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RESEARCH ARTICLE

A RADIATION SAFETY ASSESSMENT OF X-RAY DIAGNOSTIC UNITS IN S.M.S HOSPITAL JAIPUR: AN INSTITUTIONAL STUDY

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Abstract

The aim of a quality assurance (QA) program is to assist a radio-diagnostic facility in consistently obtaining adequate radiological information with a minimum of dose and a minimum of cost. An integrated part of a quality assurance program is quality control (QC) in which a series of examinations and checks on equipment performance are undertaken, so that any changes can be objectively monitored and remedies made. The main objective of the present work was to carry out an independent audit of the important features of QA tests and radiation safety parameters in medical X-ray installations, which would reflect the safety status and to assess the regulatory requirements of the safety code. We conducted a radiological safety and quality assurance audit of 32 medical X-ray diagnostic machines installed in SMS hospital, Jaipur. A QA kit consisting of a kVp test meter, ionization chamber-based radiation survey meter and other standard accessories were used for the required measurements. The study mainly covered eight quality control checks that is; accuracy check of accelerating potential (kVp), linearity of tube current (mA station)and timer, congruence of radiation and optical field, and total filtration, beam alignment, focal spot size, leakage radiation survey, and beam out. The status test is carried out in order to establish the functional status of the equipments. They operated and functioned correctly and prevented movement when activated. All measured values were well within the tolerance limit.

Introduction:-

Diagnostic Radiology's basic task is to provide high quality diagnostic image information about anatomic detail or ongoing physiological process within patient's body, where such information cannot be provided using alternative diagnostic method which excludes the use of ionizing radiation. Ensuring adequate clinical diagnostic information together with the least possible exposure of the patient to radiation (As Low As Reasonably Achievable – ALARA principle) at the lowest costs is the quality assurance (QA) program's main goal. Implementation of QA program does not mean just meeting legal requirements regarding quality control (QC) of X-ray and associated equipment and areas where they are installed but also implies optimum use of equipment, human and material resources inspected through film rejection analysis and monitoring of patient doses received in particular radiological diagnostic examinations [1].

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In today's modern medicine a large number of different radiological diagnostic procedures are performed in which patients sometimes receive a significant doses of radiation where the costs of radiological services regarding the equipment and resources needed are high and rising . The imperative of establishing and implementing a quality assurance program includes not only fulfilling the requirements on the technical performances of the equipment (accuracy and repeatability of X-ray tube high voltage, mAs values, collimation and beam alignment etc.) required by the law, but also optimum use of equipment and other resources primarily monitoring of patient doses received in particular type of radiological diagnostic examinations and film reject analysis. Given that the poor quality of radiological diagnostic images, which as a result often has a repetition of radiographs, is the major cause of unnecessary patient exposure. The main component of the QA program is evaluation of image quality and identifying the cause of poor quality images and the determination of doses that patients receive in particular diagnostic procedures [9].

Materials and Methods:-

The study was done over 32 X-ray (fixed and mobile) machines in SMS medical college jaipur. In order to verify whether or not the relevant parameters are in agreement with the criteria, test measurements must be carried out. The study included major QA tests on every X-ray machine, conduct of radiological protection surveys at each X-ray installation, and verification of the implementation of the regulatory requirements of the safety code. Quality Assurance Tests for diagnostic X-ray Equipment includes 8 test such as congruence of radiation and optical fields, Central beam alignment, Effective Focal spot size measurement,Timer Accuracy, Accuracy of Accelerating Tube Potential, Linearity of radiation output, Total filtration, Radiation leakage through tube housing. A QA kit consisting of Cobia Flex general kVp meter for kVp measurement and RTI Survey Meter (digital, hand-held pressurized ion chamber) for air kerma measurement were used. These instruments provided instantaneous and reliable values. The kVp meter automatically measures kVp in the range from 38 kVp to 155 kVp, providing the results within seconds and updating it every second for fluoroscopy.

Congruence of Radiation and Optical Fields:-

If the optical field and radiation field are not congruent, the area of clinical interest may be missed in the radiograph leading to retakes and unnecessary radiation exposure to patients. The X-ray field must be aligned with the light field so that the operator can accurately position the body part to be imaged. Collimator test tool, fiber glass board were used for this measurement. The collimator is also called as the light beam diaphragm, which prevents the irradiation of unwanted area of the patients. The used test tool is consists of a fiber glass board of area $24x27cm^2$ with a rectangular area of $20x16\ cm^2$ marked on it by the coating of x-ray opaque material. This area is divided into 4 equal segments by two perpendicular bisectors. The two concentric circles with radii 4mm and 8mm are engraved in the centre, this facilitates in the beam alignment test tool also (Fig.1).

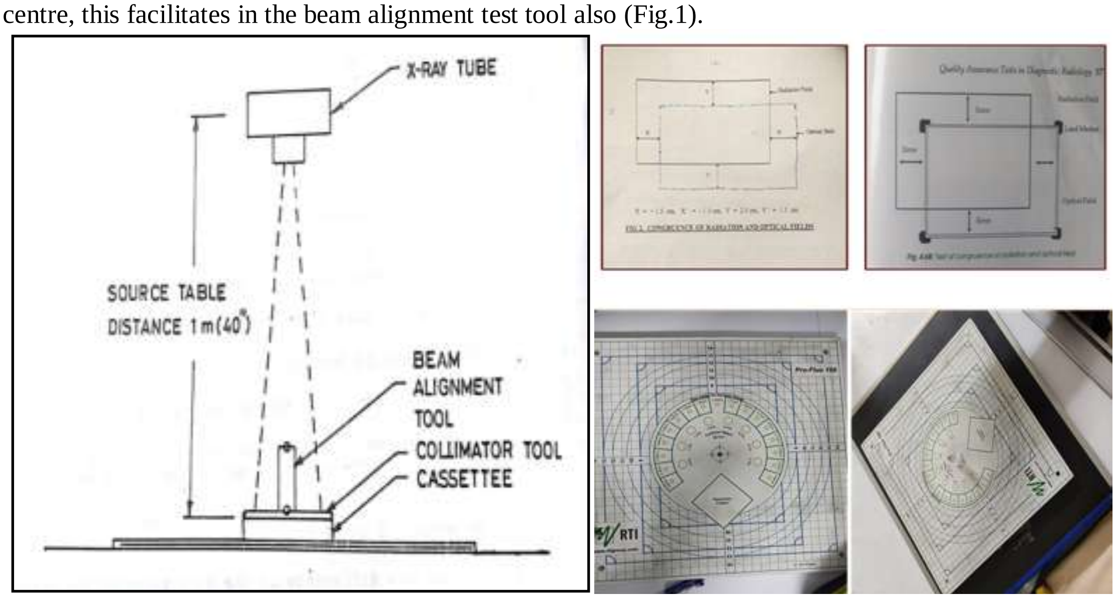

Fig 1:- Collimation/ Beam alignment tool and set up.

Measurement was done with Cassette ($25x25cm^2$) loaded with medium speed x-ray film at the centre of the table. Target to the film distance was adjusted to the 100 cm. The collimator test tool was kept above the cassette. The field was made to co-inside with the rectangular outline of the collimator test tool ($14x18\ cm^2$).The beam alignment test tool was placed at the centre of the collimator test tool (Fig.2). Film was exposed with 70 KVp and 10 mAs from the radiograph, the shifts (X, X', Y, Y') b/w the edges of optical and radiation fields were measured. It should be within 2% of FFD.The difference between the optical (X+X') and radiation fields (Y+Y') was also recorded, it should be within 3% of FFD.The difference between the sum of the length and width of optical and radiation fields must be within the 4% of FFD.

Fig 2:- Measurement setup.

Beam Alignment:-

If the x-ray beam is not perpendicular to the image receptor, the image may be distorted. If grid is used, the distortion will be magnified resulting in complete loss of minute details. For measuring the beam alignment, collimator test tool, stainless steel ball were used. The test tool was consists of a clear transparent acrylic cylinder of inner dia 6.3cm, outer dia 7.5cm and length 15.2cm.The acrylic circular disc of 6mm thickness was fastened on both sides of the cylinder. Stainless steel ball of dia 1.6mm was co-axially fixed at the centre of the both these discs. Beam alignment test tool was kept over collimation test tool so that the middle spot of the collimation test tool, beam alignment test tool and cross line of the beam coincide with each other. The machine was adjusted to 60 kVp and 10 mAs. The film was exposed and processed. If the beam alignment is perfect, the image of the top ball will merge with the image of the ball at bottom. The deviation of beam from the perpendicular is determined from the location of the top steel ball in the circles in the radiograph (Fig.3). Tolerance for central beam alignment should be within $<1.5^{o}$.

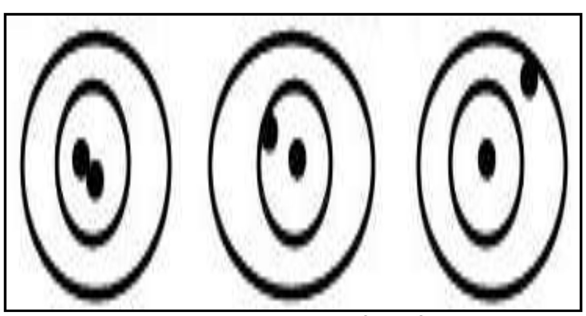

Fig 3:-Possible ways of beam alignment (Beam Alignment$<1.5^o$, $1.5^o<$Beam Alignment$<3^o$, Beam Alignment$>3^o$ (left to right)).

Effective Focal Spot Size Measurement:-

The actual focal spot size is the area on the anode that is struck by electrons and it is primarily determined by the length of cathode filament and the width of the focusing cup slot.The effective focal spot size is the length and width of the focal spot as projected down the central ray in the x-ray field.

Effective focal length = (Actual focal length) x (SinØ)
Here, Ø is the anode angle

Fig 4:- Focal spot test tool with non-screen film cassette.

Tolerance:-

a. For $f < 0.8$ mm + 0.5 f
b. For $0.8 \le f \le 1.5$ mm + 0.4 f
c. For $f > 1.5$ mm + 0.3f

Fig 5:- Set up for effective focal spot measurement.

Accelerating Potential (kVp):-

Thepeak potential of the x-ray generator affects quality& quantity of the x-ray beam and exposure to the patient. This in turn influences the contrast and density of the radiograph. Presentlysolid–statedetectors,which employnon-invasivemethodforpeaktube potential measurement, are quite handy for this test. Assessment of the tube potential ensures that the delivered kVp is close to that set on the equipment by the operator. This test was done through kVp meter.

Fig 6:- kVp meter.

The kVp meter employs two solid state detectors with different beam hardening filters. When exposed the ratio of signals produced by these detectors will be proportional to the peak tube voltage**.** Beam was centred on marked area on the top of the kVp meter at proper distance (Fig 6). Meter was exposed for a given kVp, mA and time settings. Meter reading was noted and repeated for different kVp settings. This method is instantaneous reading. Correction for beam filtration must be applied if necessary. Tolerance is ± 5kV**.**

Fig 7:- Set up for accelerating potential.

Accuracy/Linearity ofExposure Timer:-

If the exposure timer time set on diagnostic X-ray unit is not optimal, the radiograph can be used over exposed or under exposed. For tests for linearity of exposure time the dosimeter was kept at the center of the radiation field of area 20x20 cm^2 at the distance of 100 cm from the target. Dosimeter was exposed at 50kv and 200 mA with exposure time 0.5sec. Measurement was repeated for five times. Similar measurements was taken for exposure time for 0.75,1, and 1.5 sec. (X=mR/mAs) for each set of measurements was calculated.

Coefficient of linearity =(X max -Xmin) / (Xmax + X min).

Tolerance: COL<0.1

Linearity of mA Loading Stations:-

The tube current (mA) is equal to the number of electrons flowing from the cathode to the anode per unit time. The exposure of the beam for a given kVp and filtration is proportional to the tube current.This test was carried out to check the linearity of radiation output with respect to change in tube current (mA) stations by keeping timer station constant at a particular kV station.Pocket dosimeter was kept at the center of the radiation field of area 20x20 cm^2 at the distance of 50 cmfrom the target. For a fixed KVp and time an available mA stations was selected, the x-ray tube was energized and pocket dosimeter reading was noted for different 3 mAs stations, keeping all the other parameters constant. (X=mR/mAs) was calculated for each set of measurements & averaged, and then the coefficient of linearity (COL) was evaluated from the average mR/mAs or mGy/mAs.

Coefficient of linearity =(X max -Xmin) / (Xmax + X min). Tolerance should be COL<0.1

Output Consistency:-
To check the constancy of radiation output Pocket dosimeter was kept at the center of the radiation field of area 20x20cm^2 at the distance of 100 cm from the target. For fixed mA and time, select an available KVp, energized the x-ray tube and noted the reading .With two more available kVp, with keeping all other parameters constant, readings were noted and the measurements were repeated 5 times and Coefficient of Variation was calculated. Tolerance: Coefficient of Variation < 0.05

Total Filtration ofX-ray tube:-
To cutoff low energy components from X-ray beam, which do not contribute to diagnostic image formation but result in unnecessary patient exposure. If the filtration is too high, image contrast will be poor and unit will be overloaded. Therefore it is necessary that the total filtration (inherent + added) provided for the X-ray tube be as per the recommended value. The determination of half value thickness (HVT) of the X-ray beam was the method of evaluation of total aluminum equivalent filtration of the X-ray tube. Pocket dosimeter was kept at the center of the radiation field of area 20x20 cm^2 at the distance of 100 cm from the target. For a given KVp and mAs the dosimeter was exposed and the reading is noted. An Al filter (Fig.8) of 0.5 mm was interposed (at the collimator level) and the measurements are repeated. The experiment was repeated for various thickness of Al filter. Results were tabulated for different filters and ploted the curve on a semi log graph, with the exposure on Y axis and filter thickness on X axis and evaluate half value layer.

Minimum total filtration (mm/Al):-
a. Less than 70 KVp - 1.5 mm Al
b. 70 to 100 KVp - 2 mm Al
c. Above 100 KVp - 2.5 mm Al

Fig 8:- Al flters.

Radiation Leakage Levels from Tube Housing:-
The radiation leakage measurement was carried with an ionization chamber/semiconductor based radiation survey meter (Fig.9). For checking the leakage radiation, the collimator of the tube housing should be fully closed and the tube should be energized at maximum rated tube potential and tube current at that kVp. The exposure rate at 1m from the focal spot was measured at different locations (anode side, cathode side, front back and top) from the tube housing and collimator. From the maximum leakage rate (mR/h) from both tube housing and collimator, leakage radiation in onehouris computed on the basis of the workload of the unit.

Work load=180 mA-min in one hour
Radiation leakage from tube housing

$$\text{Max leakage from thetube} = \frac{\text{180 mA min in onehour} \times \text{Max exposure (mR/hr)}}{60 \times \text{applied mA for measurement}}$$

Tolerance limit:
Radiation Leakage at 1 m distance from the focus < 115mR in one hour (<1mGy in one hour)

Fig 9:- Survey meter.

Results:-

Each QA checks were tested and we had satisfactory results. They operated and functioned correctly and prevented movement when activated. In this study, a complete dosimetric data set for the x ray machines was obtained. Quality assurance of diagnostic X- ray unit should include functional aspects of the unit such as, mechanical checks, electrical checks, radiation checks as regards to clinical and radiation safety .Various parameters were checked in x ray unit through the Quality Assurance procedure and the measured values were well within the tolerance limit.

Eight QC test were carried out for the general X-Ray machines at SMS medical college, Jaipur.

The deviation between the measured central beam alignment and quoted by manufacturer was found to be within <1.5 for all the 32 x ray machines.

The observation of agreement between congruence of radiation and optical field was found to be within 1cm to 2cm, which is below the tolerance.

The effective focal spot measurement was also performed. Measured values limits waswithin limits for all machines For the verification of the accelerating potential (kVp), tube current values from 10 mAs to40 mAs and focus-to-detector distance (FDD) of 100 cm were used. The kVp ranges verified included kVp values from 50 kVp to 90 kVp. Accuracy of operating potential was found to be ± 2 to ± 3.2kV which can be accepted, where the tolerance is ± 5 kV or 5%.

The percentage of deviation between measured and quoted value of accuracy of irradiation time was within 0.2% to 3% which is well within the tolerance limit of <10%.

The determination of half value thickness (HVT) of the X-ray beam is the method of evaluation of total aluminum equivalent filtration in the X-ray tube. The filtration values were found to be within limits as specified by the AERB.

The linearity of mA / mAs was also performed. For assessing the linearity of tube current (mA station), FDD of 100cm, accelerating potential 60 kVp, and exposure time of 0.1 second were used. The coefficients of variation was found to be <0.1 for all the machines.

The coefficient of linearity for consistency of radiation output was found to be <0.05 and which was within limit.

Radiation leakage measurements were also carried out. The radiation level at 1m from the tube housing and collimator was measured and a maximum reading of 0.0024 mGy was found at tube of the x ray machine and maximum reading of 0.0038 mGy was found from collimator. These values were well within tolerance that is <1 mGy in one hour.

For safe radiation protection of the worker and general public, a radiation survey was carried out at different locations (door, console, patient waiting area, lead barrier etc.) around the machine installation. These values were well found within tolerance that is <1 mR/hr.

Conclusion:-

The QA tests such as measurement of Congruence of radiation and opticalfields, Central beam alignment, Timer accuracy, Accuracy of accelerating tube potential, Linearity of radiation output , Reproducibility of radiation output ,Total filtration, Radiation leakage through tube housing were performed. For the radiation safety of working personnel, patients and attendants of the hospital, survey of radiation level and unit leakage measurement has been undertaken and found to be within the described limit. This study makes significant contributions for improving the radiological safety status of medical X-ray installations and could provide a vital feedback in reviewing and preparation of regulatory documents pertaining to medical diagnostic X-ray practice.

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