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Assessment of Organs Mean Absorbed Dose Using a Local Phantom Radiography

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HIGHLIGHTS

1. Assessing organ dose via local phantom.
2. Mean absorbed dose determined accurately.
3. Phantom radiography aids dose evaluation.
4. Local phantom ensures precise measurements.
5. Organ-specific dose assessment in radiography.

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ABSTRACT

Introduction: Dose quantities have been designed to protect human beings (protection quantities) and operational quantities, by ICRU and ICRP as dose absorption varies depending on the organ or tissue density of the part of the body been irradiated (exposed). Dose absorbed by an organ need to be measured or quantified to know the amount of dose absorbed by an organ or tissue, as various organs have their dose limits given by the ICRU and ICRP. Materials and Methods: In this study, a locally constructed in-homogeneous phantom was to measure the mean absorbed doses by the organs around the head/neck region from conventional X-ray units in Jos metropolis, Nigeria. Thermoluminescence dosimeters (LiF: Mg, Ti) TLDs were used for the measurement and the statistical analysis was performed using Microsoft excel (version 2007). Results: The results in this study falls within the acceptable dose range of the organs concerned comparing with international and national findings by varying the exposure factor parameters (i.e kVp and mAs in the various X-ray units within the Jos metropolis. The mean absorbed dose by the organs from varying kV, are 0.36mSv brain, 0.21mSv eye lens, 0.42mSv thyroid, 0.25mSv heart, and 0.24 mSv lungs, for varying mAs, 0.40mSv brain, 0.25mSv eye lens, 0.43mSv thyroid 0.29mSv heart and 0.26 mSv lungs and for varying FFD (cm) 0.38 mSv brain, 0.31 mSv eye lens, 0.4 mSv thyroid, 0.26 mSv heart, and 0.25mSv lungs. Conclusion: The results for the designed phantom seemed to be applied for conventional X-ray dose validation and could be used as dose reference level for the various organs within the head/neck region.

INTRODUCTION

X-radiation (composed of X-rays) is a form of electromagnetic radiation that is a part of the electromagnetic spectrum. X-rays have wavelength shorter than those of ultraviolet rays and longer than those of gamma rays which is in the range of 0.01 to 10 nanometers, corresponding to frequencies in the range of 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz) and energies in the range 100 eV to 100 keV [1]. Radiography is an imaging technique using X-rays, gamma rays, or similar ionizing radiation and non-ionization radiation to view the internal form of an object which find application

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in medical radiography ("diagnostic" and "therapeutic"). To create an image in conventional radiography a beam of X-rays is produced by an X-ray generator and is projected toward the part of the body. A certain amount of the X-rays is absorbed by the part of the body, dependent on the part of the body's density and structural composition [2]. The X-rays that pass through the body part of interest are captured behind the body part by a detector (either photographic film or a digital detector). The generation of flat two dimensional images by this technique is called projectional radiography. Since the body is made up of various substances with differing densities, ionizing and non-ionizing radiation can be used to review the internal structure of the body on an image receptor by highlighting these differences using attenuation, or in the case of ionizing radiation, the absorption of X-ray photons by the denser substances (like calcium-rich bones). Phantoms are used to estimate radiation dose and transmission (or attenuation) of radiation in the human body for radiological studies and this discipline involved the study of anatomy through the use of radiographic images which is known as radiographic anatomy [2].

The patient effective dose takes into account, the dose to all organs that irradiated using a radiological examination as well as their sensitivity to radiation. The effective dose and exposure rates are respectively proportional to the exposure factors. As far as possible, this dose must be kept low so as to minimize any possible harm to the patient and it is a professional responsibility of the radiographer to ensure this. In fact, the patient may suffer more harm (because of incomplete or inadequate diagnosis, and need to repeat the radiographic exposure), from a poor film than he is ever likely to suffer from the exposure associated with a good radiograph. The use of grid always leads to an increase in the patient dose, but when the grid is needed, this must be accepted, for without the grid the radiograph may well be almost useless [3].

Various dose quantities have been designed by ICRP and ICRU to meet the need to protect human beings (protection quantities) and operational dose quantities which are designed for use in radiation measurements of eternal irradiation. All those quantities are based on the fundamental definition of absorbed dose in a point as the ratio of d_E by d_M, where d_E is the mean energy imparted (deposited) to the matter in an infinitesimal volume d_V at a point (target) of interest in a material of density p, during a certain period of time by ionizing radiation and d_M is the mean mass in d_V [4]. The absorbed dose is defined as $D=d\bar{E}/dM$

To assess radiation exposure to human and correlate it with the risk of exposure, mean absorbed dose in tissue or organ is used. The absorbed dose Dr. averaged over the tissue or organ $_T$, is defined as $D_{T=} E_{T/}M_T$

Where $E_{T,}$ is the mean energy imparted in a tissue or organ $_T$ and M_T is the mass of that tissue or organ [4].During the radiographic examination, the patient will be exposed to a minimum amount of radiation. But it should be noted that any radiation over exposure has some slight risk of damage to cells or tissues of the part of the body exposed. The radiation exposure in the body part is minimized by the type of X-ray high speed film which does not require as much radiation exposure as in the past. There is always a slight risk of damage to the cell or tissues of the part radiography to obtain a quality image or a clear image view on an image under minimal radiation being exposed to radiation. However, radiologists are provided with guidelines designed and revealed by both the department of health and human services, national and international radiology protection councils [5].

MATERIALS AND METHODS

This study was carried at the X-ray Department of the Bingham University Teaching Hospital, Jos using these materials; Local phantom, Perpex glass, Digitizer, MIN X-ray (digital) X-ray machine, Thermoluminescent dosimeters, Monitor screen and Radiation survey meter.

A. Local phantom: A local phantom with bovine tissues as the organs were used as shown in Plate 3.1.

Plate 3.1: Locally Constructed phantom

B. Perspex glass: A perspex glass that has a thickness of 3mm was used to construct the local phantom for adult examination.
C. Digitizer: This was used to process the radiation that traverses the local phantom to give out an image of the head/neck and chest organs which were displayed on the monitor.
D. Thermoluminescent dosimeters (TLDs): These were used to measure the direct dose absorbed by the organs as they are sensitive to radiation using an automatic reader, HARSHAW 4500was used to anneal the TLDs to remove residual dose before irradiation and readout TLDs responses after irradiation with a dedicated personal computer link to the reader to initiate the reading programs as well as the annealing processes.
E. MIN digital X-ray machine: This was used for exposing (irradiating) the local phantom to obtain the radiographic images shown in plate 3.2.

Plate 3.2: MIN X-ray (digital) Machine.

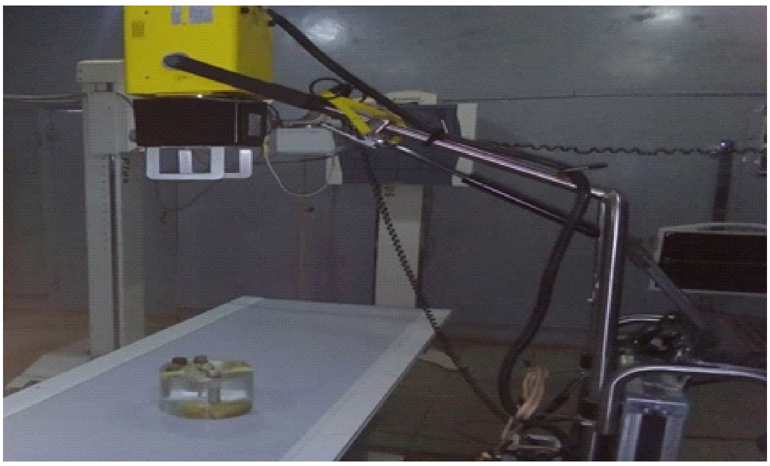
A. Monitor screen: This is where images are displayed for the radiologist to read.
B. Survey meter: This was used to measure the background radiation in the exposure room

Construction of a Local Phantom

The local phantom was constructed using a transparent perspex plastic with a thickness of 3mm to follow the standard CT/ conventional X-ray dosimetry phantom. The local phantom was cylindrical in shape and 16cm in diameter. The phantom is consisted of five probe holes; one at the centre and the four arou- -und the perimeter, 90^0 apart and 1cm from the edge.The probe holes contained bovine tissues, which were used as the organs. Three organs in the head, neck (that is brain, eye lens and thyroid), two organs in the chest (that is, heart and lungs) regions were selected for the measurement [6].

Data Collection

The dose absorbed by the organs were obtained by irradiating or exposing the local phantom placed in opposite direction with the X-ray machine under varying exposure factors on the machine selection keyboard.



After proper collimation and pre-selection process at the control panel, exposure was made on the control knobs and the incident divergent beam traverses the compression plate, through the specimen [7].

Processing of the TLDs

The TLD reader in Center for Energy Research and Training, Zaria is the Harshaw Model 4500. It has a hardware comprising the following system.
The model 4500 Harshaw TLD reader which contains data processing electronic, a sample drawer assembly, a precision light measurement system, a detector heating system, a light voltage power supply, data storage facilities and photo multi-

plier tubes.
2. A video display unit (VDU) for the display of data graphics, operating instruction and messages.
3. Keyboard that provides the interactive central interface with the TLD reader Harshaw model 4500.
4. A set of floppy disk for backup.

The model 4500 Reader is capable of reading a number of forms of thermo luminescence dosimeters, such as the whole body and the environmental dosimeter. The Harshaw Model 4500 Manual TLD Reader with WINREMS is a state-of-art; tabletop instrument used for thermo luminescence dosimetry (TLD) measurement of a wide variety of TL materials in many forms and sizes. This model incorporates two Photomultiplier Tubes in a sliding housing, with both planchet and hot gas (nitrogen or air) heating methods. The TL element may be heated by hot gas or by a planchet. Hot gas is used for whole body and Environmental TL cards and extremity Dosimeters (Chipstrates and Ringlets), while the planchet is used for the unmounted TL elements: chips, disks, rods, and powders. The system consists of two major components: the TLD Reader and the Windows Radiation Evaluation and Management System (WinREMS) software resident on a personal computer (PC), which is connected to the Reader via a serial communications port [8].

WinREMS Application software

The data architecture of the system includes both a host computer in the Reader and a Windows based PC connected through an RS-232-C serial communication port. The dosimetric functions divided between the Reader and the Harshaw WinREMS (Windows Radiation Evaluation and Man-agement System) software on the PC. All dosimetric data storage, instrument control, and operator inputs are performed on the PC, transport subsystem control, gas and vacuum controls, and signal acquisition and conditioning are performed in the Reader [8].

Population Sample

Five Bovine tissue samples were used; Brain, Eyelens, Thyroid, Heart and Lung

Data Analysis

For the measurement of organ dose, two TLDs were placed in each of the probe holes of the phantom in order to improve the counting statistics. Each of the probe holes contained a specific organ for the different x-ray protocols. All x-rays exposures were performed in posterior-anterior (PA) mode. The chips were later removed and returned to the laboratory for reading. The TLD was read in photon count and converted to doses by subtracting the background count from the actual thermoluminescence counts. Therefore the dose;

$$D = \frac{Q * ECC}{RCF}$$

Where
D=Dose
Q=Charge (the glow peak value, in nano-Columb).
ECC=Element correction coefficient = 3749
RCF=Reader calibration factor = 0.0171

Statistical Analysis

In this study, Microsoft Excel Version 2007 was used for data analysis in calculating the mean absorbed dose.

DATA PRESENTATION AND ANALYSIS

Varying Kilo-Voltage (kV)

Table 4.1 presents the results of dose absorbed by the organs as the kV is varying while milli-Ampere seconds (mAs) and Focal Film Distance FFD (cm) where kept constant.

Table 4.1: Results of absorbed dose by the organs under varying kV.

				Absorbed Dose(mSv)				
S/N	kV	mAs	FFD (cm)	Brain	Eye lens	Thyroid	Heart	Lung.
1.	70	20	100	0.21	0.08	0.31	0.14	0.11
2.	76	20	100	0.29	0.12	0.36	0.20	0.18
3.	80	20	100	0.37	0.19	0.42	0.26	0.23
4.	84	20	100	0.42	0.28	0.48	0.31	0.29
5.	90	20	100	0.49	0.36	0.53	0.39	0.37
			Mean	**0.36 ± 0.06**	**0.21 ± 0.05**	**0.42 ± 0.05**	**0.25 ± 0.05**	**0.24 ± 0.06**

Varying milli-Amperage Seconds (mAs)

Table 4.2 presents the results of dose absorbed by the organs as the mAs is varying while kV and FFD (cm) where kept constant.

Table 4.2: Results of absorbed dose by the organs under varying mAs.

				Absorbed Dose(mSv)				
S/N	kV	mAs	FFD (cm)	Brain	Eye lens	Thyroid	Heart	Lung.
1.	80	30	100	0.51	0. 41	0.59	0.42	0.40
2.	80	25	100	0.42	0.35	0.50	0.35	0.32
3.	80	20	100	0.39	0.20	0.41	0.28	0.23
4.	80	15	100	0.32	0.17	0.35	0.22	0.20
5.	80	10	100	0.28	0.11	0.29	0.18	0.15
			Mean	**0.40 ± 0.05**	**0.25 ± 0.06**	**0.43 ± 0.06**	**0.29 ± 0.05**	**0.26 ± 0.07**

Varying Focal Film Distance FFD (cm)

Table 4.3 presents the results of dose absorbed by the organs as the FFD is varying while kV and mAs where kept constant.

Table 4.3 Results of absorbed dose by the organs under varying FFD (cm).

				Absorbed Dose(mSv)				
S/N	kV	mAs	FFD (cm)	Brain	Eye lens	Thyroid	Heart	Lung.
1.	80	20	120	0.24	0. 11	0.29	0.16	0.10
2.	80	20	110	0.31	0.25	0.34	0.21	0.16
3.	80	20	100	0.37	0.30	0.40	0.26	0.22
4.	80	20	90	0.45	0.37	0.46	0.30	0.33
5.	80	20	80	0.51	0.53	0.51	0.37	0.39
			Mean	**0.38 ± 0.06**	**0.31 ± 0.07**	**0.40 ± 0.05**	**0.26 ± 0.06**	**0.24 ± 0.06**

Table 4.4: Comparison of this study mean dose for radiographic examination with European Commission, United Kingdom, Australian Radiation Protection and Nuclear Safety Agency and IAEA DRLs for adult posterior-anterior chest and skull examinations.

Organs	**This study (mGy)**	**ARPANSA DRL(mGy)**	**EC DRL (mGy)**	**UK DRL (mGy)**	**IAEA (BSS)[1996] (mGy)**	**Michael et al (2019) (mGy)**
Brain	0.38	1.8	0.7	1.8	0.4	0.40
Eye lens	0.26	1.8	0.7	1.8	0.4	0.40
Thyroid	0.40	5.0	4.0	3.0	0.4	0.38
Heart	0.26	0.5	0.3	0.2	0.4	0.36
Lungs	0.25	0.5	0.3	0.2	0.4	0.40

PA= Posterior-anterior, EC= European commission, UK = United Kingdom, ARPANSA= Australian Radiation Protection and Nuclear Safety Agency, IAEA= International Atomic Energy Agency, DRL=Dose Reference Level and BSS=Basic Safety Standard.

Data Analysis

Table 4.1 shows that as the kV is increasing the dose absorbed by the organs also increases which indicate that an increase in the tube voltage produces more energetic X-rays which has the ability to penetrate the phantom. This is because the kV affects the energy of the x-ray beam. As the voltage increases, it tends to increase the acceleration of the electrons travelling to the target, which also increases the energy of the X-rays produced. By so doing, harder X-rays will be produced which increases the penetration power and reduces the attenuation level of the organs of the head/neck and the chest.

Table 4.2 shows that as the mAs increases the dose absorbed by the organs also increases due to increase on number of electrons produced. This means that mAs determine how much current is allowed to flow through the filament which is the cathode side of the tube.

Table 4.3 shows that as the distance decreases the dose absorbed by the organs increases because the tube is brought closed to the phantom more radiation reaches the phantom which increases the rate of dose absorbed by the organs. This because the closer the beam to the phantom the more the radiation reaching the phantom. The more the distance reduces the more the exposure which agreed with the inverse square law and dose limitation in radiation protection i.e shielding, distance and time. In general, an increase in energy and intensity increases the dose absorbed by the patient while reduction in distance increases exposure, so ALARA (As Low As Reasonably Achievable) principle i.e optimization of patients dose must be observed to ensure safety and operation to be justified i.e benefit must outweighed detriment.

The mean absorbed dose by the organs from varying kV, are 0.36mSv brain, 0.21mSv eye lens, 0.42mSv thyroid, 0.25mSv heart, and 0.24 mSv lungs, for varying mAs, 0.40mSv brain, 0.25mSv eye lens, 0.43mSv thyroid 0.29mSv heart and 0.26 mSv lungs and for varying FFD (cm) 0.38 mSv brain, 0.31 mSv eye lens, 0.4 mSv thyroid, 0.26 mSv heart, and 0.25mSv lungs.

From Table 4.4, the mean dose for the various organs for this study for PA chest and head (skull) examination indicated that the dose is within the acceptable range and showed a good correlation with already established reference dose guide lines national and international.

DISCUSSION

It has been observed in this study that the dose absorbed by the organs depends on these exposure parameters.

An increase in these exposure parameters (kV and mAs) increases dose absorption by the organs and in a reverse way, decrease in FFD (cm) increases dose absorption by the organs. The mean dose absorbed by the organs was compared with some national and international DRLs studies for adult PA chest, neck and skull examination, especially that of IAEA (BSS) [10] as seen in Table 4.5 and found that they were within the acceptable range.

The mean absorbed dose of this research which is the same as the effective dose when multiplied with the radiation weighing factor of 1 for X-rays to get the effective dose which is still found to be within the acceptable range DRLs for the effective dose in [11] and [8] and also with [10]. Comparing with Sherman-ray (1986) in his in Telography by extending focus film distance (FFD) noted that lengthening the focus film distance reduces the radiation burden to the patient and enhances final film result by improving geometric physical sharpness and exposure factors. Which in my work it has been confirmed, increasing the FFD reduces dose absorbed by the organs and improved image quality on the radiographs. Also, in his work, a minimum of 150 centimeters (cm) was advised to be used and preferably 200 centimeters while in my work, a minimum of 100 centimeters and preferably 120 cm. The reason for these differences is from the equipments used for the research. I used a digital Min-X-ray Machine which does not require film and gives minimal dose compared to his own where he used GE X-ray and this requires the use of X-ray film and gives higher dose [12].

In his investigate the dose-reducing efficiency of change in FFD and exposure factors for a pelvis x-ray examination using TLDs to measure the radiation dose using an anthropomorphic phantom and patients which the result shows a significant reduction in effective dose and that was also confirmed in my work using locally constructed phantom and TLDs and found that reducing exposure factors reduces patients dose.

CONCLUSION

The steady increase in professional and public concern regarding the biological effects of ionizing radiation on human tissues motivated me to undertake this research. There is need for radiography professionals to improve imaging techniques with minimal radiation exposure to patients at all times. The data (values) obtained in this study shows that exposure factors affect the total absorbed dose received by the patient. Therefore, the radiographer has to come to a compromise between the image quality and the radiation dose to the patient according to ALARA (As Low As Reasonably Achievable) principle. The findings of this work can be used as reference values for head/neck and chest X-ray procedures in radiological establishments.

The study also shows that a suitable exposure factors can substantially reduce patients' dose while maintaining acceptable image quality with no additional cost implication.

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