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Assessment of kVp Accuracy, Reproducibility and Consistency in diagnostic x-ray units of some selected hospitals and radiology centres in Jos and environs, Plateau state Nigeria.

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ABSTRACT

To ensure that radiation doses received by both patients and medical staff are kept as low as reasonably achievable. Quality Assurance program implementation in conventional diagnostic radiology is necessary. The exposure factors of the x-ray machine need to be checked from time to time as required by the International Commission on Radiological Protection (ICRP). In this research, assessment of the tube output variation with kVp accuracy, reproducibility and consistency in diagnostic x-ray units of some selected hospitals and radiology centres in Jos, Plateau state were carried out using Gammex digital kV meter with model number: 330. Eight hospitals x-ray units and four radiology centres were studied and the test for kVp accuracy, kVp consistency and kVp reproducibility were conducted on the x-ray machines at varied kV and mAs set on the control panel at a focus to film distance of 10m. From the results obtained, seven x-ray units (58%) had values ranging from (1.78 to 4.26) within the tolerance limit of ±5% in kVp accuracy while five x-ray units (42%) were above the tolerance limit. In kVp reproducibility eight x-ray units had values ranging from (1.52 to 9.78) within the recommended tolerance limit of ±10%, while four x-ray units were above the recommended tolerance limit with values between (- 13.30% to 15.86%) and in kVp consistency with the recommended tolerance limit ±5%, 67% of the x-ray units were all within the tolerance limit with values ranging from (-0.8 to -5.0) but 33% had values (5.3 to 18.1) of high deviations outside the tolerance limit. This show that the set value of exposure factor kV from the control console gives values within the tolerance limit for about 67% of the studied x-ray machine, meaning there is a good quality assurance programme in place most of the diagnostic x-ray units studied.

Keywords: kVp accuracy; kVp reproducibility; kVp consistency; X-ray machine; tolerance limit; radiation dose;

Introduction

Radiation protection culture is important in our diagnostic radiology units for optimization of radiation safety of both patients and staff. The implementation of quality assurance is a well needed effort in the achievement of radiation protection culture.

In Nigeria, X-ray has remained the most frequently used ionizing radiation in medicine despite advances in magnetic resonance imaging and ultrasound techniques. It has maintained a key role in diagnosis of diseases, injury and in X-ray therapy (Oluwafisoye et al, 2010). In effect it is the largest man-made source of ionizing radiation to the world population (ICRP, 1991, UNSCEAR, 1993). The level of compliance with the regulatory control and radiation protection if poor will constitute in unpredictable high and low tube output voltage and beam misalignment. Which will lead to over or under exposure, poor image quality, poor diagnosis and even retakes as the case may be.

The World Health Organization (WHO) defines a quality assurance (QA) programme in diagnostic radiology as an organized effort by the staff operating a facility to ensure that the diagnostic images produced are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation (WHO, 1982). Quality assurance therefore means the planned and systematic actions that provide adequate confidence that a diagnostic x-ray facility will produce consistently high quality images with minimum exposure of the patients and healing arts personnel. It is also an essential step in the implementation of Radiation Protection Culture (RPC).

Methodology and techniques used

The Gammex digital kV meter with model number: 330 kV was placed on a radiographic table on top of a grid and positioned at the centre of the beam axis with a focus field distance (FFD) of 100cm; the light field was collimated and centered to fall on the kV meter placed on a grid to reduce scattered radiation. In the first procedure for kVp accuracy, mAs value was kept constant and kVp values were changed to investigate the set kV value from the measured kV value. In the second procedure for kVp reproducibility, kVp value was kept constant and mAs values were changed to investigate the dose variation with mAs and in the third procedure for kVp consistency, a constant value for kV and mAs was used for chest x-ray for a normal body size which varied for each unit studied. The test was then done at constant mAs but gradually increasing tube potential (kV) set on the control console of the x-ray machine for kVp accuracy, for kVp reproducibility at constant tube potential and gradually increasing mAs and for kVp consistency it was determined at a constant mAs and tube potential (kV). In each case readings were recorded and tabulated for each x-ray machines. The reading obtained was used to determine the percentage error for kVp accuracy, kVp reproducibility and kVp consistency using the equations (1),(2) and(3). Graph of dose output (dose/mAs) was plotted against $(kVp)^2$ to determine the linearity.

$$\text{kVp accuracy} = \frac{kVp_{measured-kVp_{set}}}{kVp_{set}} x100\% \quad (1)$$

$$\text{kVp reproducibility} = \frac{kVp_{measured-kVp_{set}}}{kVp_{measured}+kVp_{set}} x100\% \quad (2)$$

$$\text{kVp consistency} = \frac{kVp_{measured-kVp_{set}}}{+kVp_{set}} x100\% \quad (3)$$

RESULTS

Table 1: The kVp accuracy for M1

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	% error
50	30	68.0	185.4	802.4	18.54	2500	23.40
60	30	71.0	394.2	810.1	39.42	3600	8.30
70	30	80.9	534.6	813.8	53.46	4900	7.29
80	30	84.9	693.0	803.9	69.30	6400	-0.88
90	30	96.7	815.0	803.3	81.50	8100	1.11

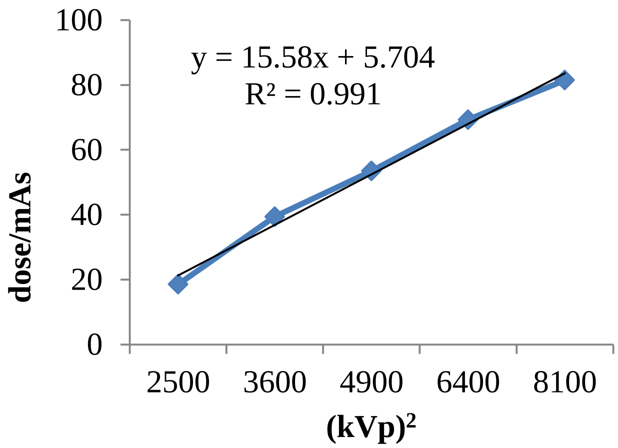

Figure 1: A graph of Dose output against $(kVp)^2$ for M1

Table 2: The kVp accuracy for M2

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error
50	10	42.8	197.5	74.6	19.45	2500	-14.4
60	10	54.1	375.6	74.6	37.56	3600	-9.8
70	10	63.5	543.2	74.6	54.32	4900	-9.3
80	10	73.1	713.4	74.6	71.34	6400	-8.6
90	10	83.1	876.3	74.6	87.63	8100	-7.7

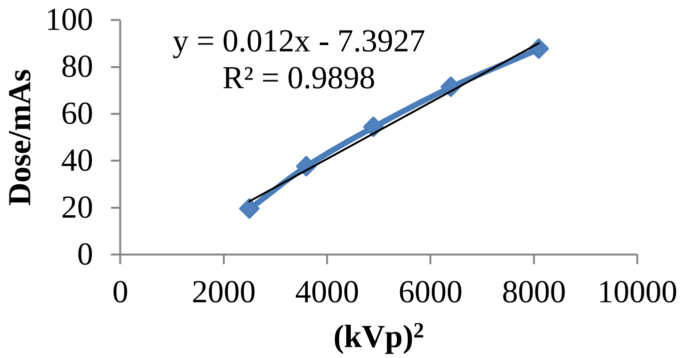

Figure 2: A graph of Dose output against $(kVp)^2$ for M2

Table 3: The tube potential or kVp accuracy for M3

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	% error
50	10.0	51.2	173.5	20.0	17.35	2500	2.6
60	10.0	61.4	279.6	20.3	27.96	3600	2.3
70	10.0	72.3	398.6	20.3	39.86	4900	3.3
81	10.0	85.4	346.5	20.6	34.65	6561	5.4
90	10.0	91.9	681.1	20.6	68.11	8100	2.1

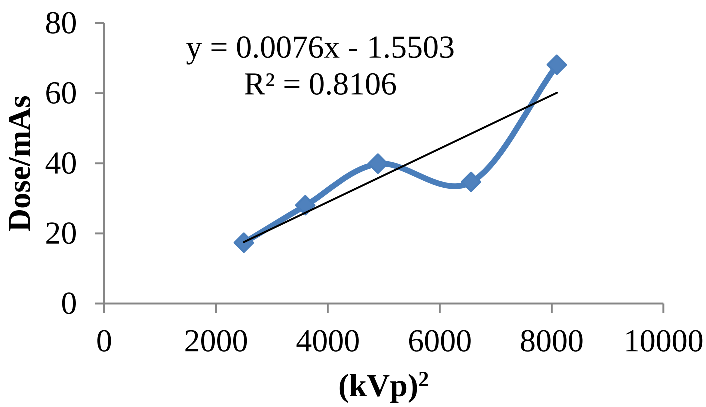

Figure 3: A graph of Dose output against $(kVp)^2$ for M3

Table 4: The kVp accuracy for H4

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error
50	10.0	50.9	119.8	532.4	11.98	2500	1.8
60	10.0	62.0	187.9	533.6	18.79	3600	3.3
70	10.0	70.9	274.1	533.6	27.41	4900	1.3
80	10.0	83.7	338.2	534.5	33.82	6400	4.6
90	10.0	92.0	453.5	549.0	45.35	8100	2.2

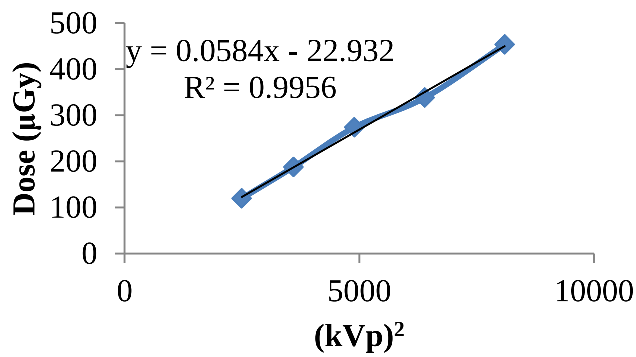

Figure 4: A graph of dose output against $(kVp)^2$ for M4

Table 5: The tube potential or kVp accuracy for M5

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error
50	4.0	52.6	168.0	259.6	42.0	2500	5.2
60	4.0	61.4	281.2	259.3	70.3	3600	2.3
70	4.0	72.3	312.0	259.3	78.0	4900	3.2
80	4.0	80.4	533.3	259.0	133.3	6400	0.5
90	4.0	89.7	657.4	259.0	164.4	8100	-0.3

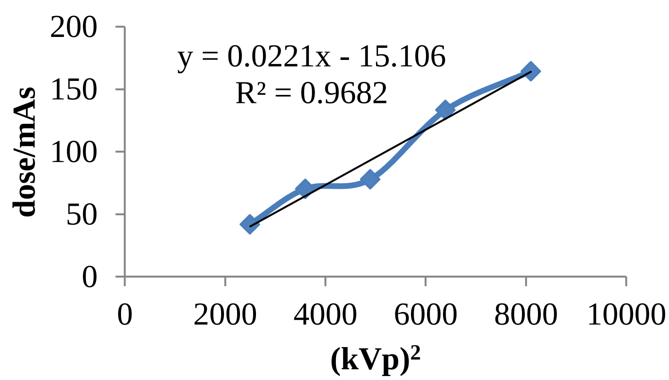

Figure 5: A graph of dose/mAs against $(kVp)^2$ for M5

Table 6: the kVp accuracy for M6

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error

60	24.0	59.6	67.6	723.1	2.82	3600	-0.7
65	24.0	52.0	46.4	721.3	1.93	4225	-20
70	24.0	50.4	42.7	714.2	2.16	4900	-28
80	24.0	55.2	56.5	737.0	1.78	6400	-31
85	24.0	57.7	62.2	723.8	2.26	7225	-32.1

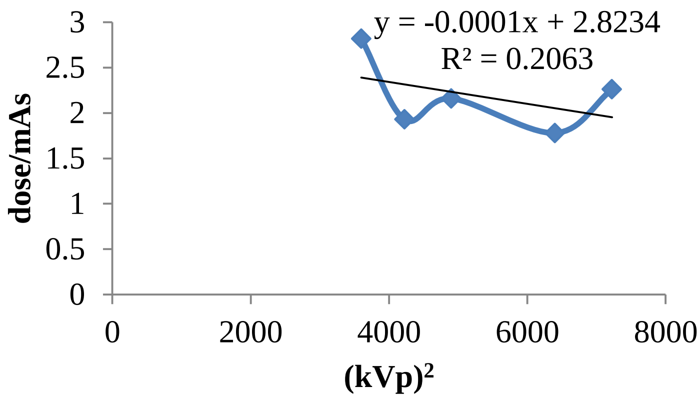

Figure 6: A graph of dose/mAs against $(kVp)^2$ for M6

Table 7: The kVp accuracy for M7

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error
50	10.0	72.9	592.0	273.2	59.20	2500	45.8
60	10.0	85.9	387.1	586.4	38.71	3600	43.2
72	10.0	100.9	540.5	592.3	54.05	5184	40.1
83	10.0	116.0	614.5	595.7	61.45	6889	39.6
91	10.0	124.3	760.4	599.3	76.04	8281	36.6

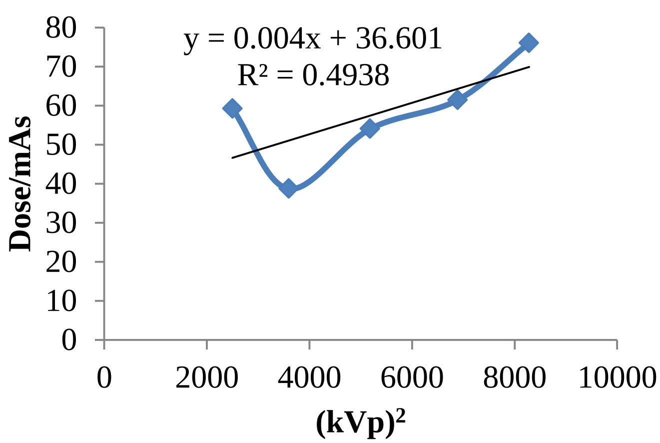

Figure 7: A graph of dose/mAs against $(kVp)^2$ for M7

Table 8: The kVp accuracy for M8

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error
56	12.0	44.7	43.7	100.5	3.641	3136	-20.2
60	12.0	46.4	48.5	100.5	4.042	3600	-22.7
66	12.0	57.6	113.7	139.8	9.475	4356	-12.7
74	12.0	59.8	109.7	101.1	9.142	5476	-19.2
80	12.0	79.0	275.5	141.0	22.958	6400	-1.3

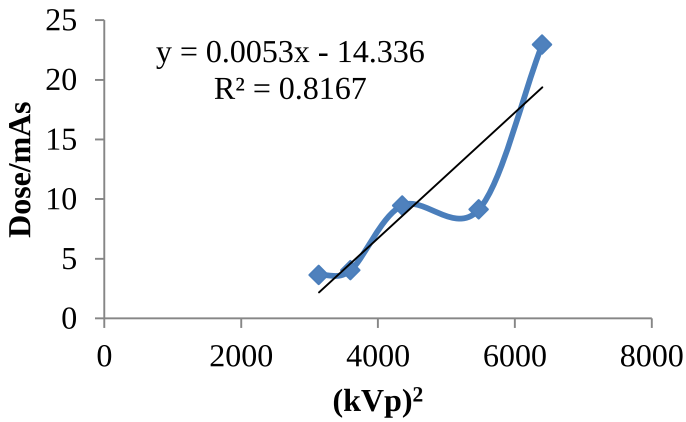

Figure 8: A graph of dose/mAs against $(kVp)^2$ for M8

Table 9: The kVp accuracy for H9

Set kVp	mAs	Measured kVp	Dose (µGy)	ms	Dose/mAs	$(kVp)^2$	%error
50	10,0	50.6	115.0	51.8	11.50	2500	1.2
60	10.0	62.8	196.0	96.2	19.60	3600	4.7
70	10.0	71.2	292.1	154.5	29.21	4900	1.7
80	10.0	83.3	482.1	183.4	48.10	6400	4.1
90	10.0	90.3	513.4	217.6	51.34	8100	0.3

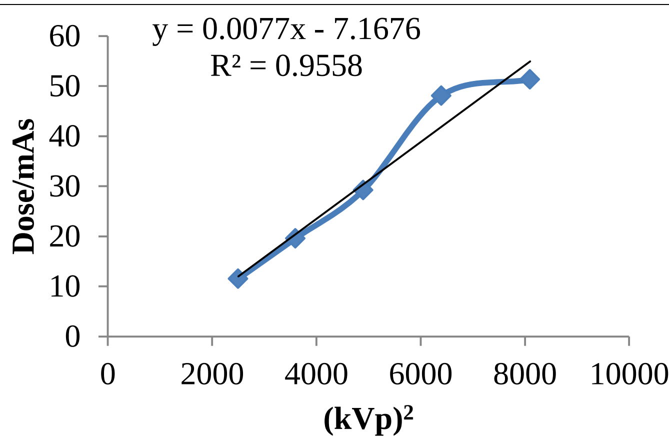

Figure 9: A graph of dose/mAs against $(kVp)^2$ for M9

Table 10: The kVp accuracy for M10

Set kVp	mAs	Measured kVp	Dose (μGy)	ms	Dose/mAs	$(kVp)^2$	%error
50	7.10	48.4	112.0	20.9	15.78	2500	-3.2
60	7.10	64.9	254.2	17.2	35.80	3600	8.2
70	7.10	75.6	342.3	21.5	48.21	4900	8.0
81	7.10	80.5	417.7	25.8	58.83	6561	0.6
90	7.10	91.2	497.3	27.8	70.04	8100	1.3

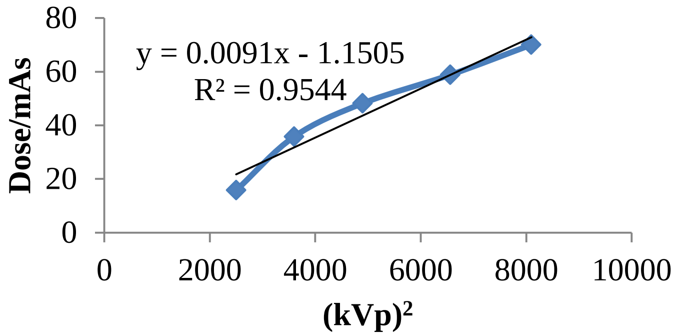

Figure 10: A graph of dose/mAs against $(kVp)^2$ for M10

Table 11: The kVp accuracy for M11

Set kVp	mAs	Measured kVp	Dose (μGy)	ms	Dose/ mAs	$(kVp)^2$	%error
50	10.0	50.2	164.6	20.1	16.46	2500	0.4
60	10.0	60.8	328.0	28.0	32.80	3600	1.3
70	10.0	70.9	438.1	34.0	43.81	4900	1.3
81	10.0	83.9	596.9	36.5	59.69	6561	3.6
90	10.0	92.3	741.3	39.6	74.13	8100	2.3

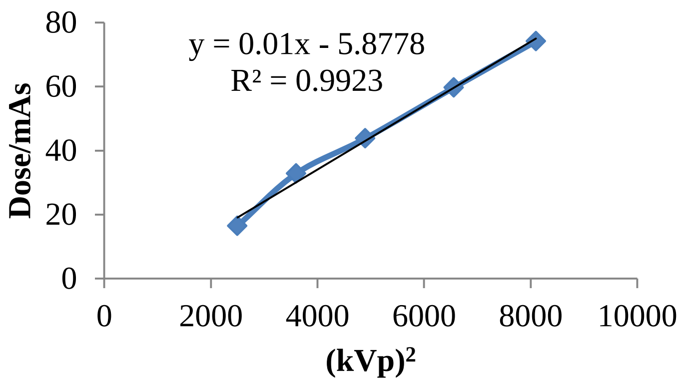

Figure 11: A graph of dose/mAs against $(kVp)^2$ for M11

Table 12: The kVp accuracy for M12

Set kVp	mAs	Measured kVp	Dose (μGy)	ms	Dose/mAs	$(kVp)^2$	%error

50	10.0	48.9	166.1	26.7	16.61	2500	-3.0
60	10.0	59.7	294.7	35.0	29.47	3600	-0.5
70	10.0	68.6	439.1	73.1	43.91	4900	-2.0
80	10.0	78.5	562.2	83.9	56.22	6400	-1.9
90	10.0	89.0	726.4	353.9	72.64	8100	-1.1

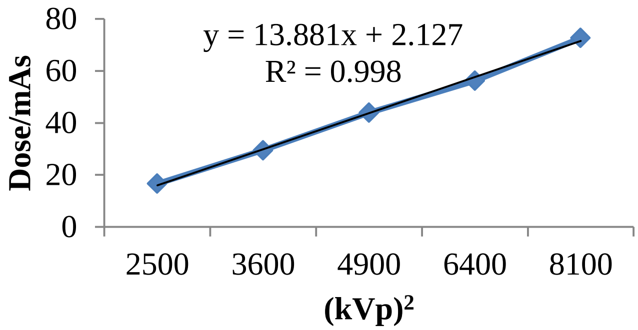

Figure 12: A graph of dose/mAs against $(kVp)^2$ for M12

Table 13: Comparison of %error ± 5% variation in kVp accuracy for M1- M12

Machines/Readings	1	2	3	4	5	Average	±5%
M1	36.0	18.0	15.6	6.1	7.4	16.62	Fail
M2	-14.4	-9.8	--9.3	-8.6	-7.7	9.96	Fail
M3	2.6	2.3	3.3	5.4	2.1	3.14	Pass
M4	1.8	3.3	1.3	4.6	2.2	2.64	Pass
M5	5.2	2.3	3.2	0.5	-0.3	2.30	Pass
M6	-0.7	-20.0	-28.0	-31.0	-32.1	22.36	Fail
M7	45.8	43.2	40.1	39.6	36.6	41.06	Fail
M8	-20.2	-22.7	-12.7	-19.2	-1.3	15.22	Fail
M9	1.2	4.7	1.7	4.1	0.3	2.40	Pass
M10	-3.2	8.2	8.0	0.6	1.3	4.26	Pass
M11	0.4	1.3	1.3	3.6	2.3	1.78	Pass
M12	-3.4	-0.5	-2.0	-1.9	-1.1	1.78	Pass

Table 14: Summary and comparison of %error ± 10% for variation in kVp reproducibility for M1 – M12

Machines/Readings	1	2	3	4	5	Average	±10%
M1	-2.9	1.4	15.6	21.3	38.1	15.86	Fail
M2	-9.9	-10.4	-9.9	-9.4	-9.3	9.78	Pass
M3	5.3	5.6	5.6	5.6	5.7	5.56	Pass
M4	1.5	2.0	1.8	3.9	3.3	2.50	Pass
M5	1.0	1.6	1.6	1.9	1.5	1.52	Pass
M6	-29.7	-30.0	-9.7	-9.7	-13.5	18.52	Fail
M7	18	19.5	18.8	19	19	18.86	Fail

M8	-23.1	-12.6	-6.3	6.6	17.9	13.3	Fail
M9	3.0	2.0	3.9	4.9	2.9	3.34	Pass
M10	4.6	1.3	3.5	4.5	4.9	3.76	Pass
M11	4.4	4.3	4.2	1.5	4.3	3.74	Pass
M12	1.5	-0.8	-3.1	-3.1	-2.4	2.18	Pass

Table 15: Summary and comparison for variation in kVp consistency ± 5%for M1 –M12

Machines/Readings	**1**	**2**	**3**	**average**	**±5%**
M1	5.1	6.8	8.0	5.6	Fail
M2	-5.0	-5.0	-5.1	5.0	Pass
M3	1.7	1.7	1.5	1.6	Pass
M4	1.4	2.4	2.3	2.0	Pass
M5	0.7	0.8	0.8	0.8	Pass
M6	-5.3	-5.1	-5.6	5.3	Fail
M7	9.0	8.7	8.7	8.8	Fail
M8	9.7	10.1	10.1	10.1	Fail
M9	1.7	1.7	1.7	1.7	Pass
M10	1.5	1.7	1.5	1.6	Pass
M11	1.9	1.8	1.9	1.9	Pass
M12	-1.6	-0.8	-0.9	1.1	Pass

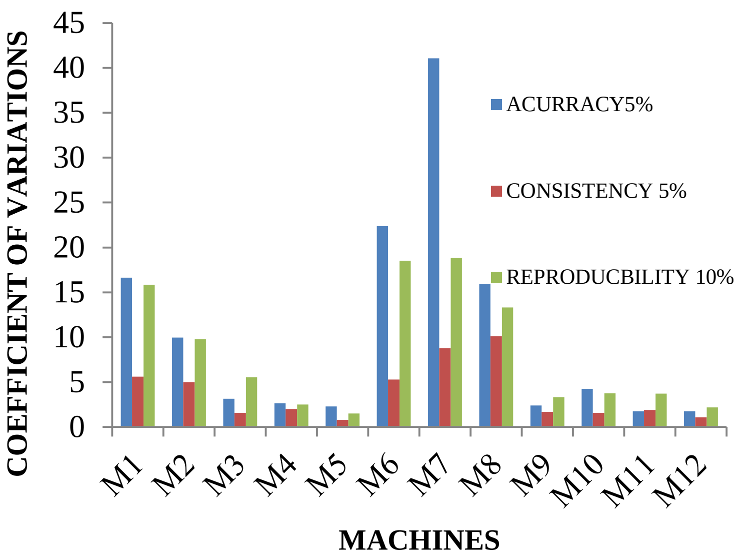

Figure 13: A bar chart of coefficient of variations against machines

DISCUSSION

Tube Potential Accuracy

Accuracy of the kV settings ascertains that the kV selection at the control console results in the same kV applied across the x-ray tube. From the values collected on twelve x-ray machines Tables 1-12 shown above and Table 13 on summary and comparison of % error of kVp accuracy. The variation of tube output with kVp was calculated using equation (1). Seven x-ray units was found to be within acceptable limit while five x-ray units fell short of the acceptable limit of ±5%.The magnitude of deviation(% error) in kVp accuracy varied from hospital to hospital, ranging from 1.78 to 41.06. The reason for this high deviation in kVp values may be as a result of the age of the x-ray machine, variation in x-ray generator not being set correctly upon installation or poor maintenance and as a result of excessive power line voltage drop (Mallam et al; 2004). It is advised that this test be formed upon acceptance and after a major system repair then annually (IAEA & Rehani, 1996, 1995). It is important the kV setting function properly as it determines the X-ray beam quality, image contrast and has implications on the patient dose (WHO, 1982).

Graphs of tube specific dose output intensity (dose/mAs) for each exposure was plotted against the corresponding $(kVp)^2$ as shown in Figures 1-12. For each graph the linearity function (μGy/mAs) = F $(kVp)^2$ was gotten and the regression square value (R^2). The R^2 values for almost all the machines showed a good linearity and correlation, that any significant increase in the specific dose output intensity will also increase the kVp. The poor linearity relationship between the output and kV recorded on figures 6 and 7 may be as a result of drift from calibrated values on the x-ray machine in the units due to faulty setting on the control console or voltage fluctuation from the power source.

Tube Output Reproducibility with kVp

kVp reproducibility was calculated from the values recorded during the test at a constant kV and sequential increasing mAs using the equation (2) (Papp , 2011) from Table 14 and Figure13. It was found that eight x-ray units have values ranging from 2.4% to 9.3% within recommended tolerance limit of ±10% while four have values ranging 13.5% to 38.1% above the recommended tolerance limit. The variation in the output could be attributed to the waveform, anode material, filtration, and tube age and anode surface damage (Oluwafisoye et al 2010). Readings which fall below the relevant diagnostic reference level (DRL) will produce exposures that either do not provide useful diagnostic information or do not yield the expected medical benefit to patients. This implies that, the voltage of the generator type is fluctuating. It is evident therefore that areas that require little or low radiation exposure were over exposed while areas that required high radiation receives low exposure or under exposed (Godfrey, L. D., Adeyemo, D. J., & Sadiq, U., 2015).

Tube Output Consistency

The results shown on Table 15 for x-ray tube output consistency recorded at a constant kV and mAs in each case for all the twelve x-ray units and calculated from equation (3). It was found that eight x-ray machines were within the acceptable tolerance limit of ± 5% with values ranging from(0.8% to 5.0%).While the remaining four x- ray machines M1, M6, M7 and M8 were above tolerance limit. This means that the set value of kVp does not give an output which is adequate but produces higher or lower kVp and hence affect the exposure dose of the patients and the image quality and as such creating more risk for both the patient and the staff.

Conclusion and Recommendations

Quality assessment of tube output variation with kVp accuracy, reproducibility and consistency of the twelve studied x-ray units showed that there is need for regular and effective implementation of quality assurance programs on x-ray machines for quality image and good diagnostic to be achieved. Hence, x-ray units with high tolerance limit need immediate attention from the respective authorities to ensure repairs and replacement are done were necessary to reduce over exposure of both patients and staff to radiation.

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