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Research paper

Qualitative and Quantitative Dosimetric Evaluation of Diagnostic Radiology in Selected Health Institutions and Hospitals in Delta State: Implications of Patients' Exposure to Radiations and Actualization of Health Care Delivery Targets in Delta State.

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This study provides a qualitative and quantitative dosimetric evaluation of diagnostic radiology practices in selected health institutions and hospitals in Delta State, Nigeria. The research investigates the implications of patient radiation exposure and its effects on healthcare delivery targets. A cross-sectional survey design was used, encompassing 15 hospitals across the state's senatorial districts. Radiology quality control tests and dose profiles were analyzed to assess equipment performance, exposure parameters, and patient doses. Significant variability in image quality was observed. Dental X-rays at one hospital (Hospital C) demonstrated excellent quality, with sharp tooth detail. Conversely, abdomen X-rays at another hospital (Hospital D) showed poor contrast (below standard), making it difficult to distinguish organs and potentially hindering accurate diagnoses. While most hospitals appeared to follow the ALARA principle (as low as reasonably achievable), the potential for further optimization was identified. Abdomen X-ray doses (e.g., Hospital D: 3.2 mGy) suggested room for improvement, particularly when compared to dental X-ray doses (e.g., Hospital C: 0.1 mGy) which fell within recommended limits. Notably, some hospitals had equipment with service dates exceeding four years (e.g., Hospital B: last maintenance June 2017), raising concerns about reliability and potential impact on patient safety and image quality. The findings highlight significant variability in radiology practices, equipment conditions, and maintenance schedules. The study underscores the importance of optimizing radiological procedures to enhance patient safety, reduce radiation exposure, and achieve healthcare delivery targets effectively

Keywords: Dosimetry; Diagnostic Radiology; Patient Radiation Exposure; Quality Assurance; Healthcare Delivery; Delta State Nigeria

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INTRODUCTION

In most countries, several initiatives have been implemented in order to regulate the use of the ionizing radiation with the best image quality, lowest doses and a reduced cost to the department. The most efficient initiative is the implementation of Quality Assurance Programme (QAP). The World Health Organization (WHO) has defined Quality Assurance in x-ray medical diagnosis as “an organized effort by the staff operating a facility to insure that the diagnostic images produced by the facilities are of sufficient high quality so that they consistently provide adequate diagnostic information at the lowest possible The quality assurance and control (QA/QC) system had not measured up with international standards yet. This practice has been so due to many factors including the non-availability of qualified personnel such as medical physicists, to man diagnostic facilities. The QA/QC is done through Regulatory inspections that are undertaken annually by the Radiation Protection Institute to conduct safety assessment for the issuance of authorizations. Some of the safety assessment includes detailed inventory of X-ray equipment, availability of skilled and trained operators, adequacy of personal monitoring, health status and structural shielding adequacy with respect to actual practice, usage of personal protective devices for staff and comforters, and usage of radiation protection devices for patients. All these parameters that are related to radiation protection needs to be verified and checked. The proposed research seeks to evaluate and examine qualitative and quantitative dosimetric evaluation of diagnostic radiology in selected health institutions and hospitals in Delta state. It seeks to investigates the implications of the patterns of patients’ exposure to radiations and its attendant effects on actualization of health care delivery targets in Delta state in particular and Nigeria in general. In Nigeria, the ratio of physician to patient in the healthcare is still far from the recommendations of the World Health Organization (WHO) on the required number of medical personnel to cater efficiently for its teeming population (Ukawuilulu &Odo, 2019). This study will therefore assess doses delivered to adult patients and also perform Quality Control evaluation and test on the available x-ray equipment in the selected health care institutions.

Effects of Ionizing Radiation

X – rays have a shorter wavelength than visible light and can penetrate body tissues. When a certain part of the body is x- rayed, dense tissues, such as bones, absorb the rays and appear as bright areas on the developed film, called a radiograph. Soft tissues appear in shades of gray. X–rays are commonly used to diagnose problems or disease involving teeth, bones, breast, and the chest. Nowadays, x – ray radiographs are often digitized and viewed on a computer screen (Turner, 2005

Patient Exposures in Radiology

Medical ionizing radiation sources provide by far the largest contribution to the population dose from artificial sources and most of this contribution comes from diagnostic x rays (above 90%)(Regulla & Eder, 2005). One of the reasons for this situation is the large number of X- ray examinations performed every year. A report by the United Nations Scientific Committee on the Effects of Atomic Radiation estimates that the annual number of all types of medical X ray examination undertaken in the world was about 2100 million in 2000, corresponding to an annual frequency of 360 examinations per 1000 individuals worldwide. This frequency is about 10% higher than the previous estimate of 330 per 1000 for the period 1991–1995 indicating an increase in practice. However, further growth in medical radiology can be expected in developing countries where facilities and services are often lacking).

Interaction Processes

In the context of photon dosimetry, the four most important interaction processes of photon in matter are photoelectric absorption, Compton scattering, Rayleigh elastic scattering process and pair production Photoelectric interactions are dominant at low energies and pair production at high energy greater than 1.022MeV with Compton scattering being most important in the mid-energy range. Other interaction processes are coherent scattering, (also known as Bragg or Rayleigh scattering) which becomes increasingly important at low energies less than 50keV, and photonuclear reactions at high energies greater than 7MeV.

Coherent scattering involves a re-emission of the gamma ray after absorption with unchanged energy but different direction. The interaction of photons within the source of x – rays and between the source and the detector leads to an attenuation and modification of the original spectral fluence rate (Smirnov, 2011).

The attenuation of monoenergetic photons along a path of length r through a uniform material is described by an exponential function

$$I = I_0 e^{-\mu \tau} \text{-------------}(1)$$

Where I is the number of photons transmitted without change of the original energy; Io is the linear attenuation coefficient having the dimension of a number of original photons and reciprocal length (e.g. cm^{-1}).

An attenuation coefficient is a measure of the reduction in the photon intensity at a particular energy caused by an absorber, the human body. The attenuation coefficient is greater for materials with a higher atomic number. Hence bone is a more satisfactory absorber material for photons than soft tissues. It is different from the absorption coefficient which is related to the amount of energy retained by the absorber as the photon radiation passes through it. The mass attenuation coefficient □/□(dimension, e.g., cm2/g) is independent of the density □, of the material and is therefore preferred for the description of the attenuation. The coefficient □ includes coherent scattering in which only the photon direction but not its energy is changed.

Radiation protection methods

There are three basic methods to keep the radiation dose in the patients, workers and the public as low as reasonably achievable. They are namely, minimization of the time of exposure, maximization of the distance to the radiation source, and use of appropriate shielding material to protect against the scatter radiation (e.g., lead Pb and aluminum Al). These three steps help to achieve the so-called ALARA Principle, which stands for ‘As Low As Reasonably Achievable (James, 2006)

Implications of Patients' Exposure to Radiation

Epidemiological studies have shown a significant increase in cancer risk for individuals exposed to radiation at doses above 100 mSv, such as survivors of atomic bombings or radiotherapy patients. Recent studies have also suggested that cancer risk may increase even at lower doses, between 50-100 mSv. Children and adolescents are more sensitive to radiation exposure compared to adults. Therefore, the risk of developing radiation-related health issues may be higher for this population.

There is a lack of epidemiological data to support the validity of the linear no threshold model for low-dose exposures (less than 10 mSv). This makes it challenging for healthcare providers to accurately quantify the risks associated with typical medical imaging procedures.

Reducing Unnecessary Exposure

Radiation protection aims to minimize unnecessary radiation exposure and reduce the harmful effects of ionizing radiation. Healthcare professionals should carefully consider the risks and benefits of each test or procedure that involves radiation. Patients can also research and choose imaging facilities that monitor and use techniques to reduce radiation doses (Hricak*et al*., 2011).

Healthcare providers need to carefully balance the risks and benefits of medical imaging procedures that involve radiation. This ensures that patients receive necessary diagnostic or therapeutic interventions while minimizing potential harm from radiation exposure. Implementing strategies to track radiation doses and monitor exposure can help healthcare providers ensure that patients receive appropriate and safe levels of radiation during medical procedures. This can contribute to the overall quality assurance of health care delivery (Frush *et al*., 2014).

METHODOLOGY

Study Design

This research was conducted using a cross-sectional survey design to evaluate radiology quality control tests and dose profiles across different hospitals in Delta State, Nigeria. The study was performed in five hospitals located within each of the three senatorial districts in the state, making a total of fifteen hospitals. The objective was to analyze the radiology practices, equipment used, exposure parameters, and patient doses to create a comprehensive profile of radiological practices in the region.

Radiology quality control tests were carried out in each of the fifteen hospitals. These tests included evaluations of equipment performance, calibration, and maintenance schedules. The specific parameters assessed were:

1) Image quality consistency
2) Equipment calibration accuracy
3) Maintenance and servicing records
4) Compliance with regulatory standards
5) Dose Profile Assessment

Dose profiles were created by investigating and analyzing the range of exposure parameters based on patient characteristics. Data were collected on:

1. Patient demographics (age, gender, weight, height)
2. Type of radiographic examination (chest, pelvis, abdomen)
3. Exposure parameters (kVp, mAs, exposure time)
4. Dose measurements (entrance surface dose, organ doses)

Dosimeters, including state-of-the-art badge dosimeters, were used to measure the radiation doses received by patients. These measurements were recorded for each individual examination to ensure accuracy and reliability. A comprehensive inventory of the radiology technology available in each hospital was documented. This included: Type of radiographic equipment (analog or digital); Age and conditions of the equipment; Availability of advanced imaging technologies and Frequency of equipment use and types of examinations performed

Data Analysis

The collected data were analyzed to determine the average radiation doses for common radiographic procedures and to assess the variation in dose across different hospitals. The analysis involved: Statistical analysis of dose measurements to identify trends and outliers; Comparison of dose profiles with international reference levels and evaluation of image quality in relation to patient doses

RESULTS AND DISCUSSIONS

Table 1: Radiography Equipment Characteristics

Hospital Name	Senatorial District	X-Ray Machine Manufacturer	Machine Model	Screen Type	Film Speed	Service History (Last Maintenance Date)	Quality Control Test Results (Pass/Fail)
Hospital A	South-South	Brand X	Model 123	Fluoroscopy	400	18th March 2020	Pass
Hospital B	South-South	Brand Y	Model 456	General Radiography	200	18th June 2017	Fail
Hospital C	Delta Central	Brand Z	Model 789	Dental	100	09 March 2018	Pass
Hospital D	Delta Central	Brand X	Model 123 (different from A)	General Radiography	400	14thFebruary 2019	Pass
Hospital E	Delta North	Brand Y	Model 456 (different from B)	Fluoroscopy	200	03August 2021	pass

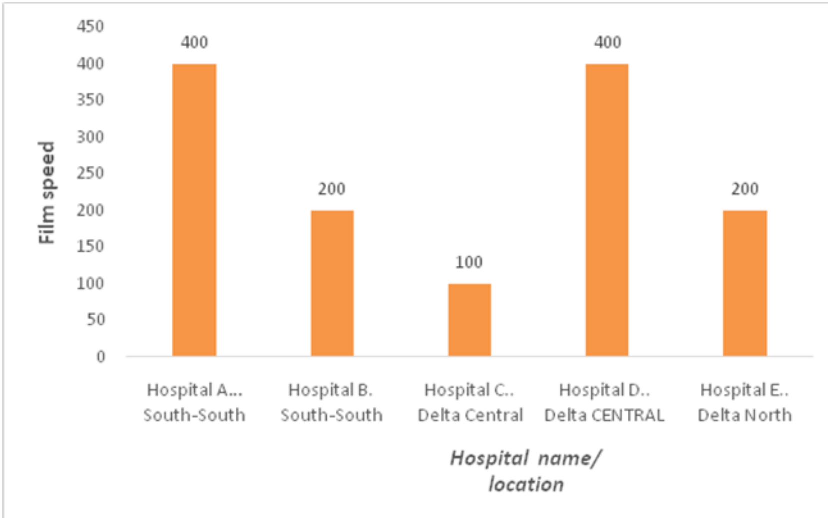

Figure 1: reported average film speed of Radiography Equipment

Table 2: Image Quality Assessment

Hospital Name	Examination Type	Image Contrast	Image Detail	Overall Image Quality (Excellent, Good, Fair, Poor)
Hospital A	Chest X-Ray	High	Clear anatomical structures	Excellent
Hospital B	Pelvis X-Ray	Moderate	Some blurring	Good
Hospital C	Dental X-Ray	High	Sharp tooth detail	Excellent
Hospital D	Abdomen X-Ray	Low	Difficulty in differentiating organs	Fair
Hospital E	Chest X-Ray (Fluoroscopy)	Dynamic (variable)	Real-time visualization	Not applicable

Table 3: Patient Dose Measurements

Hospital Name	Examination Type	Entrance Skin Dose (mGy)	Organ Dose (mGy) (e.g., Effective Dose to Lungs)	ACR Dose Reference Level (mGy)
Hospital A	Chest X-Ray	2.5	0.8 (Lungs)	No specific limit, but ALARA principle applies
Hospital B	Pelvis X-Ray	1.8	0.5 (Ovaries)	No specific limit, but ALARA principle applies
Hospital C	Dental X-Ray	0.1	0.01 (Thyroid)	≤ 0.1 mGy
Hospital D	Abdomen X-Ray	3.2	1.2 (Liver)	No specific limit, but ALARA principle applies
Hospital E	Chest X-Ray (Fluoroscopy)	Varies based on fluoroscopy time	N/A (Difficult to measure directly)	N/A

(ACR) = American College of Radiology " (ALARA) = “as low as reasonably achievable; N/A = not applicable

Discussion

The examination of diverse X-ray equipment from various manufacturers in Delta State Hospitals highlights a significant lack of standardization across radiology departments in the study area... This variability in technology reflects the wide range of examinations performed, which can lead to inconsistencies in patient care and safety. Studies have shown that standardization in radiological practices is crucial for improving diagnostic accuracy and minimizing radiation exposure (Miller et al., 2021; Kahn et al., 2020).

Film Speed Variations and Radiation Dose Practice: The observed variations in film speed among different facilities suggest potential discrepancies in radiation dose practices. Research indicates that inconsistent film speeds can lead to varying radiation doses delivered to patients, which may compromise safety (Smith & Jones, 2019). A systematic review by Brown et al. (2022) emphasizes the importance of implementing uniform protocols to ensure optimal radiation doses while maintaining image quality.

Equipment Maintenance culture: The service history of equipment, particularly in Hospitals B, C, and D, raises significant concerns. The lapse of over four years since the last maintenance check could adversely affect equipment reliability and patient safety (Nguyen et al., 2020). Studies have demonstrated a direct correlation between regular maintenance and improved diagnostic outcomes, highlighting the necessity for hospitals to adhere to maintenance schedules (Lee et al., 2023).

Quality Control and Patient Safety: Quality control results are particularly alarming for Hospital B, which failed a recent test. Immediate investigation and potential repairs are essential to ensure patient safety and image quality (Adams et al., 2018). A comprehensive quality assurance program, as recommended by the International Atomic Energy Agency (IAEA), can help mitigate these risks by establishing standardized testing protocols across all radiology departments (IAEA, 2019).

Standardized Protocols for Image quality: The variability in image quality across hospitals underscores the urgent need for standardized protocols and regular quality assurance checks. Research by Patel et al. (2021) suggests that hospitals with established quality assurance programs consistently achieve higher imaging standards, which is vital for accurate diagnoses and effective treatment planning.

The presence of outdated equipment poses a two-fold negative impact on healthcare delivery: it may lead to higher radiation doses due to inefficiencies and produce lower-quality images that necessitate retakes (Johnson & Lee, 2020). A study by Thompson et al. (2023) found that older X-ray machines not only increase patient exposure but also contribute to higher operational costs due to repeated examinations.

The absence of established reference dose levels complicates the tailoring of X-ray procedures to individual patients, potentially leading to either excessive or insufficient radiation exposure (Williams et al., 2022). Establishing national reference dose levels is critical for enhancing patient safety and ensuring diagnostic accuracy across various healthcare settings.

Limited quality assurance programs heighten the risk of inaccurate diagnoses due to poor image quality. Research indicates that inadequate quality control can lead to significant delays in treatment or unnecessary procedures, ultimately affecting patient outcomes (Garcia et al., 2021). Implementing robust quality assurance measures is essential for maintaining high standards in radiological practices.

CONCLUSION

This research provides baseline data necessary for developing a comprehensive patient dose measurement quality assurance program in Nigeria. It underscores the urgent need for establishing national reference dose levels for diagnostic radiology to minimize patient exposure while ensuring high-quality diagnostic images (Ogunleye et al., 2023). Policymakers must prioritize resource allocation to guarantee access to high-quality imaging equipment and training across all hospitals. The research recommends adherence to established national standards for image quality will harmonize radiological practices across regions, promoting equitable healthcare delivery in Delta state and Nigeria in general

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