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Evaluation of Quality Control Parameters of Half Value Layer, Beam Alignment and Collimator Test Tools on Diagnostic X-Ray Machines

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ABSTRACT

Quality control on diagnostic X-ray machines in Radiological units of two major Hospitals in Makurdi, Benue State, designated A and B was carried out using Half-Value Layer (HVL), Beam alignment and Collimator test tools which were based on technical standards for radiological protection and quality control in medical diagnosis. The quality filtration of diagnostic X-ray in use at Hospitals A and B were checked using HVL at 80kVp, 70kVp and 60kVp while the collimator and beam alignment test were used to measure the degree of misalignment of the target points. The technique employed in determining HVL was based on reducing the intensity of the X-ray beam to half its original value using aluminum filters added at 2cm from the table and dose detected using DIAVOLT placed at 98cm from the centre of the X-ray tubes. The attenuation coefficient was obtained from a standard graph of Dose (μGy) verses Aluminum thickness (mm) where the slope gives the attenuation coefficient (μ) which was used in calculating HVL using the relationship $HVL = \frac{ln2}{\mu}$. The values of HVL calculated were then compared with minimum acceptable HVL values at the kVp setting as recommended by the International Commission on Radiological units and measurement. Also Hospital A was shown to have a misalignment of 0.2cm at 60kVp, 10mAs, 100cm FFD using a film size of 10x8cm^2 while Hospital B had a misalignment of 0.6cm at 25mAs, 81cm FFD using a film size of 10x8cm^2. The result of the work shows that the misalignment falls within the acceptable limit of 2.0cm as recommended by International Commission on Radiological Protection.

Keywords: *Radiation Protection, Misalignment, Attenuation Coefficient, Basic Safety Standard*

1. INTRODUCTION

X-radiation is produced whenever a substance is bombarded by high speed electrons. All X-ray tubes consist of a cathode and anode assembly, placed inside a glass envelop that has been evacuated (Harold and Cunningham, 1983).
Transmitting X-ray photons through the body onto an X-ray sensitive detector forms images. Some of the photons interact with tissue in the body and are scattered or absorbed; other photons make it to the detector and are recorded. The resulting image is a transmission image showing the amount of X-ray attenuation along a path through the body (alternatively, the image can be formatted as an attenuation image showing how much of the energy was absorbed in the body). Dense materials absorb more X-ray photons than less dense materials. Different absorption characteristics allow us to distinguish different materials in the image (Edwin and Reinhardt, 2009).

For a typical unfiltered X-ray spectrum, the average energy is about one-third to one-half of the peak energy, or applied kilovoltage (Cuny, 1984). Hence, most of the X-ray produced are much lower in energy than the applied kilovoltage of the beam and are attenuated by the torso or other portion of the body being radio-graphed and never reach the film. These X-rays are of little value in radiography but contribute significantly to patient dose.

To reduce the dose to patient, filtration in the form of specified thickness of absorbing material is added to the beam. This has the net effect of absorbing a large fraction of the lower energy X-rays that are of little or no value in making the radiograph while allowing most of the more energetic and radio-graphically useful X-ray photons to pass. A filtered X-ray spectrum has a corresponding higher average energy than before it was filtered, such a beam is said to have been hardened.

Beam energy is typically specified in terms of the half Value Layer (HVL) in mm of Aluminum. HVL is the amount of filtration that reduces the exposure rate to one half of its initial value (Papp, 2011). In the course of measuring the HVL, the absorbers act as filters and the beam is further hardened thus, the first HVL is always thinner than the second, which in turn is even less than the third and so forth. A useful, although rarely available measure is the homogeneity factor, which is the ratio of the second HVL to the first HVL (Trout *et al.*, 1952)

The best method to determine if adequate filtration exists is to measure the half value layer because normally it is not possible to measure Inherent filtration. This is due to filament evaporation that is continually taking place which adds a layer of tungsten onto the inside of the X-ray tube window (Papp, 2011). Generally, the HVL should not vary from its original value (which is established at its acceptance) or its value at the beginning of the quality control program. It is dependent on the kVp used, the total beam filtration and the type of X-ray generator.

In this part of the world, where only few have the ideas about the principle of X-ray imaging technique, the necessity of diagnostic X-ray examination cannot be overemphasized due to the fact that most of the common killer-diseases of the world of which tuberculosis top the chart are best diagnosed using X-ray imaging.

A survey in Makurdi metropolis revealed that most radiological units operates without necessarily taking into account the danger the process might cause. This is because most times, so many unnecessary X-ray examinations are carried out on an individual and sometimes repeated exposures are made as a result of bad radiograph

Due to the above mentioned abnormalities it became necessary for this research to be carried out so as to estimate the minimum recommended radiographic parameters to be used in order to reduce the dose to patient and probably to personnel.

The aim of this work is to estimate the quality control parameter of total filtration of diagnostic X-ray beam in use at peak kilovoltages of 80, 70 and 60, by evaluating the HVL values of these X-rays and to also measure the degree of alignment of the X-ray tube and the target point. The results of the measurements will be compared with international standards of filtration of diagnostic X-ray beam and beam alignment compliance criteria; this will serve as a baseline for the assessment of X-ray units in the state. Recommendations for improvement can be made where necessary on the safety of patients undergoing X-ray examinations.

2. MATERIAL AND METHOD

The X-ray machines used for this work are situated at Federal Medical Centre and Bishop Murray Hospital both in Makurdi. For the purpose of this work, they shall be referred to as machine "A" and "B" respectively. The machines have the following specifications;

Table 1; machine specification

Parameters	Specification	
	"A"	"B"
Model	20046 Basano	HXD51-2040nx
Manufacturer	Italray-Italy	HangzhonWandong Electronics
Anode type	Rotational	Rotational
Phase	Single	Single
Focus to film distance	100cm = 1m	98cm
Exposure time (Selected by processor according to the mA imputed A.C.)	Not selectable	Not selectable
Max kVp	125kVp	125kVp
Max mAs	6.3mAs	2.5mAs
Inherent filtration	1.5mmAl	2.5mmAl
Field size	Selectable	Selectable
Manufacture date	November 2008	September 2006

Other materials include the set of half value layer aluminum filter which consist of seven aluminum alloy 99.9 percentage purity. These alloys are plates of area $10cm^2$ with thickness of 0.2mm x 1, 0.3mm x 2, 0.5mm x 2, 1.0mm x 2 and 2.0mm x 1. These were used as added filters.

The dosimeter used for this work is a DIAVOLT universal model 43014. DIAVOLT is a test device for quality control and acceptance testing in diagnostic radiology. It is a digital electronic device with a screen which displays kVp (maximum), Dose (μGy), inherent filtration (mmAl) and other parameters DIAVOLT is powered via an external multi range power supply which automatically adopts the voltage of the power line. It is manufactured by PTW-Freibung-German. A measuring tape is used to measure the distance of focus to dosimeter.

The DIAVOLT dosimeter is placed at the Centre of the X-ray beam on the radiographic table top on top of a lead apron (to avoid backscatter). The X-ray tube head is adjusted such that the tube to dosimeter distance is 100cm and 90cm for tubes "A" and "B" respectively. The beam is then adjusted slightly beyond the size of the dosimeter (6.5cm x 3.5cm). kVp of 80, 70 and 60 were selected with mAs of 50, exposures were made at the selected kVps first without any filter added and dosimeter readings recorded. The dosimeter was cleared; 1mm of aluminium alloy was added at a fixed distance from the focus. Exposure was made and the reading recorded, then dosimeter cleared. The procedure was repeated adding aluminium plates in 0.5mm increments until a total of 5.5mm Al were in place. Using dose (μGy) and linear attenuation coefficient as in the equation $\ln\left(\frac{D}{Do}\right) = \mu x$. The HVL were the evaluated using the equation

$$HVL = \frac{\ln 2}{\mu} = \frac{0.693}{\mu}(cm \ or \ mm) \qquad (1)$$

This value gives the quality of the X-ray beam filtration by comparing the estimated HVL values with the minimum recommended HVL values set by ICRU (ICRU, 2005).
The experimental setup for beam alignment and collimator test tools was done before exposure; the table was leveled and the X-ray tube was placed in such a way that the beam was perpendicular to the table. The table was leveled by a bubble level such as the one included in the Radiographic/Fluoroscopic quality control kit. The tube was centered to the table and the distance from the focal spot to the table top was set at 100cm for hospital A and 81 cm for hospital B which were their maximum focal film distance (FFD). The collimator tool was then oriented such that the dot in the lower left corner corresponds to the position of a supine patient's right shoulder. This allows the direction of the collimator error to be determined at a later time. The film for the experiment was a 10 x 8cm cassette at approximately 60kVp, 10mAs for hospital A at FFD of 100cm and 60kVp, 25mAs at FFD of 98cm.

The experiment set up for the beam alignment and collimator test tools, before exposure; the table was levelled and the X-ray tube was placed in such a way that the beam was perpendicular to the table. The table was levelled by a bubble level such as the one included in the Radiographic/Fluoroscopic Quality Control Kit. The tube was centred to the table and the distance from the focal spot to the table top was set at 100cm (1m) for hospital A and 98cm (0.98m) for Hospital B which were their maximum focal film distance (FFD). The beam alignment tool was then placed on the centre of the collimator test tool and both tools placed in the centre of the light field. The collimator shutters was then adjusted such that the edges of the light field coincide with the rectangular outlines of the collimator test tool. The collimator tool was then oriented such that the dot in the lower left corner corresponds to the position of a supine patient's right shoulder. This allows the direction of the collimator error to be determined at a later time. The film for the experiments was 10x8cm cassette at approximately 60kVp (peak kilo voltage), 10mAs (milliampere second) for hospital A at film focal distance FFD of 100cm; 60kVp and 25mAs for hospital B at (FFD) of 98cm.

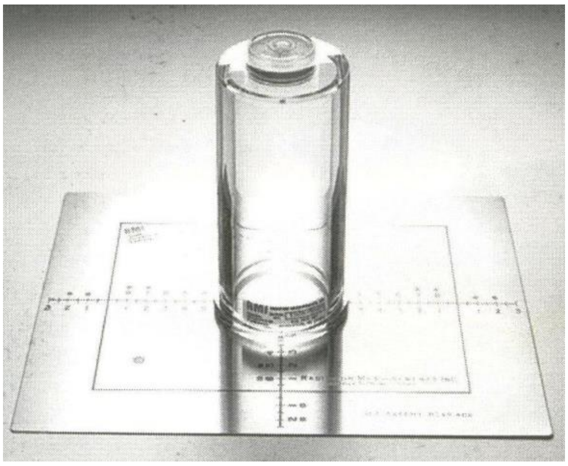

Figure1. Collimator and Beam Alignment Test Tool

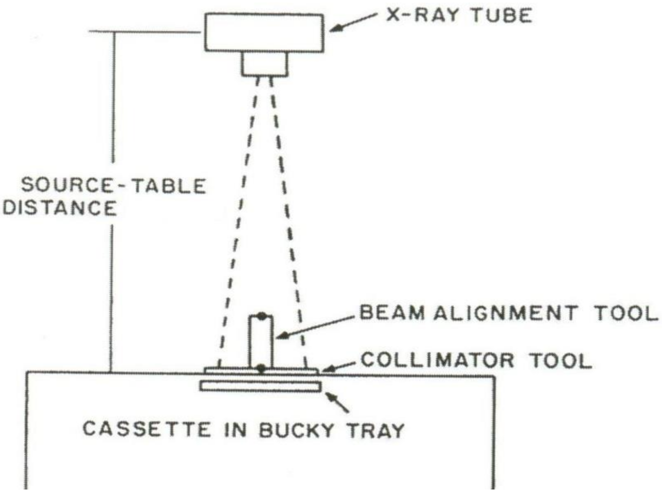

Figure 2. Placement of Collimator and Beam Alignment Test Tools for proper exposure

3. RESULTS AND DISCUSSION

The result of measurement of radiation doses(μGy) from the two X-ray machines situated at Federal Medical Centre Makurdi ("A") and Bishop Murray Hospital Makurdi ("B") using various machine parameters and thickness of aluminium filters are presented in tables 2-7 Machine "A" has inherent filtration of 1.5mmAl

Table 2; Doses measured at 80kVp, 50mA using various thicknesses of aluminium filters.

S/N	(mm)	1st	2nd	Avg	ln Avg dose
1	0.0	3885.0	3912.0	3898.5	8.268
2	1.0	2973.0	3005.0	2989.0	8.003
3	1.5	2672.0	2658.0	2665.0	7.888
4	2.0	2377.0	2364.0	2375.0	7.773
5	2.5	2139.0	2130.0	2134.5	7.773
6	3.5	1797.0	1799.0	1798.0	7.495
7	5.5	1282.0	1008.0	1145.0	7.043

Table 3: Doses measured at 70kVp, 50mA using various thickness of Al filter

S/No	thickness (mm)	dose (uGy)			
		1st	2nd	Avg	In Avg.dose
1	0.0	2486.9	2484.0	2485.45	7.818
2	1.0	1844.0	1844.0	1844.0	7.520
3	1.5	1621.0	1617.0	1619.0	7.390
4	2.0	1433.0	1431.0	1432.0	7.267
5	2.5	1279.0	1277.0	1278.0	7.153
6	3.0	1146.0	1147.0	1146.5	7.045
7	3.5	1035.0	1034.0	1034.5	6.942
8	4.0	959.0	958.9	958.95	6.866
9	5.5	728.0	729.8	728.9	6.592

Table 4: Doses measured at 60kVp, 50mA using various thickness of Al filter

S/No	thickness (mm)	dose (μGy)			
		1st	2nd	Avg	In Avg.dose
1	0.0	1485.0	1490.0	1487.5	7.305
2	1.0	1073.0	1074.0	1073.5	6.979
3	1.5	930.0	930.3	930.2	6.836
4	2.0	813.5	816.9	815.2	6.702
5	2.5	718.1	716.7	717.4	6.576
6	3.0	358.1	652.6	505.4	6.482
7	3.5	583.9	580.8	582.4	6.367
8	4.0	522.4	523.1	522.8	6.253
9	5.5	383.6	383.9	383.8	5.950

Machine "B" has inherent filtration of 2.5mmAl

Table 5: Doses measured at 80kVp, 50mA using various thickness of Al filter

S/No	thickness (mm)	dose (uGy)			
		1st	2nd	Avg	In Avg.dose
1	0	560.8	604.5	582.65	6.368
2	1	436.4	369.2	402.8	5.999
3	1.5	390.9	389.8	390.35	5.963
4	2	335.7	316.1	325.9	5.789
5	2.5	282.5	272.6	277.55	5.626
6	3	231.7	245.2	238.45	5.474
7	3.5	0.7	273.5	137.1	4.921
8	4	246.6	251.6	249.1	5.518
9	5.5	196.6	198.4	197.5	5.286

Table 6: Doses measured at 70kVp, 50mA using various thickness of Al filter

S/No	thickness (mm)	dose (uGy)			
		1st	2^{nd}	Avg	In Avg.dose
1	0	266.4	209.8	238.1	5.473
2	1	171	164.3	167.65	5.122
3	1.5	165	162.9	163.95	5.1
4	2	111.7	158.2	134.95	4.905
5	2.5	144.9	149	146.95	4.99
6	3	95.7	0.7	48.2	3.875
7	3.5	82.7	85.3	84	4.431
8	4	96.7	95.4	96.05	4.565
9	5.5	83.8	84.8	84.3	4.434

Table 7: Doses measured at 60kVp, 50mA using various thickness of Al filter

S/No	thickness (mm)	dose (uGy)			
		1st	2nd	Avg	In Avg.dose
1	0	172.2	82	127.1	4.845
2	1	108.5	58.6	83.55	4.425
3	1.5	118.3	129.7	124	4.82
4	2	124.5	130	127.25	4.846
5	2.5	26.7	90.4	58.55	4.07
6	3	89	41.2	65.1	4.19
7	3.5	79.4	52.7	66.05	4.201
8	4	66.4	57.1	61.75	4.123
9	5.5	39.1	37.7	38.4	3.648

From the experimental results obtained at various kVps for machines "A" and "B", graphs of ln Avg. Dose (μGy) against the thickness (mm) were plotted according to the straight line equation of doses and attenuator thickness thus

$$\ln D = \ln Do - \mu x$$

Where we define D as the attenuator doses D_o is the dose without attenuator and $\mu(mm^{-1})$ gives the linear attenuation coefficient of 3 in one of the graphs of machine A and B.

Table 8: Linear attenuation Coefficient of aluminium alloy at 80, 70 and 60kVp for machines A and B respectively as obtained from the graphs

machine A		machine B	
KVp	$\mu(mm^{-1})$	KVp	$\mu(mm^{-1})$
80	0.2174	80	0.1622
70	0.2204	70	0.2058
60	0.2419	60	0.2138

To estimate the HVL we use

$$ln\frac{1}{2} = -\mu x_{\frac{1}{2}} \qquad (2)$$

But inverting the expression, we have

$$\ln 2 = \mu x_{\frac{1}{2}}$$

Where $x_{\frac{1}{2}}$ is the HVL

$$\therefore HVL = \frac{ln2}{\mu} = \frac{0.693}{\mu} \qquad (3)$$

Using this equation we found the HVL for machine "A" at 80, 70 and 60kVp to be 3.2, 3.1 and 2.9mmAl respectively. Similarly, for machine "B", the HVL at 80, 70 and 60kVp were 4.3, 3.4, and 3.2mmAl respectively.

Table 9: HVL (mmAl) of machines "A" and "B" at 80, 70 and 60kV

KVp	HVL(mmAl)	KVp	HVL(mmAl)
80	3.2	80	4.3
70	3.1	70	3.4
60	2.9	60	3.2

In order to establish the quality of filtration of diagnostic X-ray from different tubes, the ICRU sets minimum recommended HVL at different kVp above which the filtration is said to be adequate. However, using other factors such as linear attenuation coefficient values in addition to the HVL of these machines shows that the estimated HVL values are very high i.e 2.9mmAl, 3.1mmAl and 3.2mmAl for "A" and 3.2mmAl, 3.4mmAl and 4.3mmAl for "B" and 60, 70 and 80kVp respectively. These values are extremely high compared to the minimum recommended HVL values of 1.3mmAl, 1.5mmAl and 2.3mmAl at the same kVps. The high HVL values obtained are a consequence of the aluminium alloy used. This shows that the alloy has high percentage of impurities from which the HVL values and attenuation coefficient are reflecting. More so, by using aluminium alloy of unknown percentage purity, it becomes difficult to obtain an exact result. So the only approximate bases of evaluation are the minimum recommended values in table 1.

A consequence of the high values of HVL of the two machines is that, though the danger of patient absorbed dose is highly reduced, there is a threat of low image quality (lost of contrast) (Curry et al., 1984). This shows that there is a high level of filtration in the beam. The effect of low image quality is that for complex X-ray examination which requires precise result, more or repeated exposures may be required. This act of multiple exposures is counterproductive as it renders the aim of ALARA principle abortive.

Table 10: Radiographic parameters

Hospital	kVp	mAs	FFD (cm)	Film Size (cm)	Misalignment (cm)	SID (cm)
A	60	10	100	10 x 8	0.2	84.5
B	60	25	81	10 x 8	0.6	65.5

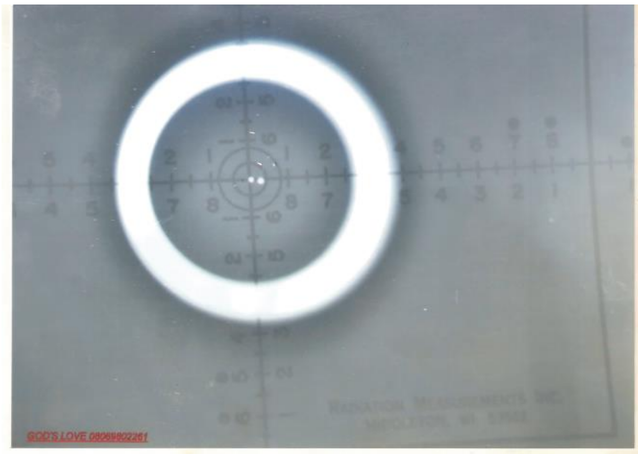

Figure 3. Exposure film (Hospital A)

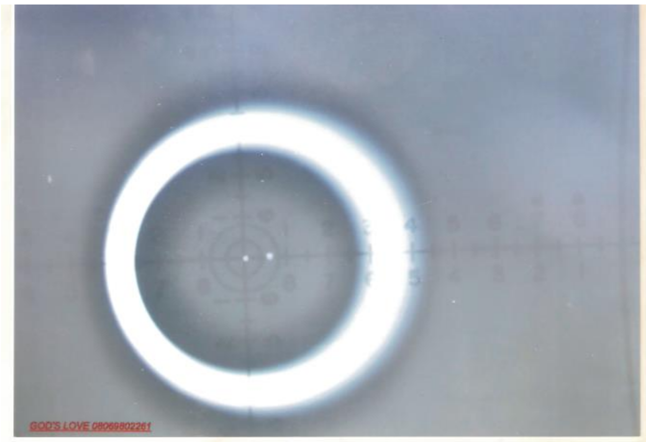

Figure 4. Exposure film (Hospital B)

During the experiment, there were various problems identified that contributed to the breakdown, malfunction and consequent poor Quality Control performance of the equipment. These problems are grouped into procurement and acceptance problems, maintenance and repair problems, and common causes of failure rate. The results obtained from this research have revealed some lapses in the quality control programme. The IPEM (Institute of Physics and Engineering in Medicine) report no. 77 recommended the following for X-ray/light beam test. The test should be carried out one to two times yearly [CRCPD, 2001 and Papp, 2011].

This research work was done at a 60kVp (peak kilovolt) with exposure time of 10mAs and 60kVp with exposure time of 25mAs. In both cases the results obtained showed a misalignment of 0.2cm and 0.6cm respectively which is still within the recommended value which is 2cm of the source to image distance.

From the results obtained even though the misalignment is within the accepted range, it was observed that the operation manuals had been misplaced or taken away by service engineers during repair visits, the manual for the machines in hospitals B was not available to get the full specifications as seen in the limited information in tables10. With regard to maintenance records, it was also noted that the equipment had no maintenance records. Repairs had been done, and users were left without any records to show what had gone wrong and what repairs had been carried out, which is risky for patients coming for X-ray examinations. It was also observed that there was no follow-up action on the Quality Control results such as making the necessary corrective maintenance. There was a problem of coordination/feedback between personnel who perform Quality Control procedure and service agents who were supposed to perform the corrective maintenance. It should be noted that Quality Control, Preventive Maintenance and repairs are integral procedures in the way complementary to radiation protection procedure.

The X-ray field area restriction plays a significant role in patients dosage (because it controls the amount of patient anatomy that is exposed to radiation) and image contrast (because an increase in the area of the field increases the production of scattered radiation) [Papp, 2011].

4. CONCLUSION

This research work demonstrates a typical method of determining the attenuation coefficient (μ) and the HVL (beam quality) from diagnostic X-ray machines. The result of this work can be use to concluded whether or not the filtration of two tubes is adequate (i.e of high beam quality) at such HVL when pure aluminium is used. However, comparing the HVL of the two tubes of which "A" has 2.9, 3.1 and 3.2mmAl and "B" has 3.2, 3.4 and 4.3mmAl at 60, 70 and 80kVp respectively shows that "A" has more stable filtration using this alloy than "B" which has high probability of low image quality due to contrast. Quality Control measures carried out in the three hospitals using beam alignment and collimator test tools, was found to be 0.2cm for hospital A, and 0.6cm for hospital B respectively. This implies that, the light-radiation field congruency were in alignment as recommended by the conference of Radiation Control Program Directors, Inc. (CRCPD), to be 2cm and acceptable by the International Commission on Radiological Protection (ICRP)

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