

Quality Estimation of Filtration of Diagnostic X-Ray at Federal Medical Centre and Bishop Murray Hospital Makurdi using Half-Value Layer (HVL)

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Abstract
Quality filtration of diagnostic X-rays in use at Federal Medical Centre and Bishop Murray Hospital Makurdi were checked using half-value layer (HVL) at 80kVp, 70kVp and 60kVp. A simple technique of determining HVL which is based on reducing the intensity of X-ray beam to half its original value using aluminium filters added at 2cm from the table and dose detected using DIAVOLT placed at 98cm from the centre of the X-ray tubes. Results were obtained from the plot of ln Dose (μGy) Versus Aluminium thickness (mm) where the slope gives the attenuation coefficient (μ). The attenuation coefficient was then used in calculating HVL using the relationship HVL=In2/μ. HVL values calculated were then compared with the minimum acceptable HVL values at the kVp setting as recommended by the international Commission on Radiological units and measurement.
Keywords: Half Value Layer, Attenuation Coefficient, X-ray, filters,Makurdi

Introduction

Diagnostic X-rays as produced in typical X-ray tubes are bremsstrahlung and as such are a distribution of spectrum of energies ranging from zero to the applied kilo voltage, which refers to the potential between the anode and the cathode of the tube. 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 Aluminium. HVL is the amount of filtration that reduces the exposure rate to one half of its initial value (Jettrey 2006). 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 (Jeffry, 2006). 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.

The minimum acceptable values of HVL as recommended by ICRU is presented in table 1

Table 1: Minimum HVL values for diagnostic X-ray units

X-ray tube voltage (Kilovolt peak)		Minimum HVL (mm of Al)	
Designed Operating Range	Measured Operating Potential	Specified Dental Systems	Other X-ray Systems
Below 50	30	1.5	0.3
	40	1.5	0.4
	49	1.5	0.5
50 to 70	50	1.5	1.2
	60	1.5	1.3
	70	1.5	1.5
Above 70	71	2.1	2.1
	80	2.3	2.3
	90	2.5	2.3
	100	2.7	2.7
	110	3.0	3.0
	120	3.2	3.2
	130	3.5	3.5
	140	3.8	3.8
	150	4.1	4.1

In modern imaging departments the HVL is considered in two important applications. The first is the HVL of the primary X-ray beam used in patient diagnosis. A second application is in the shielding of the room. This is done by shielding X-ray rooms with lead lined walls to reduce the radiation exposure to workers and the public.

Increasing the penetration ability of a radiation increases its HVL. HVL is related to, but not the same as average photon range. The difference between the two is because of the exponential characteristics of X-ray attenuation and penetration (Sprawls, 1987) The specific relationship is giving by;

HVL = 0.693 X average range

Substituting $1/\mu$ for average range gives

$$HVL = 0.693/\mu \text{ (cm or mm)}$$

This implies that HVL is inversely proportional to the attenuation coefficient.

In this part of the world, where only few have the ideas about the principle of X-ray imaging technique, but 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 of filtration of diagnostic X-ray beam in use at kilovoltage peak 80, 70 and 60, by evaluating the HVL values of these X-rays. The results of the measurement will be compared with international standards of filtration of diagnostic X-ray beam and 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.

Materials 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;

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	87.5cm
Exposure time	Not selectable	Not selectable
	(Selected by processor according to the mA imputed A.C.)	
Max kVp	125kVp	125kVp
Max mAs	6.3mAs	2.5mAs
Inherent filtration	1.5mmAl	2.5mmAl
Added filtration	5.5mmAl	5.5mmAl
Field size	Selectable	Selectable
Manufacture date	November 2008	September 2006

Other materials include the set of half value layer aluminium filter which consist of seven aluminium alloy (unknown percentage purity). This 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 mA(s) 0f 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 of 5cm 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 were in place. Using dose (μGy) and linear attenuation coefficient as in the equation $\ln\left(\frac{D}{Do}\right) = \mu x.$ graphs of ln D against x were plotted from which the slope give the attenuation coefficient. The HVL were the evaluated using the equation

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

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)

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/No	Thickness (mm)	Dose (μGy) 1st	2nd	Avg	In 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	3.0				
7	3.5	1797.0	1799.0	1798.0	7.495
8	4.0				
9	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	2^{nd}	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.

3 in 1 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

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

But inverting the expression, we have

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

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

$$\therefore HVL = \frac{ln2}{\mu} = \frac{0.693}{\mu}$$

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.

Conclusion

This research work demonstrates a typical method of determining the attenuation coefficient (μ) and the HVL (beam quality). From the result of this work it can be 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.

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