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Assessment of Diagnostic X-ray Facilities in Calabar, Nigeria: A Comparative Study with International Standards and NNRA Regulations

Luntsi Kenneth Danbaba
Department of Physics, Nigerian Defense Academy Kaduna, Nigeria
luntsiken@gmail.com

Samuel Okon Inyang
Department of Physics, University of Calabar, Calabar Nigeria
inyangso@unical.edu.ng

Andebutop Sule
Department of Physics, University of Calabar, Calabar, Nigeria
suleandebutop@gmail.com

Bassey Eyo Archibong
Department of Radiography and Radiological Sciences, University of Calabar, Calabar, Nigeria

ABSTRACT

X-ray imaging and diagnosis over the years has emerged an indispensable tool in medicine which offers rapid accessible insights into various medical conditions thereby enabling effective diagnosis, treatment and patient care across different healthcare settings. However, unregulated and indiscriminate use of X-radiation, non-compliance to regulations governing the use of ionizing radiation in diagnosis and absence of regular Quality Control (QC) measurements and Quality Assurance (QA) programs could jeopardize the safety of staff, patients and the general public by exposing them to radiation hazards. This study aimed at evaluating the adherence of diagnostic X-ray facilities in Calabar, Nigeria to international recommendations, focusing on QC measurements and QA programs. A systematic survey was conducted across multiple X-ray facilities in Calabar to gather data on their equipment, operational practices and data compliance protocols. Simultaneously, QC measurements were carried out to assess the performance and calibration of the X-ray machines.

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The findings revealed varying levels of compliance with international recommendations among the surveyed facilities. While some demonstrated commendable adherence to quality control protocols, others exhibited shortcomings in maintaining standards. Through the QC measurements conducted, specific areas of improvement were identified, highlighting the need for enhanced calibration procedures, consistent adherence to safety standards and ongoing training for personnel to ensure optimal performance and patient safety. This study underscores the importance of regular assessments and compliance with international standards in diagnostic X-ray facilities to guarantee accurate diagnoses, minimize radiation exposure and prioritize patient care. Recommendations are proposed to aid facilities in elevating their standards and promoting a safer diagnostic environment in Calabar, Nigeria.

Keywords: X-rays, ionizing radiation, Quality Control (QC), Quality Assurance (QA).

1. INTRODUCTION

X-ray diagnosis and imaging departments play a vital role in provision of quality healthcare through providing quality diagnosis of diverse diseases and (or) disorders (Ofori *et al.,* 2013). Since its discovery, the application of X-ray in diagnosis has recorded significant increase (about 5% per year according to Osibote & de Avedo (2008). However, according to the WHO (2023), Mammba *et al*., (2022) and the United Nations Scientific Committee on the Effects of Atomic Radiation (2008) inspite of the extensive usage and importance of X-rays in diagnosis, radiological examinations contribute the most to all man-made sources of public exposures to ionizing radiations worldwide. In the United Kingdom alone, about 90% of radiation exposures to the public from all sources is due to medical X-ray except for natural background radiations (Schandorf & Tetteh, 1998). Recent reports by Parkin and Darby (2011) places this figure at about 15%.

Medical use of X-rays for diagnosis and treatments is proven to be of immense benefit to man. However, unregulated use of X-rays can be very hazardous. It is required that proper care is exercised throughout the lifecycle of equipment used in a diagnostic center. This cycle entails the manufacture, supply and installation, use, maintenance, servicing among others (ISO, 2015). A typical diagnostic X-ray facility is made up of the infrastructure, the layout, the equipment (X-ray equipment) and staffing. The safety of staff, patients and the general public rests on the design and shielding of X-ray imaging rooms or radiation generation rooms (Nkubli, et al., 2017). Therefore, a well-designed X-ray imaging facility which takes into considering design such as shielding and spacing will help minimize radiation exposures and consequently, reduce the risk factor significantly (Ganapathy *et al*., 2012).

The Nigerian Nuclear Regulatory Authority (NNRA) provides the framework for handling of radiation-generating equipment (X-ray), policy making, regulation, and monitoring for nuclear and radiological protection (Idowu & Okedere, 2020). The Nigerian Radiation Safety in Diagnostic and Interventional Radiology Regulations (Nigeria basic ionizing radiation regulations, 2006) mandates all manufacturers, suppliers, and users of X-ray equipment to obtain license/authorization and approval before commencement of operations. These covers structural (layout and shielding) requirement, staffing qualification/certification, maintenance (preventive and corrective) and dose limits to mention but a few. In a bid to ensuring safety, it is also required that a qualified expert in radiological physics (Medical Physicist) measure all data required for clinical use before commissioning.

The benefits derived from the application of ionizing radiation (X-rays) in diagnosis, when properly performed is relatively small when compared to the risk associated with it (Ogbole & Obed , 2014). These risks usually include, but are not limited to radiations doses being higher than the internationally recommended average, unqualified staff operating X-ray facilities, and also lack of radiation protection equipment and program Inyang *et al*., 2015; Ofori *et al*., 2013). Thus, the need for Quality Control (QC) and Quality Assurance (QA) programs, such as regular patient dose measurement, film reject analysis (FRA), image quality assessment, to form part of the X-ray imaging activities, etc. to ensure patient radiation safety (Hamid *et al*., 2013). However, according to Eze and Adams (2017) "there are almost no measures of routine maintenance check and recalibration after servicing to ensure optimal equipment performance in Nigeria. According to Inyang *et al*., (2010), the lack of clearly outlined and routinely applied QA programs and machine servicing practices may also be responsible for the frequent radiological equipment breakdown and malfunction experienced in Nigeria as a whole.

Hassan *et al*., *(*2011) covered a study on the quality assurance of diagnostic X-ray machines and assessment of the absorbed dose to patients and found out that the quality of an X-ray beam depends on high voltage across the machine, the thickness and the nature of the total filtration, and the properties of the target. The difference in doses due to the applied voltage (kVp) was found to range from 2.66 to 3.8. Therefore, it was recommended that recalibration should be repeated at regular intervals to establish dose levels applicable to current radiological practice that influence received patient doses. The compound and expanded uncertainties accompanying these measurements are 4 ± 0.35% and 8 ± 0.7%, respectively.

Dabukke *et al.,* (2018) carried out research on Quality Control Parameters of Illumination, Collimation, and Half Value Layer on X-Ray General Radiography and Mobile Radiography, in which the results of the illumination test on general and mobile radiography passed the test because the results of illumination test were ≥ 100 Lux using the Lux meter. Testing the quality of X-ray beam (HVL) produced by general radiography and mobile radiography, variation of tube voltage of 70 kV, 80 kV, and 20mAs were made, and results showed that the quality of beam resulting from either of the two was dependent on the sizes of the inherent filter. They added that the smaller the size of the filter, the lower the beam quality, and consequently the lower the image quality produced.

Inyang *et al.,* (2010) in their study recommended all medical exposures be prescribed by a qualified medical practitioner to ensure a regulation of the amount of exposures at various diagnostic centers. Studies by Idowu and Okedere (2020) puts the number of X-ray machines in Nigeria at about five thousand (5000). It becomes necessary to evaluate the present level of compliance to laid-down rules of NNRA and report on their status and also recommend possible ways of enhancing the implementation of quality assurance programs, quality control and radiation safety.

This study is aimed at evaluating the status of diagnostic X-ray facilities in Calabar, Nigeria, and to ascertain their compliance with the regulations set up by the Nigerian Nuclear Regulatory Authority (NNRA) for the practice of diagnostic and interventional radiography by analyzing quality control tests such as beam alignment, kV accuracy test, time accuracy test, and leakage test.

2. MATERIALS AND METHODS

Questionnaire

A twenty-two (22) item, three (3) sectioned questionnaire was administered on fifty (50) radiation workers from the understudied facilities. Information such as class of radiation workers/qualification and equipment obtainable in these centers consisted section one (1), compliance to the Nuclear Safety Act of the Nigerian Radiation Safety in Diagnostic and Interventional Radiology such as administration requirement and safety policy were interrogated in the second section, while availability and frequency of various QC tests constituted the third section.

The items in the questionnaire were adapted from the NNRA's application for Authorization document. The questionnaire was tested for validity by administering to five experienced radiation workers in Radiology. Thereafter, their suggestions and comments were considered in the production of the final questionnaire. It was then administered to radiation workers present in radiology facilities visited in Calabar. The facilities were both government owned and privately owned which included University of Calabar Teaching Hospital (UCTH), General Hospital, Ash premium diagnostics, psychiatric hospital and others.

The participants were first informed of the significance of the study and why their participation was necessary. They were made to endorse a consent form before completing the questionnaire and taking part in the study. In addition, they were assured that the study was not meant for regulatory assessment and enforcement.

QC Measurement

All QC measurements were done using the non-invasive X-ray meter from PTW Inc. of Germany with model number 330. The meter was factory calibrated with accuracy of $\pm 5\%$.

Exposure Reproducibility

A lead apron was placed on the radiographic tabletop with the center of the lead apron at the center of the tabletop, and the dosimeter placed on top of the lead apron. The lead apron was meant to absorb backscatter radiation from the tabletop material, which reduces the accuracy of readings obtained. The central ray from the X-ray tube was centered on the dosimeter using a Source to image Distance (SID) of 100 cm. The beam was collimated such that the X-ray field was slightly larger than the dosimeter.

Five separate exposures on the dosimeter were made at 80 kVp and 10 mAs with the dosimeter reset to zero after each exposure. With the readings obtained, the equation below was used to determine the reproducibility variance.

$$Reproducibility\ Variance = \frac{(mR_{max} - mR_{min})}{(mR_{max} + mR_{min})} \qquad \dots\dots\dots\dots(1)$$

Where mR_{max} the maximum amount of the milliroentgens and mR_{min} is the minimum amount of milliroentgens (Jeffrey, 2014).

Beam Quality

During beam quality test, there was a direct comparison between the original installation value and future values. Just like the exposure reproducibility test, the dosimeter was placed on the radiographic tabletop on top of the lead apron with SID of 100cm as recommended by AAPM74. Exposures were made at 30 kVp and 10 mAs. The radiation measurement from the dosimeter was recorded and the procedure repeated for 15 mAs, 20 mAs, 25 mAs and 30 mAs. Readings from the dosimeter were taken on each exposure and fitted into the equation below to determine the percentage deviation (Jeffrey 2014).

$$percentage\ {}^{mR}/_{mAs}\ Variation = \frac{\left({}^{mR}/_{mAs_{max}} - {}^{mR}/_{mAs_{min}}\right)}{{}^{mR}/_{mAs_{max}}} \times 100 \quad \ldots\ldots\ldots\ldots (2)$$

KVp Accuracy

The penetrating power of the X-ray beam is determined by the appropriate kVp during X-ray production. kVp accuracy test is the one used to measure the precision of peak electric potential across the X-ray tube (Suleiman *et al.,* 2020; Shepard *et al.,* 2002). The stated kVp on the control panel is expected to produce an X-ray beam with a comparable and consistent amount of energy to the measured kVp (the measured kVp appears on the dosimeter when exposures are made). The dosimeter was placed on the radiographic tabletop on a lead apron. Exposures were made at SID of 100 cm, 20 mAs, and 30 kVp, and readings recorded. The dosimeter was reset to zero, and further readings were taken, maintaining the same technical factors but at 40 kVp, 50 kVp, 60 kVp, 70 kVp, and 80 kVp. The values from the dosimeter and that selected from the control panel were compared to determine kVp accuracy.

3. RESULTS

Based on the information obtained from the questionnaire, fifty (50) respondents consisting of thirty-five (35) radiographers, eight (8) technicians, five (5) radiologist, and two (2) Radiation Safety Officer (RSO) took part in the survey. This does not reflect the total number of radiation workers in the facilities visited but a few that were available and accessible for the study while some declined to take part in the study.

Results shows that the class of radiation workers available in diagnostic centers within Calabar, Nigeria include radiologists, radiographers, technicians and RSOs. However, one out of the centers visited indicated the presence of a medical physicist as part of the team of radiation workers. In compliance with NNRA requirements, 40% (2) of the visited centers were licensed by NNRA, while 60% (3) were not registered. 95% (48) of the respondents affirmed that patients were exposed only when accompanied with referral notes. 60% representing thirty (30) respondents, admitted to their centers not having a working safety committee and safety program, while 40%, twenty (20) affirmed the presence of a working safety program and a safety committee which meet on yearly bases to ensure that the risk associated with radiation is reduced to its barest minimum. 80% (40) of the respondents indicated that their centers had no operational manual with details on safety systems, while 20% (10) had one.

Quality Control (QC)

About 26 % (13) of the respondents indicated the presence of quality control in their centers, which is led by radiologists, while 74 % (37) had no provision for periodic QC tests in their centers. The frequencies at which the different QC tests are being carried out is shown in Table 1, indicated as Not at all (NA), Daily (D), Monthly (M), Quarterly (Q), Bi-annually (B) or Annually (A).

Between twenty-one (21) to thirty-seven (37) respondents indicated that beam alignment, table/gantry tilt, and noise tests was not performed at all, while thirteen (13) indicated that these tests are been performed bi-annually in their respective centers (Figure 1). Also, sixteen (16) respondents recorded that beam alignment test was done on a yearly bases and four (4) indicated a daily test of table/gantry tilt. 26%, 34%, 10% and 30% of respondents indicated that patient radiation dose was not evaluated at all, was evaluated daily, quarterly, and bi-annually, respectively. The radiation safety evaluation was not done at all in 60 % (3) centers, while it was done bi-annually in 40 % (2) of centers visited, as indicated by the respondents (Figure 2). 24 % of the respondents indicated that time and kV accuracy tests was not done at all while 44% and 32% was carried out on a daily basis and bi-annually, respectively (Figure 3). About 40% of the respondents further confirmed that cassette screen film contact tests (Figure 4) was not done in their centers at all while 26% indicated that it was done on a daily basis, 8% on a monthly and bi-annually basis while 18% on a quarterly basis.

Quality control tests concerning room dimension and staff training/retraining were not done at all in the centers, as indicated by 84% and 54% of the respondents, respectively. Although 6% recorded that room dimension test were carried out on daily and biannually basis while 26 and 20% of the respondents recorded biannual and yearly staff training/retraining in their various centers respectively.

Table 1. Quality Control (QC) test and frequency measurements.

S/N	QC Test	FREQUENCY							
		Not at all	Daily	Weekly	Monthly	Quarterly	Bi-Annually	Yearly	Total
1	Beam alignment test	21	0	0	0	0	13	16	50
2	Table/Gantry Tilt	33	4	0	0	0	13	0	50
3	Noise	37	0	0	0	0	13	0	50
4	Patient Radiation Dose	13	17	0	0	5	15	0	50
5	Radiation Safety Evaluation	20	0	0	0	10	20	0	50
6	Scattered radiation Measurement	25	0	0	0	5	13	7	50

7	Time Accuracy	22	15	0	0	0	13	0	50
8	kV Accuracy Test	22	16	0	0	0	12	0	50
9	Cassette screen film contact test	20	13	0	4	9	4	0	50
10	Room dimensions	42	3	0	0	2	3	0	50
11	Staff training and retraining	27	0	0	0	0	13	10	50

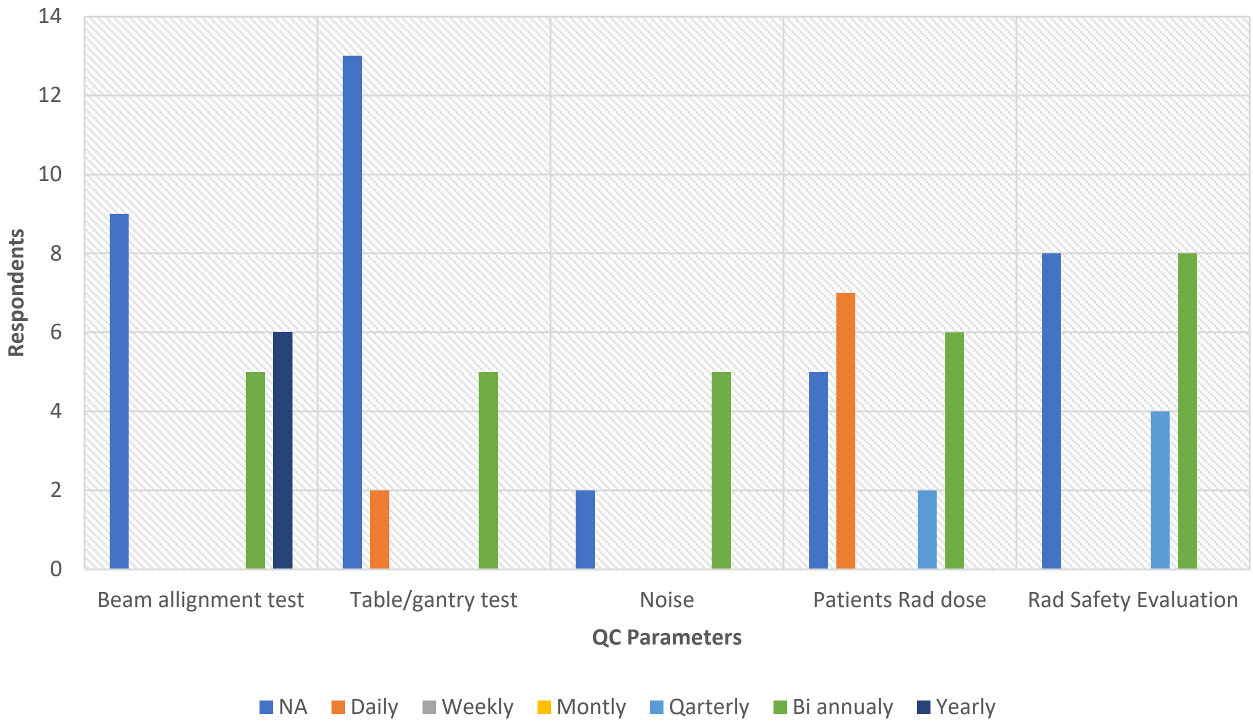

Figure 1. Rating of QC parameters by correspondents.

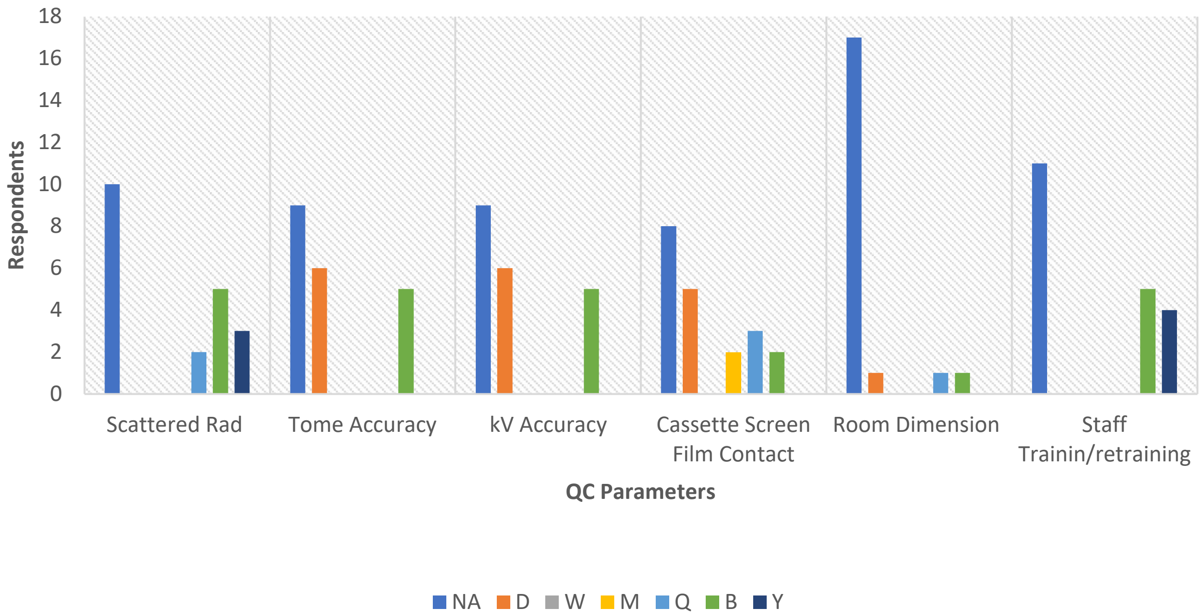

Figure 2. Rating of QC parameters by correspondents.

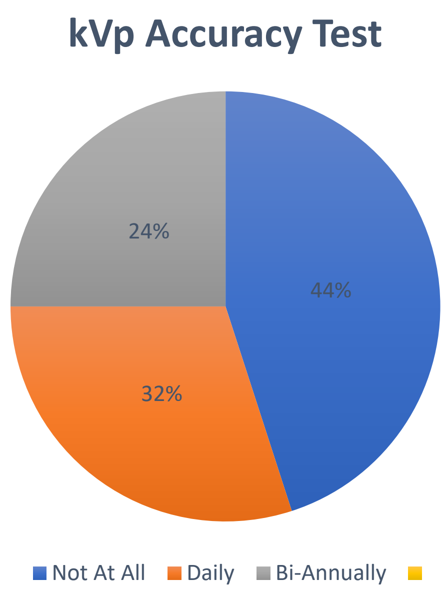

Figure 3. Time and kVp accuracy test.

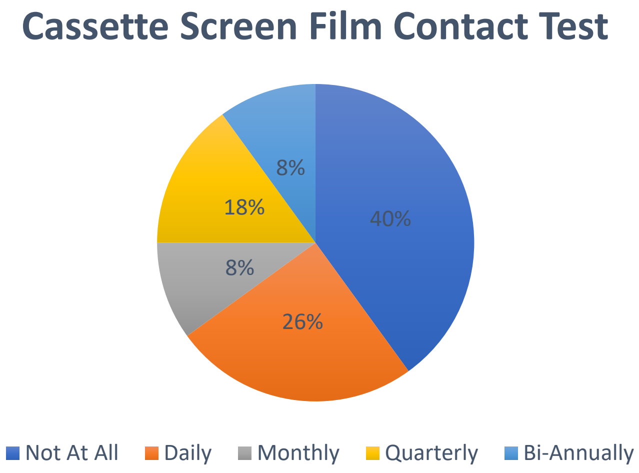

Figure 4. Cassette screen film contact test.

4. DISCUSSION

The majority of the tests carried out had about 25% to 85% (5-17) of the respondents accepting that they should be conducted daily, as indicated in Table 1. Support by respondents for the conduct of QC tests on weekly, monthly, quarterly, biannually or yearly basis was weak (0 to 16 respondents). From the results, 33(65%), 17(35%) of the respondents indicated that quality control programs are being led by radiologists and radiographers, respectively, and not medical physicists due to the absence of such staff in their facilities. This however, is not unexpected, as radiologists, followed by radiographers, have been long regarded in the country as the major professionals and drivers of all aspects of diagnostic and interventional radiology, but at variance with the recommendations of the American Association of Physicists in Medicine (AAPM) that the responsibility of establishing a QC program is clearly out of the domain of the radiology technologist (radiographer) into that of the medical physicist, who is expected to develop and supervise a quantitative QA program (AAPM, 2002)

About 35 (70%) respondents confirmed the absence of an organized quality control program in their facilities thus operating without a regular check on QC parameters as recommended by NNRA until breakdown of the X-ray machines or when major faults are recorded. This, however, poses a risk of irradiation to the patients, which could be easily dealt with when regular QC programs are available in these centers.

The observed results in this study shows that only two (2) out of the five (5) facilities visited were licensed by NNRA. This however, is contrary to the regulation as stated in the NNRA authorization for practice which states that any person who intends to utilize radiation sources in radiology shall notify his intention to the authority and apply for authorization in the form of a license (Nigerian Radiation Safety in Diagnostic and Interventional Radiology, 2006).

The QC measurements conducted during the research revealed that the reproducibility variance was at ±0.86%, beam quality (percentage dose/mAs variation) was at ±0.22% and those for kVp accuracy showed a very large variation of about 19% at a nominal kVp of 60kVp, and 4.71%, 1.36%, 1.33% and 2.90% for 70, 80, 90 and 100kVp nominal kVp values, respectively.

The frequencies of measurement of the different QC parameters presented in Table 1 was not in line with the recommendations of the American Association of Physicist in Medicine (AAPM, 2002) which states that most of the QC parameters do not require daily measurements, while some are expected to be tested annually and some semi-annually or quarterly while a few should be tested daily.

5. CONCLUSION

The compliance of most radiology facilities in Calabar, Cross River State, Nigeria, to the regulations and requirements of the NNRA and the level of implementation of QC program and safety measures in the different radiology facilities visited in this study was poor, as most of the facilities visited did not have a safety program setup by the management or a QC program in place, with no medical physicist to develop and implement the required programs as suggested by AAPM. Furthermore, the selected QC tests conducted during this study revealed that both reproducibility and beam quality tests were within acceptable standards, while kVp test showed a variation at lower nominal kVp values which was far above the acceptable limit by about 9% while at higher nominal kVp values of 70 and above, it was found to be within the acceptable range of kVp values as set by AAPM. Based on the findings of this study, it is suspected that other diagnostic facilities within Calabar that were not captured in this study, and in other states of Nigeria, may be operating similar to the ones captured in this study.

Hence, it is suggested that this study be carried out in other States of Nigeria to determine if the situation is similar to that observed in Calabar. Also, due process for accreditation and licensing should be followed before facilities are setup, medical physicists added to the list of radiation worker and proper QC programs be setup in the radiological facilities to be supervised by the medical physicist to ensure safety of both radiation workers and patients.

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