IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 17, Issue 10 Ver. 4 (October. 2018), PP 44-47
www.iosrjournals.org

Compliance of Some Quality Control Parameters of Diagnostic X-ray Equipment in Three Selected Tertiary Hospitals in South East, Nigeria to a known standard.

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Abstract
Introduction: *Periodic monitoring of X-ray equipment quality control parameters is very important to ensure precision and accuracy of radiographic tests.*
Aim: *The aim of this study is to assess the compliance of some quality control (QC) parameters of some conventional X-ray equipment to a known standard.*
Settings and Design*: Setting was in Nigeria and a cross sectional design was used.*
Method and Material*: Material used was a non-invasive digital multifunctional detector meter (MDM). Three facilities were selected from a university teaching hospital. Measurement of KVp, mAs and the exposure time accuracy was performed using MDM that incorporates computer output. The MDM was positioned at the center of the collimated beam axis with a Source to Image Distance (SID) of one meter. Eight different mAs, exposure times and KVp stations were selected and measured in each teaching hospital.*
Statistical Analysis: *SPSS was used and statistical tools used was one way ANOVA*
The result *obtained showed that the magnitude of deviation in KVp accuracy ranged from 0.01 to 6.07 % in all the four machines checked while the magnitude of deviation in mAs accuracy ranged from 0.00 to 19.20 %. In a similar way, exposure time accuracy deviated from 0.01 to 12.32 %.*
Conclusion: *The study revealed that only one out of the four X-ray units at the teaching hospital in the Southern-Eastern part of Nigeria failed exposure time, mAs and KVp accuracy compliance test.*
Keywords*: Quality control, Compliance, X-ray, Standard and measurement.*

Date of Submission: 01-10-2018 Date of acceptance: 15-10-2018

I. Introduction

Assessment of x-ray equipment QC parameters is an important practice that ensures high image quality with minimal radiation dose to both patients and personnel. According to America College of Radiology (ACR), QC of x-ray equipment is a periodic monitoring of aspects of precision or accuracy of the test [1]. QC of x-ray equipment plays important role in ensuring optimal radiographic density, check electrical and mechanical safety of equipment, minimize occupational and medical dose, ensure consistency and reduces cost. Some common malfunctions found in x-ray equipment are metal pitting in the anode (rough anode surface), x-ray tube with vacuum leak which shows spikes in tube current (mA) and decrease penetration [1], metallization due to electrical arcing in the tube and thinner filament due to overheating of filament. These malfunctions causes decrease in x-ray output. However, periodic assessment of x-ray equipment could help to detect these common malfunctions in equipment on time. On this note, QC of equipment should be carried out regularly to ensure consistency in equipment operation.

The peak potential difference (KVp), exposure time, tube current, automatic exposure control (AEC) , half value layer (HVL) and product of exposure time and tube current (mAs) are some of the QC parameters carried out in x-ray generator. Light field - x-ray field alignment, x-ray beam- bucky alignment, and focal spot size are also QC parameters carried out on x-ray tube and collimators. KVp and mAs are parameters used to characterized x-ray tube output. In diagnostic radiology, KVp accuracy and exposure time are necessary because both affects image contrast and radiation dose to patient [6].

The national and international regulatory bodies are responsible for the regulation of nuclear safety and radiation protection and ensuring that radiological practices conform to recommendation. For instance in Nigeria, the Nigeria Nuclear Regulatory Authority (NNRA) was established by the Nuclear Safety and radiation act of 1995. The NNRA is responsible to categorize and license activity involving exposure to ionizing radiation protection in particular, the possession, production, purchase, sale, import, export, storage, transport, disposal, manufacture, handling, transformation, use, trading, transfer and disposal of any radioactive material, nuclear material, radioactive waste and any equipment emitting ionizing radiation [2]. Other international commissions that are responsible for regulations of radiation safety are National commission on Radiological protection and measurement (NCRP), International Commission on Radiological Protection (ICRP) and American Association of physicist in medicine (AAPM).

Though, some researcher have carried out a study in area of QC practices in some part of Nigeria and beyond [2; 3; 4; 5] but none has paid attention to the compliance of quality control of x-ray equipment parameters in south east part of Nigeria. Some QC performed on equipment parameters in South-west, North-east, North-central parts of Nigeria showed some variance of non-compliance to recommendation [7]. These present studies were conducted to check the compliance of

KVp, mAs and exposure time parameters in conventional x-ray equipment of three selected tertiary Hospital to Known standard in south-east geopolitical zone. Known standard used in this study was AAPM recommendations [9; 10].

II. Material and method

The design was cross sectional study. Ethical approval was obtained from Nnamdi Azikiwe University Teaching Hospital ethics committee (NAUTH/CS/66/VOL.9/21) and written permission from all the centers undertakes the study. Convenient sampling method was used to select the three teaching hospitals. Additional two radiographers with more than three years experience were recruited in each hospital. Measurements of x-ray QC parameters were carried out between May and June 2018 in a three university teaching hospitals (UTHs) coded A, B and C.

Center A had two similar x-ray machines with two diagnostic rooms (room 1 and room 2). Both x-ray machines were manufactured in 2008 and installed in 2012. The specification of the x-ray machines studied at different centers was shown in [table 1]. In all the centers, x-ray equipment operational manuals were not available at the time of this study. The data for machines specification were obtained from the body of the x-ray tube and control panel. More so, only center A uses computer radiography (CR) processing. Center B and center C uses manual processing.

The KVp, exposure time and mAs were measured using non-invasive factory calibrated multifunctional radiation detector meter (piraham 500), manufactured in Sweden. Detector meter has curved marks on the body surface that shows the radiosensitive portion. This multifunctional detector meter has the capability to measure the selected KVp, exposure time and mAs and display the results with the help of computer connected to it at the same time.

The procedures were carried out by placing detector meter in the x-ray beam with SID of one meter along the central ray. Caution was taken in orienting the digital detector device to the beam and collimated light beam was positioned to the marked area of the detector to avoid systematic error, shown in figure 1. KVp, mA and exposure time were selected and recorded. Exposure was made on the detector using the selected factors and a digital number for the measured KVp, mA and exposure time in seconds were recorded and documented. Three different measurements were carried out on each KVp, exposure time and mAs station. The mean value and magnitude of deviation (E) in percentage were calculated on each station.

Table [1] showed X-ray machines specification of all the centers studied.

Parameters	Centers		
	A	B	C
Machine Type	Static	Static	Static
Manufacturer	General Electric (GE)	Stephania Radiological Solution	Siemens
Year of Manufacture	2008	2005	2005
Year of Installation	2012	2006	2010
Country of Manufacture	Germany	France	Germany
Inherent filter	1.5mmAl	2mmAl	Not available
Max mA	630	500	500
Max KVp	150	150	133

All the QC parameters selected were within the diagnostic range. For instance the KVp selected were from 40:10:110 using a variety of mA and exposure time setting. The magnitude of deviation (E) in percentage was calculated using formula in equation (1) adopted from [5]:-

$$E = \text{Abs}\left(\frac{M-s}{s}\right) \text{x}100\% \quad \ldots (1)$$

where Abs means absolute value, M is the average measured value of the parameter from the detector meter, s is the selected or set value of the parameter from the control panel. The data obtained were analyzed with the aid of the Statistical Package for the Social Sciences (SPSS) version 22.0. The significance level was set at 0.05.

III. Results

The results of the three selected UTHs were presented in tables. The measurement of the KVp accuracy of the three centers A, B and C was shown in [table 2]. The result presented indicated that measured KVp is within standard limit of 5 % of the selected KVp for center A room 1, B and C [9]. However, for center A room 2, the variance in KVp selected is higher than the recommended limit from 60 to 80 KVp. The result of the mAs presented in [table 3] showed that half of the mAs measured in center A room 2 and center C were above recommended limit of 5% of selected mAs [9]. However, center A room 1 and center B were within the recommended limit.

Some of the time accuracy of center A room 2 were above standard limit of 5% of the selected time. Although, in center A, room 1 and center B, the time accuracy are within the standard limit shown in [table 4]. However, there was no time selector for center C. The control panel of the x-ray machine in center C was configured without time selector. As a result, it is difficult to select time and measure.

Table [2]: KVp accuracy measurements for centers A, B and C

Center A, room 1			**Center A, room 2**		
Selected KVp	Average Measured KVp. (n=3)	Error (%)	Selected KVp	Average Measured KVp. (n=3)	Error (%)
40	40.56	1.40	40	38.21	4.48
50	50.02	0.04	50	48.20	3.60
60	60.60	1.00	60	63.55	5.92
70	70.70	0.10	70	73.56	5.09

80	80.94	1.18	80	84.87	6.09
90	91.35	1.50	90	94.45	4.94
100	101.43	1.43	100	104.62	4.62
110	110.06	0.05	110	112.35	2.14
Center B			**Center C**		
Selected KVp	Average Measured KVp. (n=3)	Error (%)	Selected KVp	Average Measured KVp. (n=3)	Error (%)
40	38.68	3.30	40	39.21	1.98
50	48.20	3.60	50	50.10	0.20
60	57.64	3.93	60	59.93	0.12
70	67.89	3.01	70	70.07	0.10
80	78.17	2.29	80	80.62	0.78
90	88.32	1.87	90	90.55	0.61
100	98.13	1.87	100	102.80	2.80
110	109.11	0.81	110	112.96	2.69

Table 3: Measurement of mAs accuracy in centers A, B and C

Center A, room 1			**Center A, room 2**		
Selected mAs	Average Measured mAs (n= 3)	Error (%)	Selected mAs	Average Measured mAs (n= 3)	Error (%)
10	10.18	1.80	10	11.93	19.30
16	16.13	0.81	16	18.05	12.81
20	20.00	0.00	20	23.84	19.20
25	24.92	0.32	25	28.03	12.12
51	49.30	3.33	51	50.02	1.92
64	63.88	0.19	64	66.90	4.53
100	99.89	0.11	100	103.97	3.97
110	112.01	1.82	110	112.18	1.98
Center B			**Center C**		
Selected mAs	Average Measured mAs (n= 3)	Error (%)	Selected mAs	Average Measured mAs (n=3)	Error (%)
10	9.91	0.90	10	10.44	4.40
16	15.86	0.88	16	16.64	4.00
20	20.75	3.75	20	22.30	11.50
25	25.21	0.84	25	26.16	4.64
51	51.68	1.33	51	54.60	7.05
64.	65.16	1.81	64	69.01	7.82
100	101.00	1.00	100	106.22	6.22
110	110.66	0.60	110	114.22	3.84

IV. Discussion

The primary aim of any radiological unit is to improve on image quality with minimal dose to patient and personnel considering economic and social factors. Quality control test are one of routing procedures performed on equipment to ensure optimal performance of the x-ray machine. Regular implementation of QC in diagnostic radiology is essential to identify non-compliance, which can both affect image quality and cause unnecessary dose to patients [8; 9]. The aim of this study is to determine the status of some QC parameters of conventional x-ray equipment and compare their result to known standards for compliance.

The KVp measurement for center A room 1, center B and center C showed compliance with standard recommendations while center A room 2 failed compliance test at 60, 70 and 80 KVp stations showed in [table 2]. The magnitude of deviation ranged from 2.14% to 6.07%. The reason for deviation could be due to the line voltage supply, age of the machine [2], personnel usage of the machine, work load or recent repair on the equipment. The results presented in this study agree with a similar study conducted by Akpochafor [5] who revealed that one-fourth of the total KVp accuracy failed to meet the standard limit. Also, in another research by Mehrdad [11] KVp measured; revealed some level of non-compliance at some KVp stations.

It was observed that slight elevated value of KVp from the actual selected KVp could affect both medical and occupational dose and image quality [12]. The energy of the x-ray is determined by the selected KVp. According to Oluwafisioye [13], the European commission recommended using high voltage technique which probably results in low doses, but the radiologist prefer low KVp that will result in higher contrast image quality.

Table [4]: shows measurement of exposure time (T) accuracy in centers A, B and C.

Center A, room 1			**Center A, room 2**		
Selected T (ms)	Average Measured T (ms) (n= 3)	Error (%)	Selected T (ms)	Average Measured T (ms) (n= 3)	Error (%)
100	99.0	1.00	100	98.0	2.00
249	242.0	2.81	249	240.0	3.61
1000	998.0	0.20	1000	920.0	8.00
1250	1220.0	2.40	1250	1096.0	12.32
1600	1530.0	4.38	1600	1185.0	25.93
2000	1920.0	4.00	2000	1825.0	8.75
2500	2420.0	3.20	2500	2360.0	5.60
3200	3100.0	3.13	3200	3020.0	5.63
Center B			Center C		
Selected T (ms)	Average Measured T (ms) (n= 3)	Error (%)	Selected T (ms)	Average Measured T (ms)	Error (%)
100	101.0	1.00	X		

249	240.0	3.61	X		
1000	966.0	3.40	X		
1250	1270.0	1.60	X		
1600	1659.0	3.69	X		
2000	1980.0	1.00	X		
2500	2498.0	0.08	X		
3200	3150.0	1.56	X		

X = not available.

In room 2 of center A, the magnitude of deviation in mAs ranged from 1.92% to 19.3% while in center C the magnitude of deviation in mAs ranged from 3.84% to 11.5% above the selected mAs showed in [table 3]. Deviation in the mAs may be due to the metallization in the x-ray tube or supply from the line voltage. The measurements of mAs in room 1 of center A and center B were within the standard limit of 5% of the selected mAs. Furthermore, one way Analysis of variance (ANOVA) was performed to ascertain the extent of variation between the groups. The result showed that there was no statistically significant difference between the groups ($P > 0.05$).

More so, an accurate exposure time is necessary for proper image quality at low patient dose [13]. The exposure time accuracy of x-ray equipment also influences mAs selector [14]. However, in the present study the result obtained shows that all time accuracy measurements were within recommended limit in center B and room1 of center A. But in room 2 of center A, the result deviated from the recommended limit in some of the measured exposure time [table 4]. The magnitude of deviation in exposure time of room 2 in center A ranged from 3.03% to 12.32%. This could be attributed to poor maintenance since installation. In a research carried out by Nzotta and Akhigbe [7], it was revealed that the values obtained from the various equipment settings showed a significant time variance of 1.25 % and kVp variance of 32.5%. In fact, regular QC on x-ray equipment will help to detect equipment fault early on time and effective corrective action will help to reduce the variance level. One way ANOVA performed shows that there was statistically significant difference between the groups KVp and exposure time measured ($F= 518.4$, $P= 0.001$) and ($F=12.131$, $P= 0.008$) respectively. Post Hoc indicated that significant difference in KVp was in center A room 2, center B and center C. Also, Post Hoc on exposure time indicated that significant difference was in center A room 1 and center A room 2.

V. Conclusion

Compliance of x-ray equipment parameters to known standard limits were checked to ensure minimal radiation dose to patients and personnel at three selected teaching hospitals. The results showed that only one out of the four x-ray machines studied failed exposure time, mAs accuracy and KVp accuracy compliance tests. However, only mAs of two x-ray machines out of four machines complied with the standard limits. The failure of some x-ray QC parameters may be due to poor maintenance of the equipment and line voltage supply. The ANOVA performed shows that there was no statistically significant difference between the groups of mAs measured. However, there was statistically significant difference between the groups of KVp measured ($P < 0.001$) and exposure time ($P < 0.008$).

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