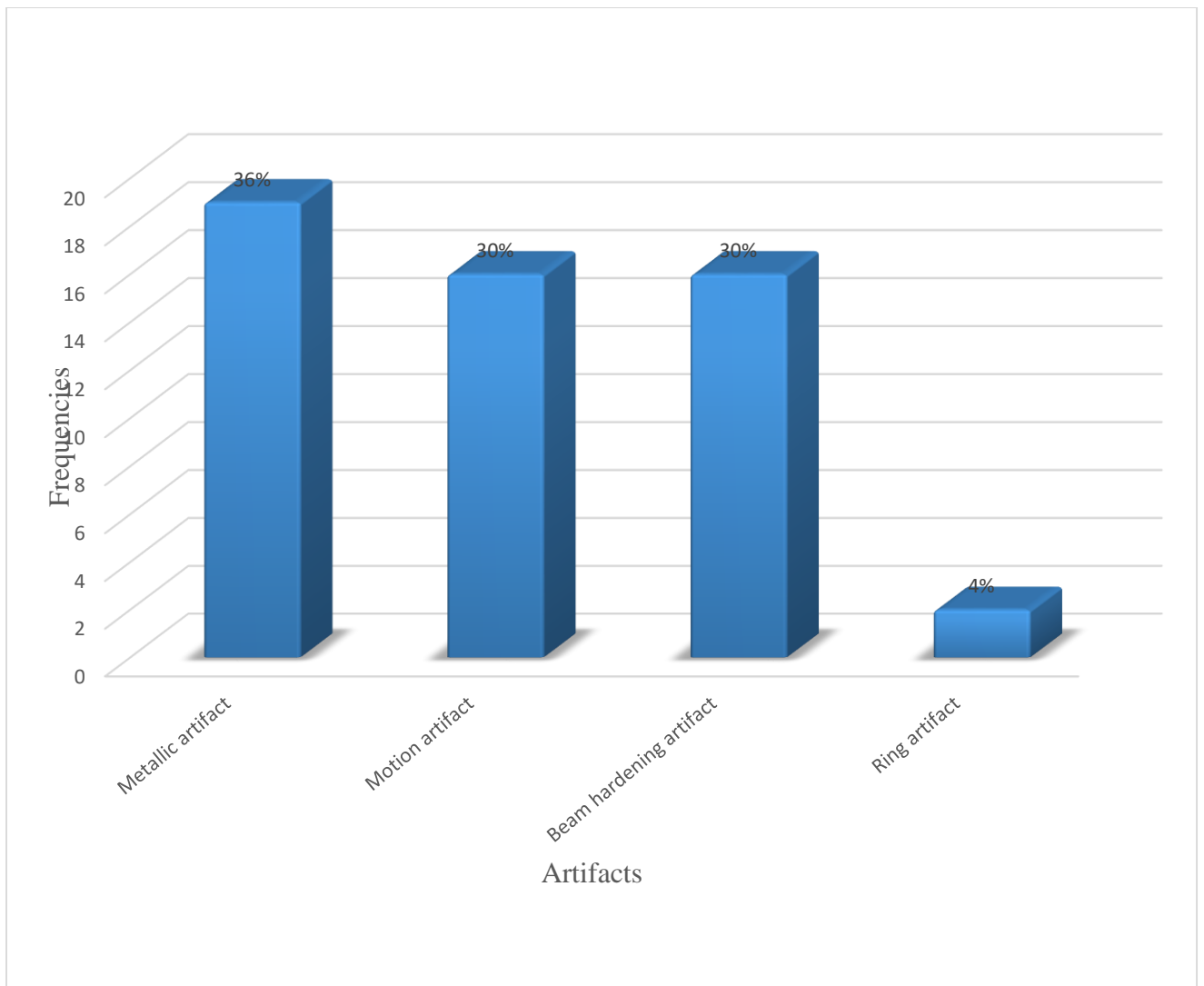


Fig (4.2) shows the frequencies of artifacts in this study

Table (4.3) demonstrate distribution of artifacts according to the CT examination

	Brain	Chest	Spine	abdomen	Pelvis	Limbs
Metallic Artifact	6	2	1	4	4	2
Motion Artifact	7	6	0	3	0	0
Beam Hardening Artifact	7	4	1	2	0	2
Ring Artifact	1	0	1	0	0	0

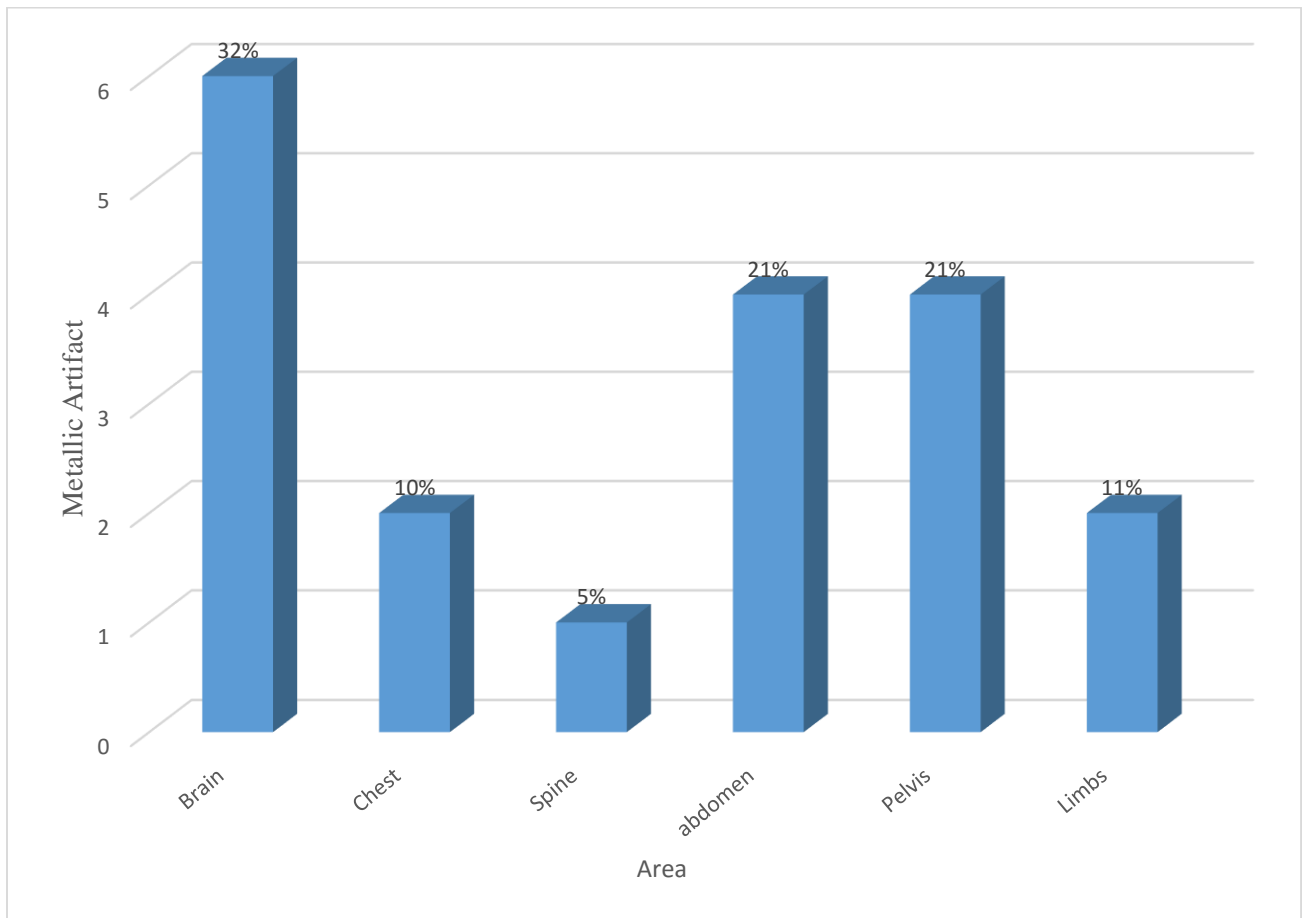


Fig (4.3) shows the distribution of Metallic artifact according to the CT examination

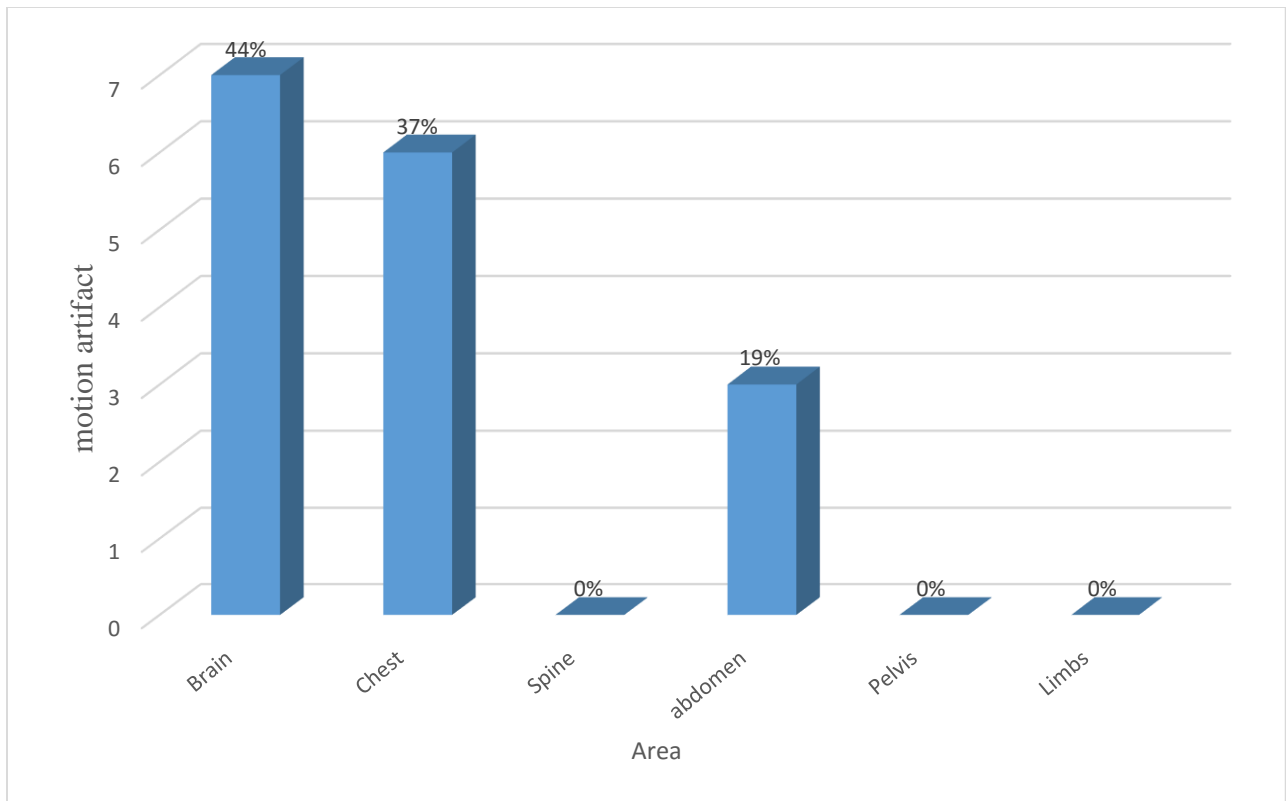


Fig (4.4) shows the distribution of Motion artifact according to the CT examination

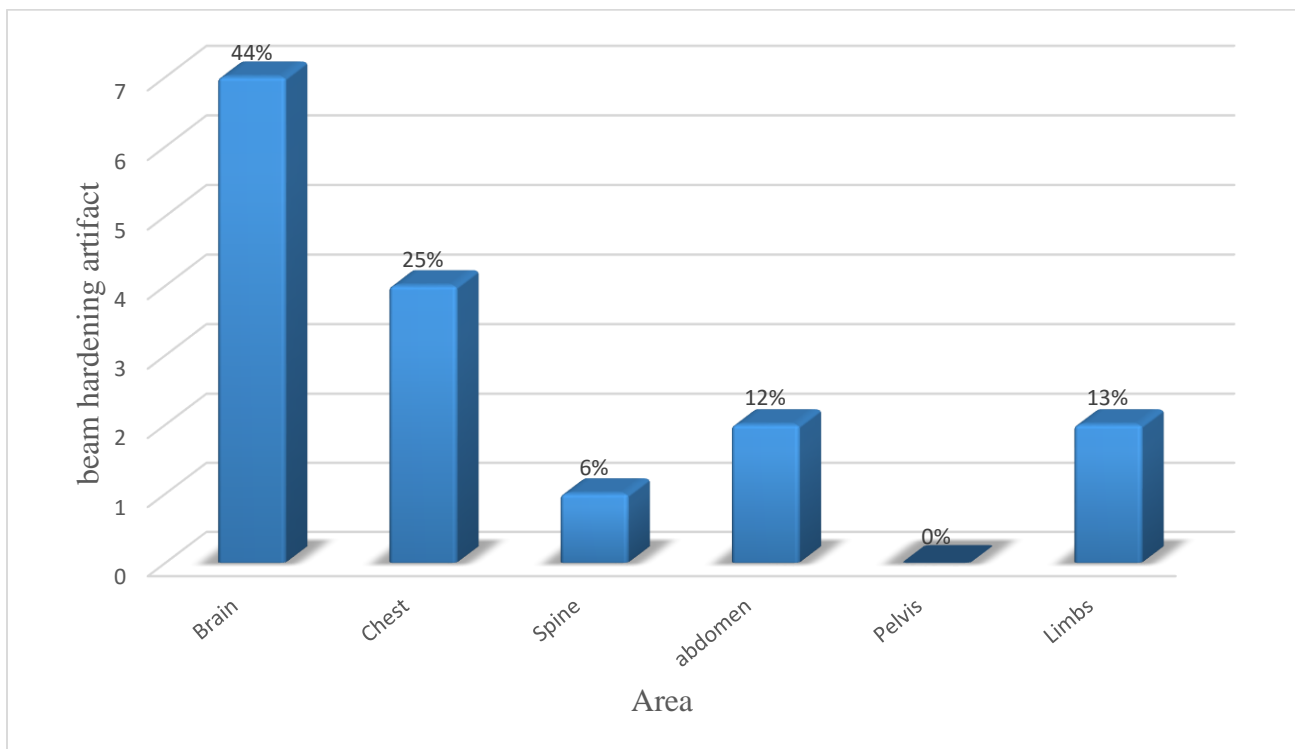


Fig (4.5) shows the distribution of beam hardening artifact according to the CT examination

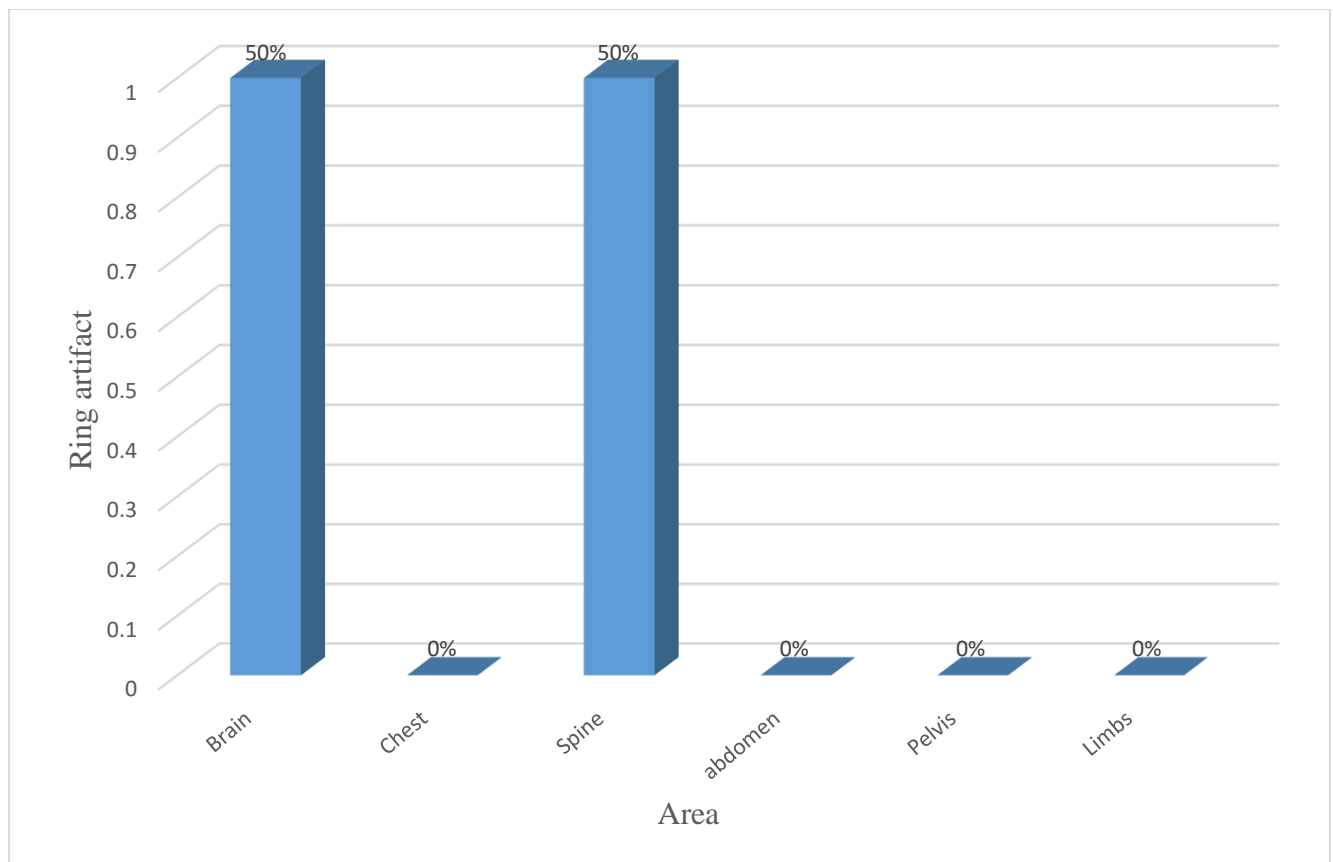


Fig (4.6) shows the distribution of ring artifact according to the CT examination

Table (4.4) demonstrate distribution of artifacts according to the age group

	1 --- 15	16 --- 30	31 --- 45	46 --- 60	61 --- 70
Metallic Artifact	2	4	5	5	2
Motion Artifact	6	2	1	3	4
Beam Hardening Artifact	0	3	7	3	3
Ring Artifact	0	1	1	0	0

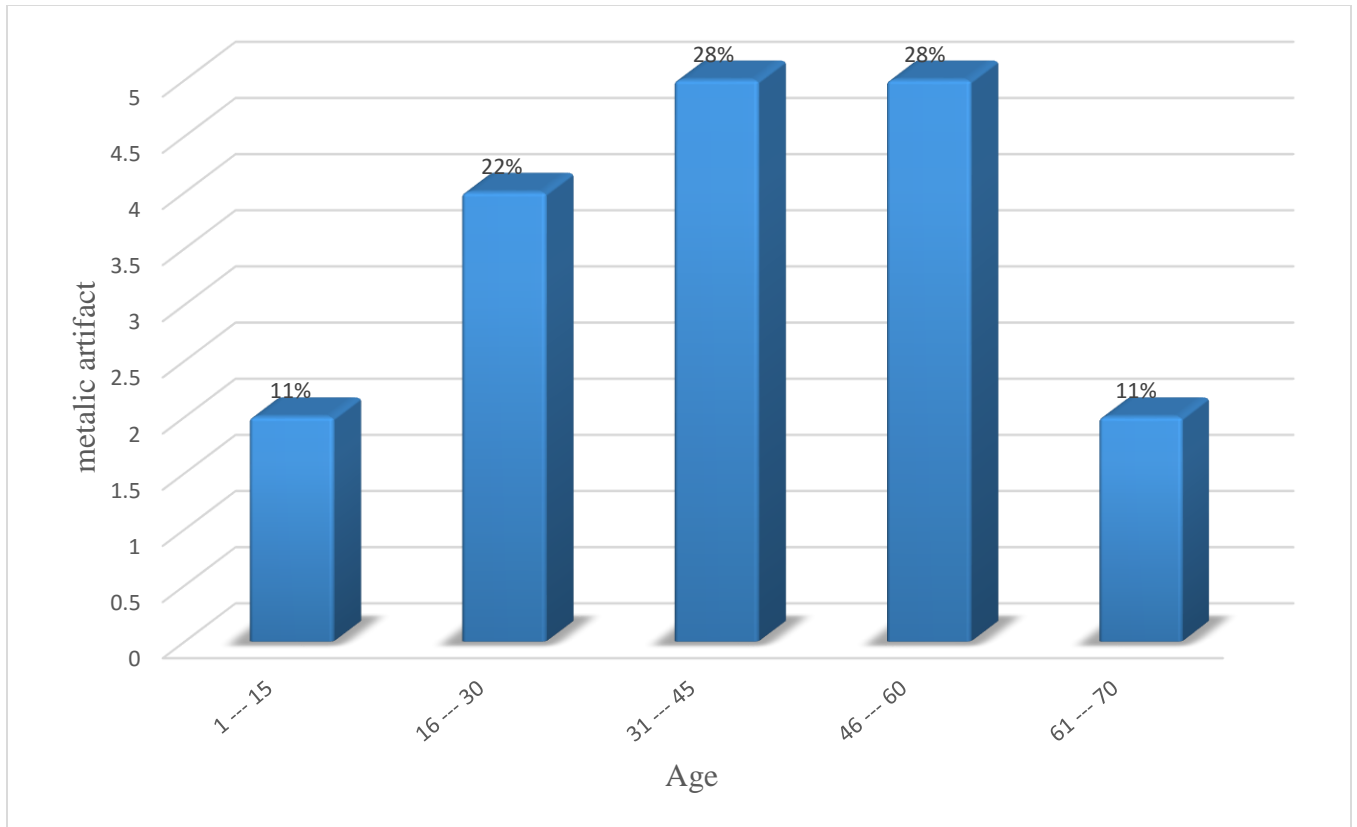


Fig (4.7) shows the distribution of metallic artifacts according to the age group

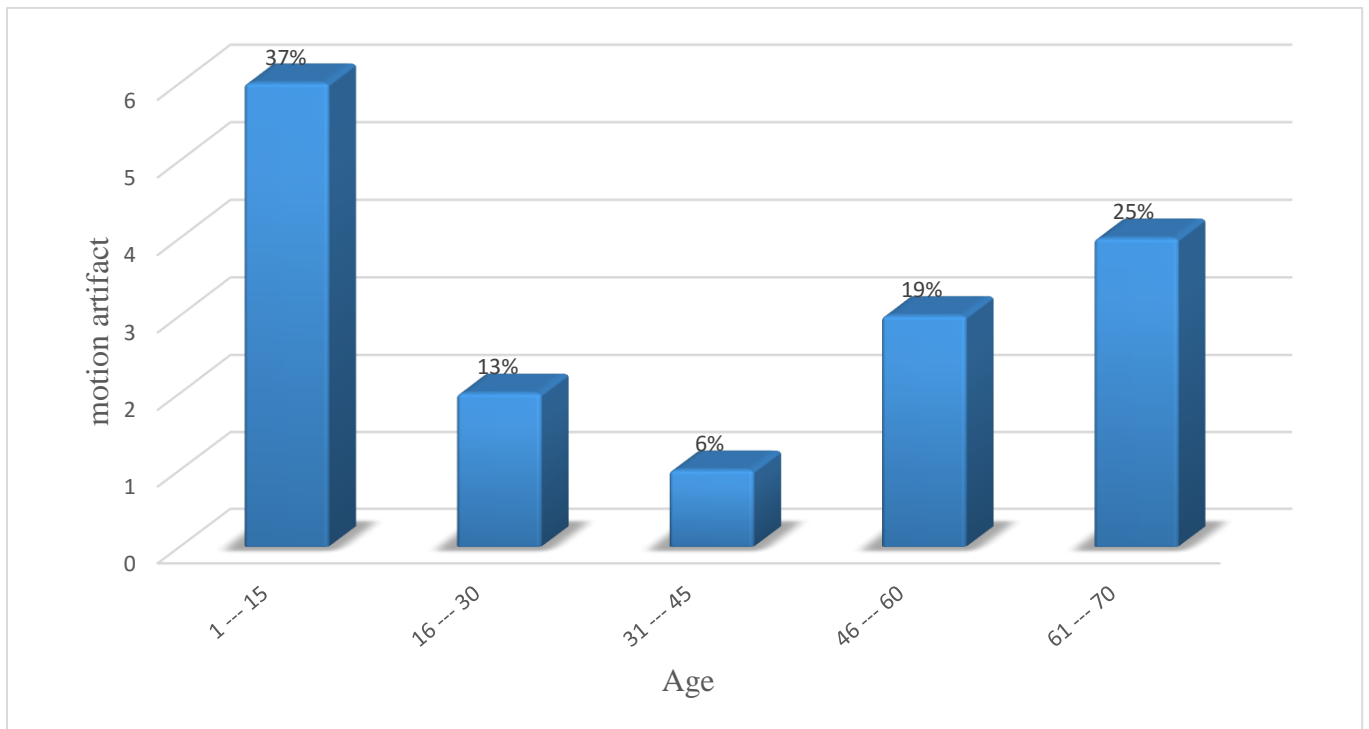


Fig (4.8) shows the distribution of motion artifacts according to the age group

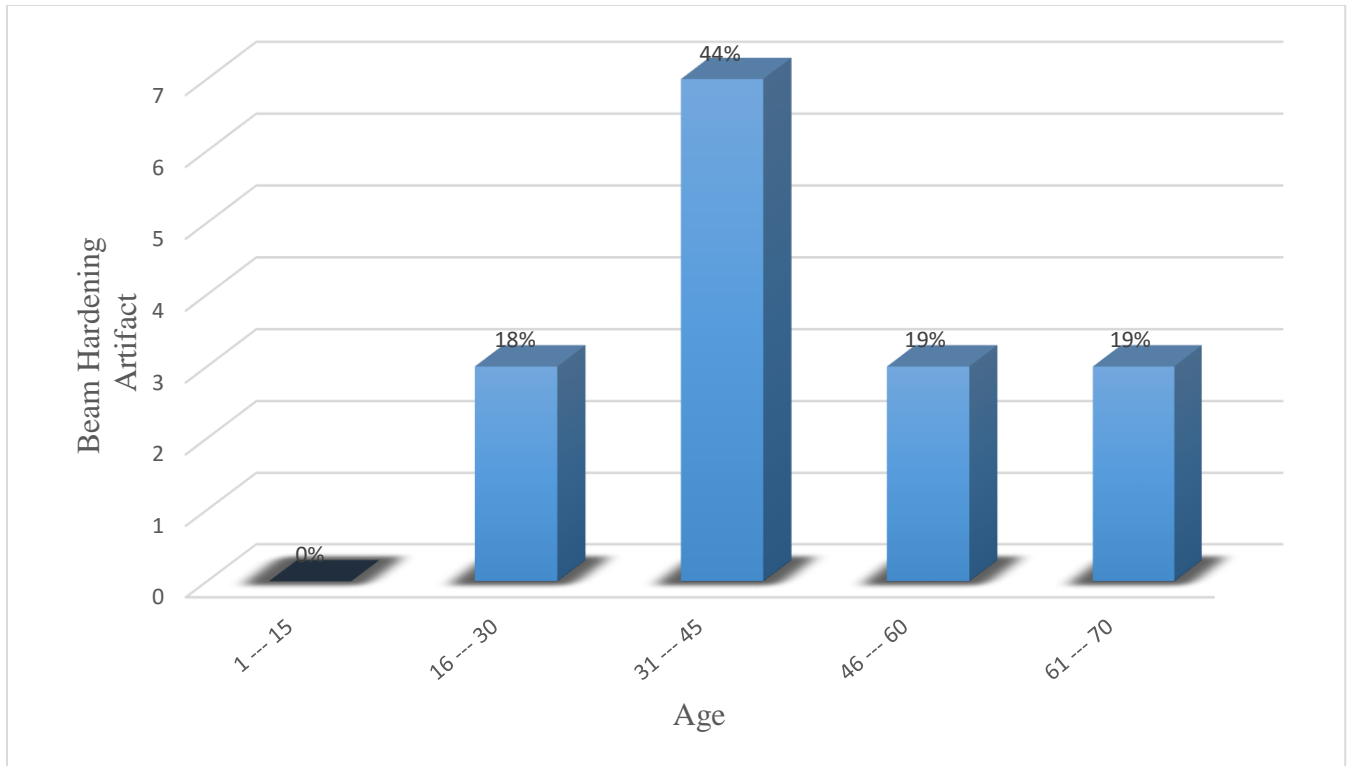


Fig (4.9) shows the distribution of beam hardening artifacts according to the age group

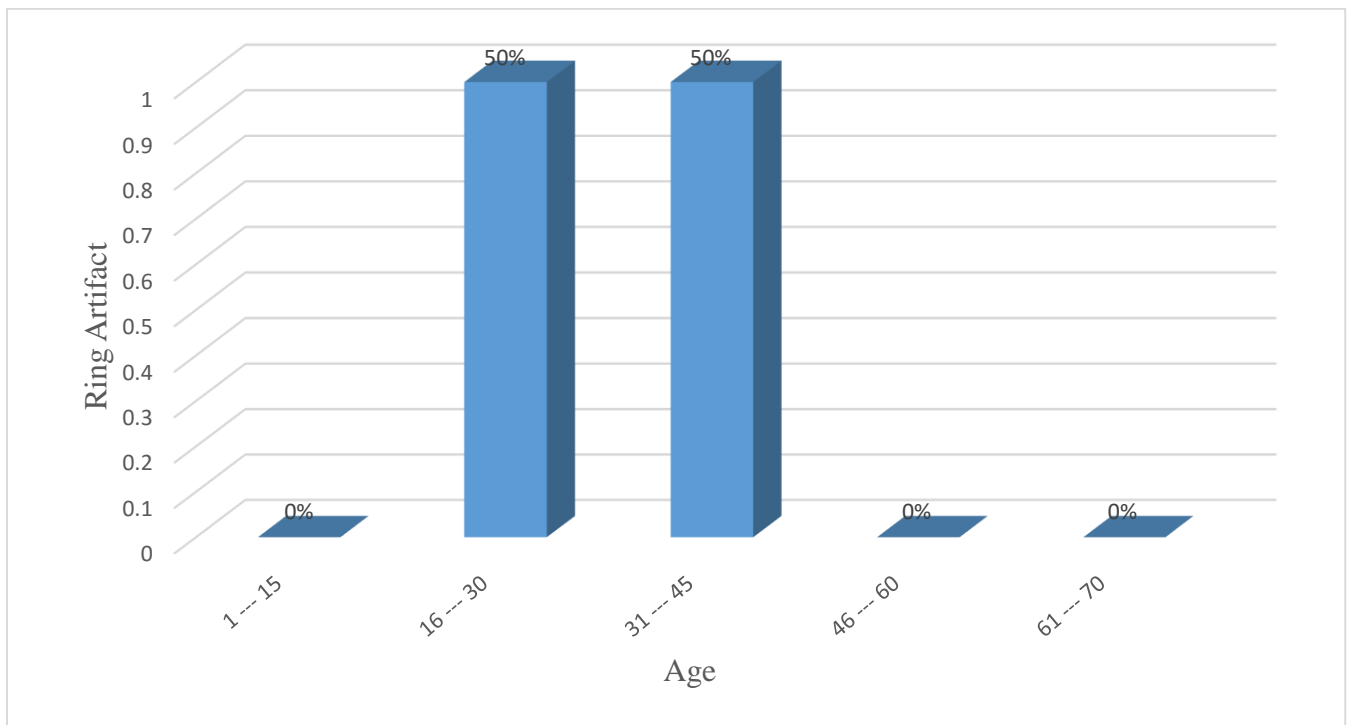


Fig (4.10) shows the distribution of ring artifacts according to the age group

Table (4.5) demonstrate metallic causes of artifacts

	Fixation	Dental filling	PEC Maker	ECG Gate	Surgical clips
Metallic artifact	9	6	1	1	2

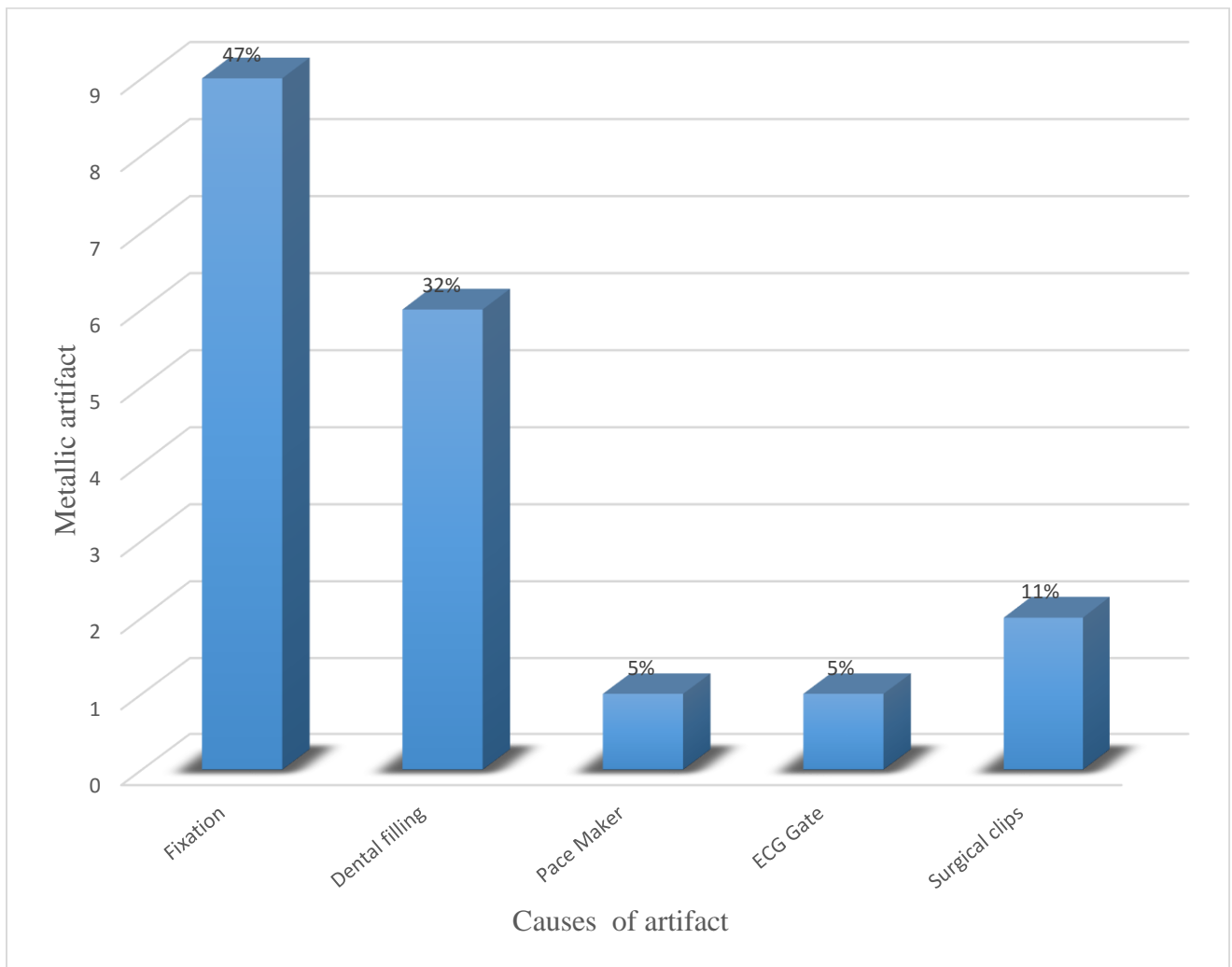


Fig (4.11) shows the causes of the metallic artifacts

Table (4.6) demonstrate causes of the motion artifacts

	Respiration	Bowel motion	Patient motion
Motion artifact	6	3	7

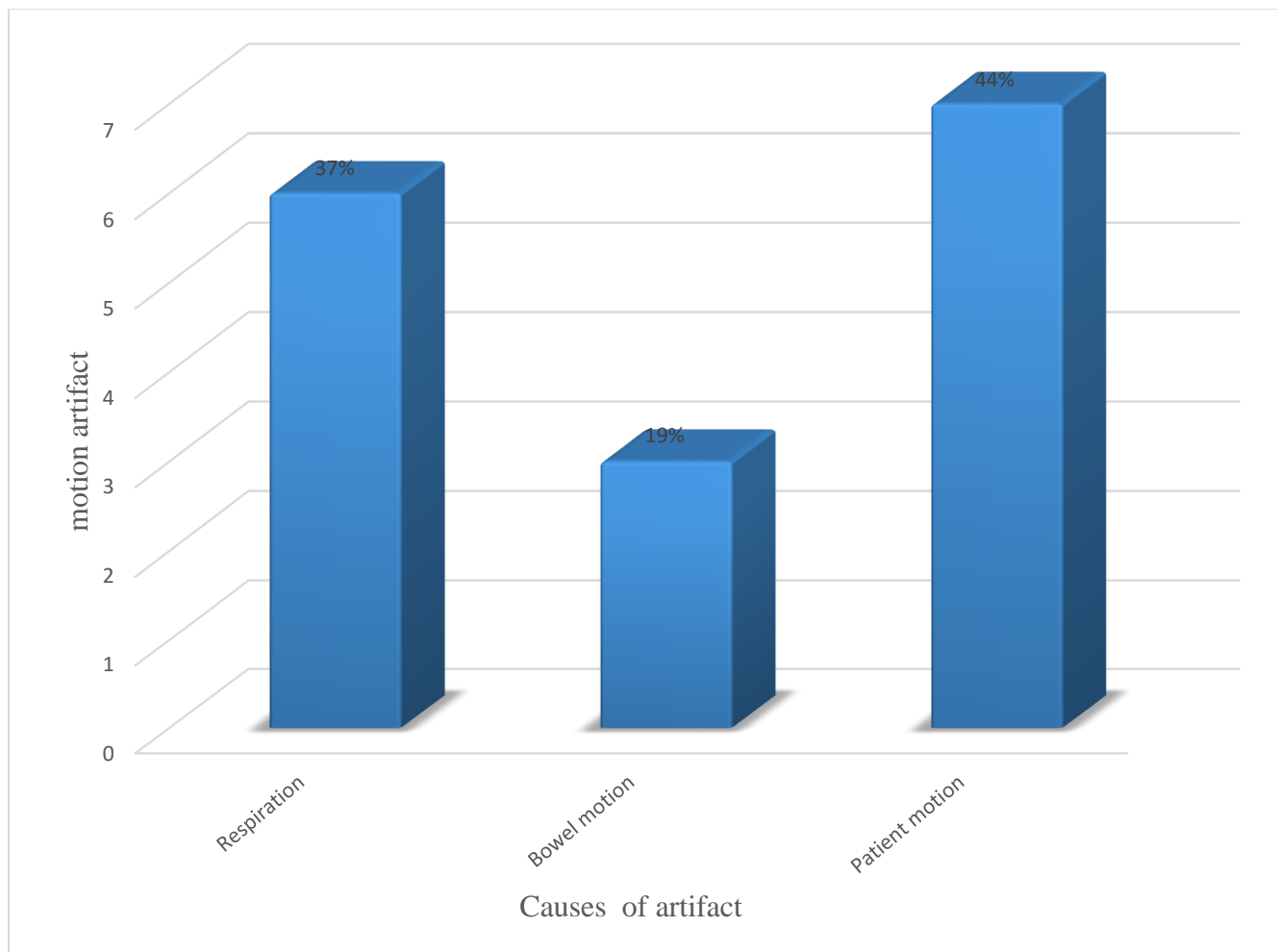


Fig (4.12) shows the causes of the motion artifacts

Table (4.7) demonstrate causes of the beam hardening artifact

	Petrous bone	Hips	Shoulder
Beam hardening artifact	8	1	7

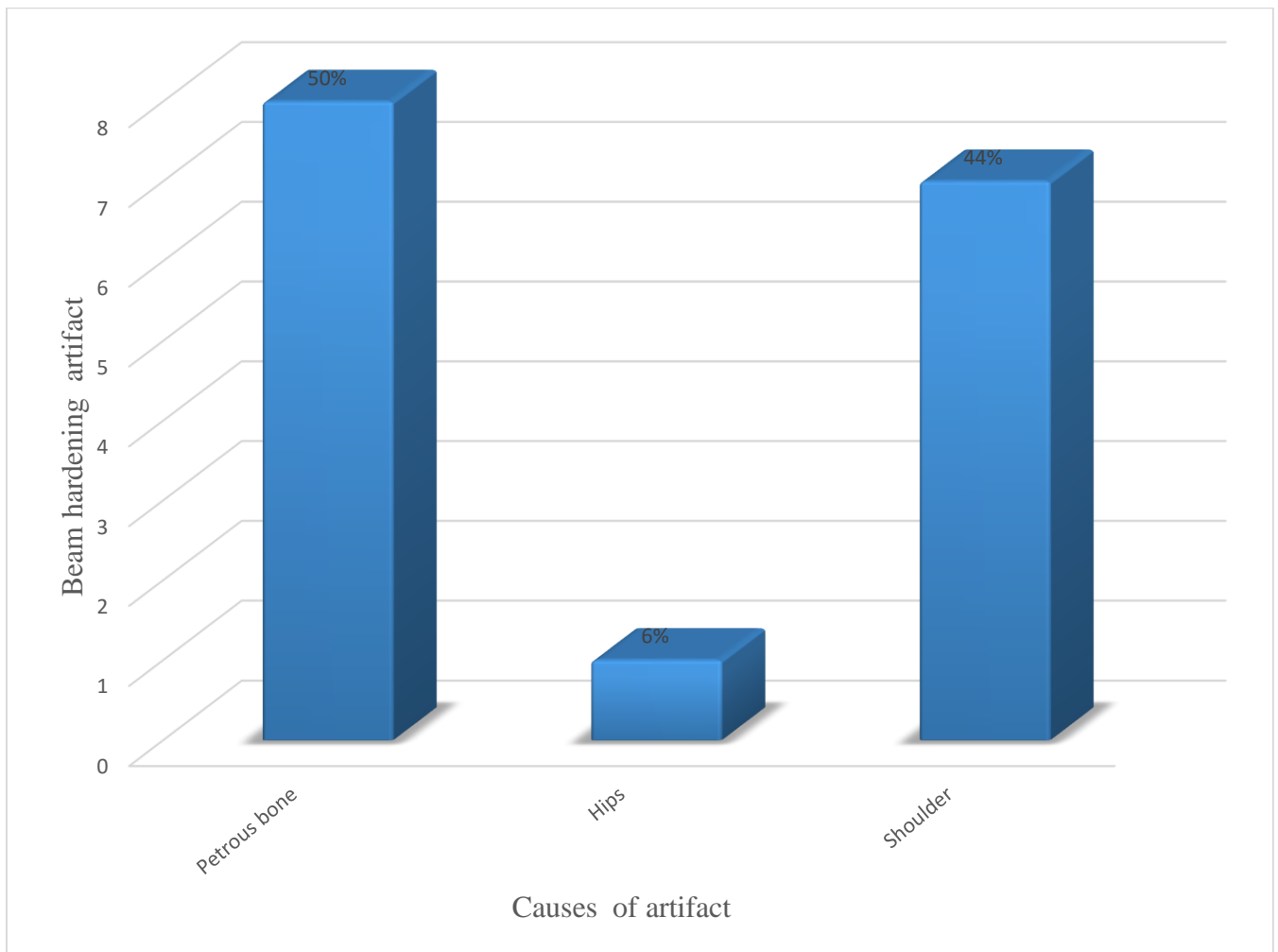


Fig (4.13) shows the causes of the beam hardening artifact

Table (4.8) Demonstrate causes of the ring artifact

	Un calibrate protocol	Un calibrate detector
Ring artifact	2	0

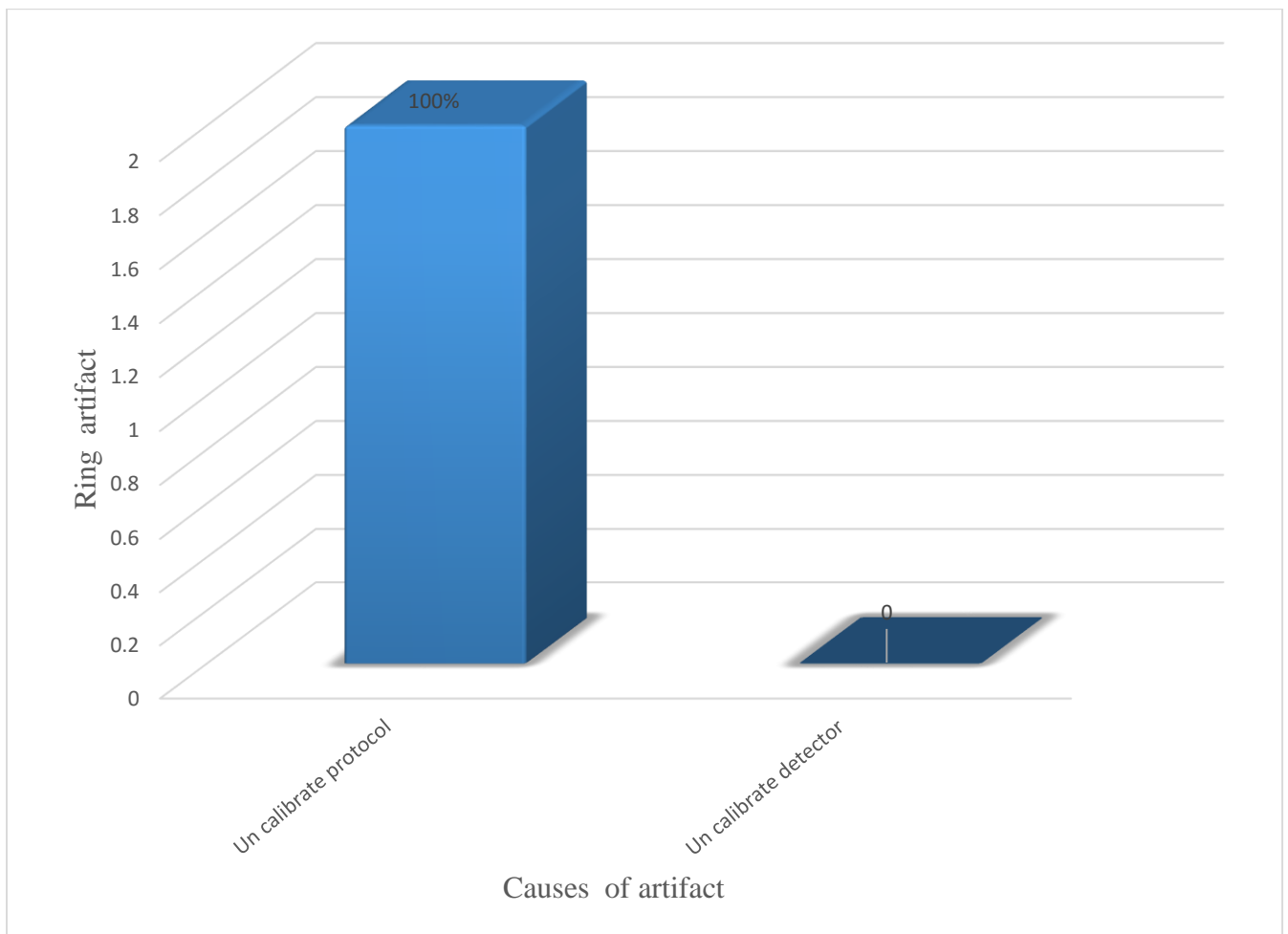


Fig (4.14) shows the causes of the ring artifact

Table (4.9) demonstrate image quality

	Excellent	Acceptable	Pad
Metallic Artifact	2	13	5
Motion Artifact	0	9	7
Beam Hardening Artifact	0	15	1
Rig Artifact	0	1	1

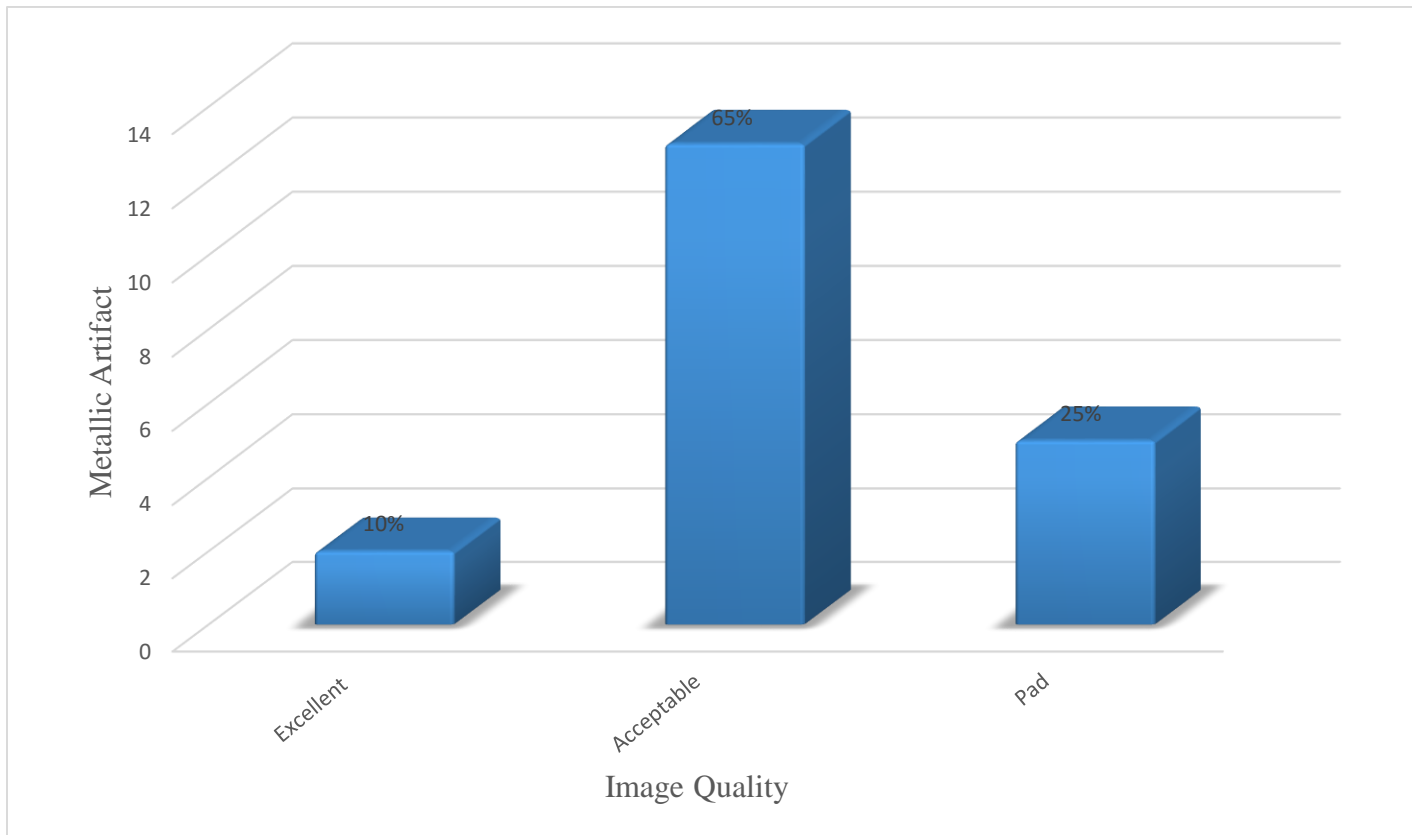


Fig (4.15) shows the image quality in image with metallic artifact

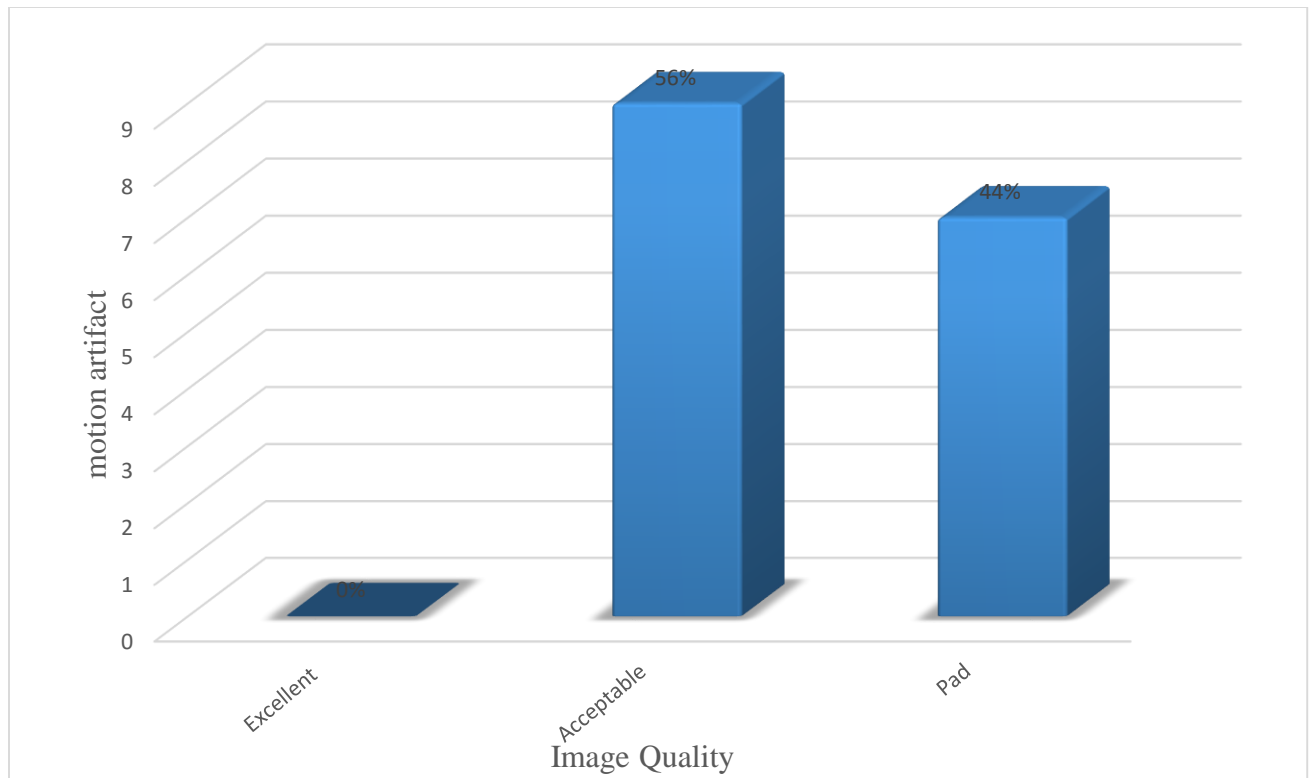


Fig (4.16) shows the image quality in image with motion artifact

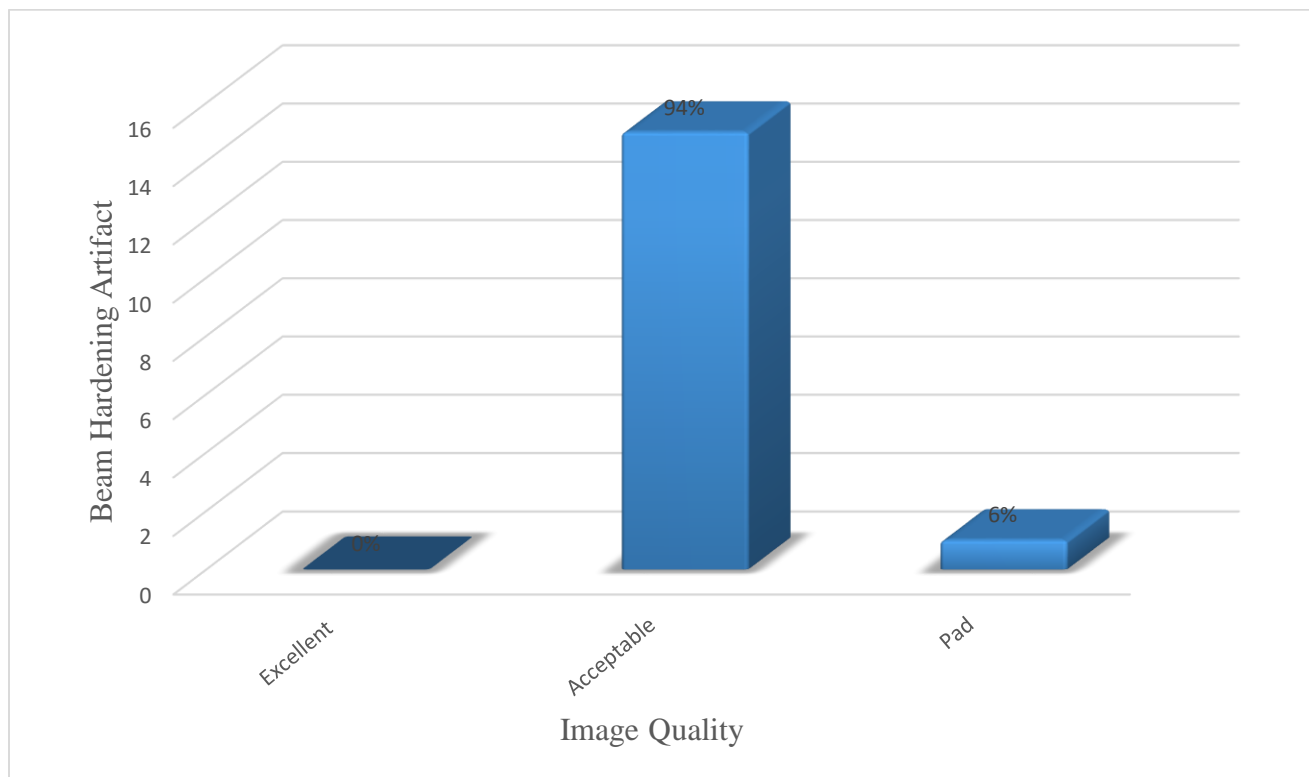


Fig (4.17) shows the image quality in image with beam hardening artifact

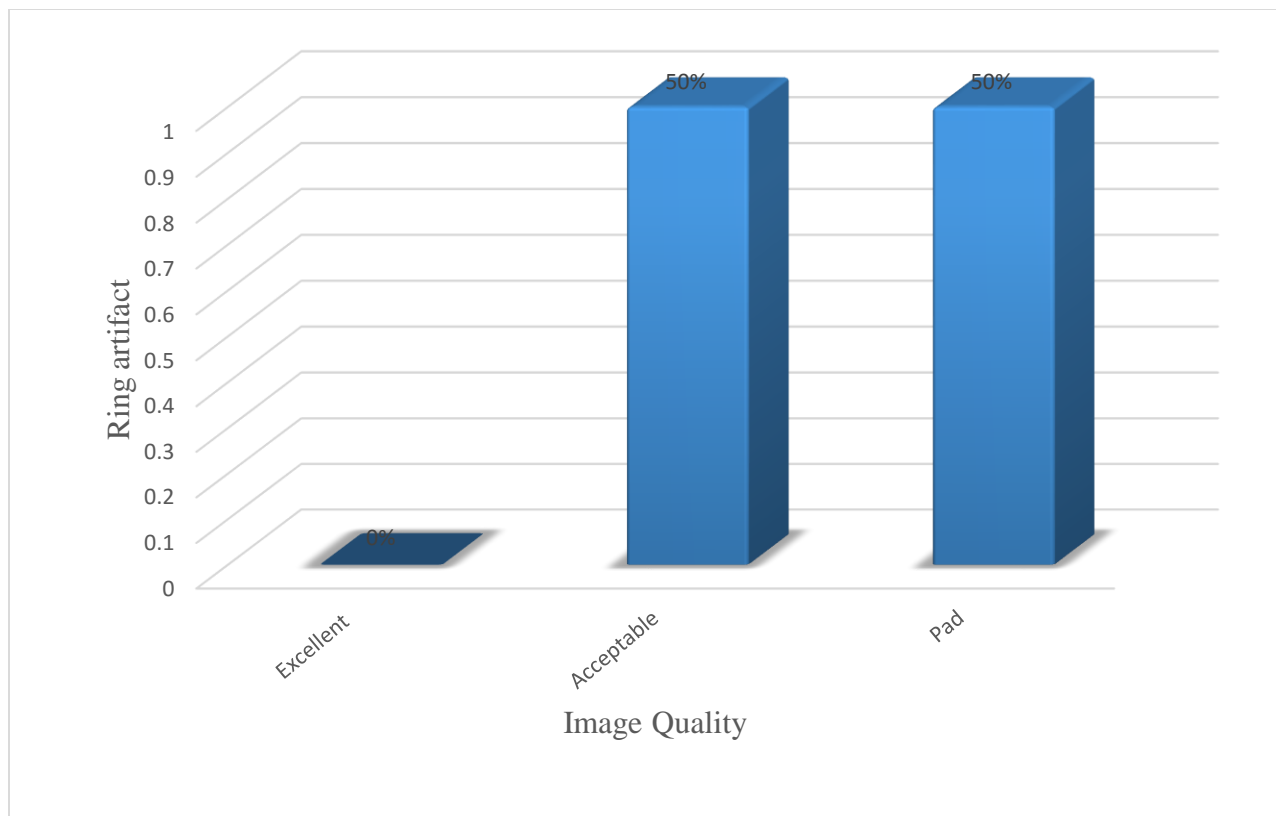


Fig (4.18) shows the image quality in image with ring artifact

Chapter Five

Discussion, Conclusion and Recommendations

5.1 Discussion:

In the table (4.1) show the population and distributions of gender male and female this study the show the male take more than two times of female and the percentage for male 70% and female 30%.

Fig (4.2) shows the distribution of the artifacts in this study and the results showed 36 % metallic artifact, 30% motion artifact, 30% beam hardening artifact and 4% ring artifact.

Fig (4.3) shows the relation between metallic artifact and CT examinations brain, chest, spine, abdomen, pelvis and limbs and the percentages of the relation its 32% in the brain, 10 % in the chest, 5 % in the spine, 21% in the abdomen, 21% in the pelvis and 11% in the limbs.

Fig (4.4) shows the relation between motion artifact and CT examinations brain, chest, spine, abdomen, pelvis and limbs and the percentages of the relation its 44% in the brain, 37% in the chest, 19% in the abdomen and 0 % in spine, pelvis and limbs.

Fig (4.5) shows the relation between beam hardening artifact and CT examinations brain, chest, spine, abdomen, pelvis and limbs and the percentages of the relation its 44% in the brain, 25 % in the chest, 6% in the spine, 13% in the abdomen, 0% in the pelvis and 13% in the limbs.

Fig (4.6) shows the relation between ring artifact and CT examinations brain, chest, spine, abdomen, pelvis and limbs and the percentages of the relation its 50% in the spine, 50% in the brain and 0 % in the other examinations.

Fig (4.7) shows the relation between metallic artifact with different age group 1 – 15 , 16 – 30 , 31 – 45 , 46 – 60 and 61 – 70 years and the percentages of the values of this relation with age groups its 11% , 22%, 28%,28% and 11% respectively .

Fig (4.8) shows the relation between motion artifact with different age group 1 – 15 , 16 – 30 , 31 – 45 , 46 – 60 and 61 – 70 years and the percentages of the values of this relation with age groups its 37% , 13%, 6%,19% and 25% respectively .

Fig (4.9) shows the relation between beam Hardening artifact with different age group 1 – 15 , 16 – 30 , 31 – 45 , 46 – 60 and 61 – 70 years and the percentages of the values of this relation with age groups its 0% , 18%, 44%,19% and 19% respectively .

Fig (4.10) shows the relation between ring artifact with different age group 1 – 15 , 16 – 30 , 31 – 45 , 46 – 60 and 61 – 70 years and the percentages of the values of this relation with age groups its 0% , 50%, 50%,0% and 0% respectively .

Fig (4.11) shows metallic artifact causes and the result shows 47% metallic fixation, 32% dental filling, 5% pace maker, 5% ECG gate and 11% surgical clips.

Fig (4.12) shows motion artifact causes and the result shows 37% respiration motion, 29% bowel motion and 44% patient motion

Fig (4.13) shows beam hardening artifact causes and the result shows 50% due to petrous bone, 6% due to hip bone and 44% shoulder.

Fig (4.14) shows ring artifact causes and the result shows 100% due uncalibrate.

From fig (4.15) show the effect of metallic artifact on image quality divide to three level acceptable image 65 % , pad image 25% and 10% excellent level.

Fig (4.16) show the effect of motion artifact on image quality divide to three level acceptable image take 56 % and pad image 44% and there is no excellent level.

Fig (4.17) shows the effect of beam hardening on image quality divide to three level acceptable image take 94 % and pad image 6% and there is no excellent level.

Fig (4.18) show the effect of ring on image quality divide to three level acceptable image take 50% and pad image 50% and there is no excellent level.

5.2 Conclusion:

Artifacts originate from a range of sources and can degrade the quality of a CT image to varying Degrees. Design features incorporated into modern Scanners minimize some types of artifact, and some can be partially corrected by the scanner Software. However, there are many instances where careful patient positioning and the optimum selection of scan parameters are the most important factors in avoiding image artifacts.

5.3 Recommendations:

As regard to imaging artifact or indirectly affecting the final image Result, we recommend the following:

- Quality control must on inseparable program for CT so as to trouble shoot and prompt diagnosis of imaging familiars before it became serious as to affect the final image quality.
- There should be routine preventive maintenance by the equipment engineers according to a pre-planned maintenance schedule.
- When preparing patient for CT imaging technologists should make sure that patients are artifact free i.e. free metal buttons, etc.
- In the teaching curriculum for radiographs there should be inclusion of a complete teaching unit dealing with imaging artifacts in CT.
- Continuing in service education staff orientation and professional development must be an ongoing process for all staff technologists.
- To avoid beam hardening should be avoid scanning bony regions, either by means of patient positioning or by tilting the gantry. It is important to select the appropriate scan field of view to ensure that the scanner uses the correct calibration and beam hardening correction data and, on some systems, the appropriate bowtie filter.
- Using of positioning aids is sufficient to prevent voluntary movement in most patients. However, in some cases (eg, pediatric patients), it may be necessary to immobilize the patient by means of sedation. Using as short a scan time as possible helps minimize artifacts when scanning regions prone to movement. Respiratory motion can be minimized if patients are able to hold their breath for the duration of the scan.

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Appendix:**Data Collection Sheet**

No	Gender	Age	Type of artifact	Causes of artifact	Image quality		
					excellent	Acceptable	bad