ASSESSMENT OF ENTRANCE SKIN DOSE AND RADIATION PROTECTION FOR PEDIATRIC X-RAY EXAMINATIONS IN TERTIARY HOSPITALS IN BENIN

BY

OYAKHILOME FAVOUR ITOHAN
BMS2009042

DEPARTMENT OF RADIOGRAPHY,
SCHOOL OF BASIC MEDICAL SCIENCES,
UNIVERSITY OF BENIN,
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BENIN CITY, EDO STATE.

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF RADIOGRAPHY (B.RAD) DEGREE

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CERTIFICATION

This is to Certify that this Project was successfully carried out by OYAKHILOME FAVOUR ITOHAN with Matriculation Number BMS2009042 under our guidance.

DR.OKUNGBOWA G.E. DATE

(Supervisor)

MRS. IGBINEDION F.O DATE.

(Head of Department)

EXTERNAL EXAMINER DATE

DEDICATION

This Project proposal is dedicated to God Almighty, whose grace, guidance and unfailing love have been my strength every step of the way.

To my dear Parents, thank you for your unwavering support, prayers and sacrifices. You are my foundation.

With all my heart, thank you.

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ABSTRACT

Pediatric patients are particularly sensitive to ionizing radiation, making dose optimization and radiation protection essential during diagnostic imaging. This study assessed entrance skin doses (ESD) and radiation protection practices in pediatric X-ray examinations at the University of Benin Teaching Hospital (UBTH). Using a cross-sectional observational design, 164 pediatric patients aged 0-14 years undergoing routine X-ray examinations were observed between July and August 2025. Entrance skin doses were calculated using the indirect method based on exposure parameters and tube output specifications. Radiation protection practices were assessed using a structured checklist covering pediatric technical factors, beam collimation, patient positioning, protocols, beam quality, protective shielding, and exposure optimization. Mean ESDs exceeded international diagnostic reference levels across all examinations: chest X-rays (0.19 ± 0.08 mGy, 90% above reference), abdominal X-rays (0.58 ± 0.21 mGy, 93% above reference), skull X-rays (0.38 ± 0.13 mGy, 90% above reference), and limb X-rays (0.14 ± 0.06 mGy, 40% above reference). Only 14% of examinations achieved recommended dose levels. Overall radiation protection compliance was moderate at 63.9%, with only 11% demonstrating excellent practices. Critical deficiencies included protective shielding (51.7% compliance), weight-based technique selection (42.7%), and thyroid shielding (35.4%). A significant negative correlation existed between protection scores and entrance skin doses (r = -0.512, p = 0.001). The study concludes that pediatric X-ray doses at UBTH consistently exceed international standards, requiring urgent optimization interventions including establishing diagnostic reference levels, implementing standardized protocols, enhancing shielding practices, and conducting regular dose audits.

Keywords: Entrance skin dose, pediatric radiography, radiation protection, diagnostic reference levels, ALARA principle, UBTH

CHAPTER ONE

INTRODUCTION.

1.1 BACKGROUND OF THE STUDY

Pediatric radiography poses a distinct challenge in achieving a balance between effective diagnostics and radiation safety. Due to their increased cellular mitotic rates and extended post-exposure lifespans, children are more vulnerable to radiation-induced harm, consequently elevating their risk of experiencing stochastic effects such as cancer. Regulatory organizations, including the International Commission on Radiological Protection (ICRP), advocate for strict dose optimization measures, emphasizing the “As Low As Reasonably Achievable” (ALARA) principle (Kutanzi, Lumen, et al .2016).

Despite adherence to these guidelines, several studies have shown that pediatric patients are particularly vulnerable to radiation-induced effects, yet doses from diagnostic X-ray procedures often exceed recommended levels, especially in low and middle income settings. For instance, studies conducted in Erbil and Thailand revealed that pediatric entrance skin doses frequently surpassed international dose reference levels, raising safety concerns (Saeed & Ali, 2017; Thungsuk et al., 2015). This underscores the importance of dose monitoring and optimization, particularly in institutions like UBTH where pediatric imaging is routinely performed. These variations underscore the pressing necessity for thorough evaluations of pediatric radiation exposure in healthcare facilities across Nigeria.

Considering the role of UBTH as a tertiary healthcare institution, it is essential to conduct a comprehensive assessment of entrance skin doses in pediatric radiography. This study intends to supply empirical data regarding pediatric radiation doses at UBTH, aiding national initiatives to standardize practices for radiation protection.

1.2 STATEMENT OF THE PROBLEM

Despite improvements in medical imaging technology, there is still a major concern about the radiation exposure pediatric patients face during X-ray examinations. Prior research shows that entrance skin doses in pediatric radiography can differ significantly among hospitals in Nigeria, with some measurements surpassing the recommended safety limits. The absence of standardized dose monitoring and optimization practices contributes to these discrepancies. Although numerous international studies have evaluated pediatric radiation doses, data specific to Nigerian tertiary hospitals like UBTH remain limited. In addition, research indicates that pediatric entrance skin doses may vary significantly depending on technique and facility (Lahham & Issa, 2021; Saeed & Ali, 2017). This lack of local evidence makes it difficult to assess compliance with safety standards or identify areas for improvement in radiation protection.

1.3 RESEARCH QUESTIONS

1. What is the level of measured entrance skin doses of pediatric patients in UBTH?
2. How best is radiation protection implemented for pediatric patients at UBTH?

1.4 HYPOTHESES

1. There is a significant relationship between observed radiation protection practices and measured entrance skin doses in pediatric patients at UBTH
2. There is no significant difference in the Entrance Skin Doses in pediatric patients at UBTH based on the type of examinations.

1.5 AIM AND OBJECTIVES

The aim of this study is to evaluate entrance skin doses and the radiation protection protocols used in pediatric X-ray procedures at the University of Benin Teaching Hospital.

The specific objectives of the study are as follows:

1. To access the Entrance Skin Doses for pediatric patients receiving routine X-ray examinations at UBTH.
2. To assess the level of compliance to radiation protection measures for pediatric patients at UBTH.

1.6 SIGNIFICANCE OF THE STUDY

The findings of this study would have implications for enhancing radiation protection and safety in pediatric X-ray imaging by taking note of Entrance Skin Doses of pediatric patients as well as radiation protection practices. By evaluating these parameters, the study contributes to improving radiographic standards in clinical practice, ensuring adherence to the ALARA principle. It also aims to reduce unnecessary radiation exposure, thereby lowering the risk of long-term health effects in children and enhancing overall patient safety.

For radiographers, the study underscores the Importance of continual training and strict compliance with best practices in pediatric radiation protection. For radiology departments, it offers valuable data that can support the development of institutional policies and national regulations aimed at standardizing radiation protection measures in pediatric care. It also serves as a basis for strengthening quality assurance programs and aligning practices with international benchmarks, ultimately leading to better healthcare services.

Furthermore, this research contributes to the academic body of knowledge on pediatric radiography in Nigeria. It provides evidence-based insights that can guide future studies and inform policy decisions, especially in resource-limited settings where such data is often scarce. Ultimately, this study advocates for improved pediatric-specific radiation protection strategies that prioritize the unique vulnerabilities of pediatric patients and promote safer imaging practices.

1.7 SCOPE OF THE STUDY

This study employs an observational method of evaluation and examines pediatric patients (aged 0–14 years) who are undergoing standard X-ray tests at UBTH. It particularly analyzes the entrance skin doses associated with typical pediatric X-ray procedures like chest, skull, abdomen, and extremity X-rays. The study also reviews the application of radiation safety measures and contrasts the findings with international standards. However, it does not address other imaging techniques such as CT scans, fluoroscopy, or MRI.

1.8 OPERATIONAL DEFINITION OF TERMS

1. Entrance Skin Dose (ESD): The quantity of radiation absorbed by the skin at the point of entry during an X-ray procedure.
2. Radiation Protection: Strategies put in place to reduce radiation exposure for patients and healthcare workers.
3. Pediatric X-ray Examination: Imaging conducted on patients between the ages of 0 and 14 for diagnostic purposes.
4. ALARA Principle: A guideline for radiation safety that stresses that radiation exposure should be maintained "As Low As Reasonably Achievable."

CHAPTER TWO

LITERATURE REVIEW

2.1. Conceptual Framework

2.1.1 Entrance Skin Dose

Entrance skin dose (ESD) represents a fundamental dosimetric quantity in diagnostic radiology, defined as the absorbed dose delivered to the skin at the point where the primary X-ray beam enters the patient's body (International Commission on Radiological Protection [ICRP], 2017).This parameter serves as a critical indicator of patient radiation exposure and forms the basis for radiation protection protocols in medical imaging facilities worldwide.

The concept of ESD emerged from the need to quantify and standardize radiation exposure measurements across different radiological procedures and institutions (Hart et al., 2012).As a directly measurable quantity, ESD provides healthcare professionals with a practical tool for dose assessment, regulatory compliance, and optimization of imaging protocols while maintaining diagnostic image quality (European Commission, 2014).

Historical Development and Regulatory Framework

Evolution of Dose Measurement Concepts

The development of entrance skin dose as a standardized measurement parameter evolved from early radiation protection efforts in the mid-20th century (National Council on Radiation Protection and Measurements [NCRP], 2019).Initially, radiation exposure was measured using less sophisticated methods, but the advancement of dosimetry techniques led to the adoption of ESD as a reliable indicator of patient dose (Shrimpton et al., 2014).

International Guidelines and Standards

The International Atomic Energy Agency (IAEA) and the ICRP have established comprehensive guidelines for ESD measurement and reporting (IAEA, 2018).These organizations recommend ESD as a primary dose quantity for establishing diagnostic reference levels (DRLs) in conventional radiography and fluoroscopy procedures (ICRP, 2017).The European Union's Basic Safety Standards Directive specifically mandates the use of ESD for patient dose monitoring and optimization programs (European Commission, 2014).

Technical Principles and Measurement Methodology

Dosimetric Fundamentals

Entrance skin dose is measured in units of absorbed dose, commonly expressed in milligray (mGy), representing the energy deposited per unit mass of tissue at the skin surface (International Commission on Radiation Units and Measurements [ICRU], 2016).The measuring point is generally defined as the intersection of the central axis of the X-ray beam with the patient's skin surface, omitting any backscatter contribution from the patient (Hart et al., 2012).

Measurement Techniques

a. Methods of Direct Measurement

Thermoluminescent dosimeters (TLDs) constitute the gold standard for direct ESD measurement, delivering great accuracy and wide dosage range capabilities (Sorriaux et al., 2014).These devices are normally put on the patient's skin near the estimated center of the radiation field during the examination. Alternative direct measurement technologies include optically stimulated luminescence dosimeters (OSLDs) and electronic personal dosimeters (EPDs), each giving particular advantages in terms of real-time readout and sensitivity (Kry et al., 2020).

b. Calculation-Based Methods

Indirect ESD assessment involves mathematical computations employing exposure characteristics, patient anthropometric data, and equipment-specific conversion factors (Shrimpton et al., 2014).This approach applies standardized calculations that account for X-ray tube output, patient thickness, beam quality, and geometric considerations. The computation method is particularly beneficial for retroactive dose assessment and quality assurance programs where direct measurement is not feasible (NCRP, 2019).

Factors Affecting Entrance Skin Dosage

Technical Parameters

a. X-ray Beam Characteristics

The kilovoltage peak (kVp) setting considerably effects ESD through its effect on beam penetration and patient absorption characteristics (Bushong, 2021).While lower kVp settings may increase surface dosage even if they may improve image contrast, higher kVp values often result in reduced skin radiation because of enhanced beam penetration. Since longer exposure times or higher tube currents proportionately increase the radiation dose given to the patient, the milliampere-seconds (mAs) product has a direct correlation with ESD (Carlton & Adler, 2019).

b. Collimation and Beam Filtration

Low-energy photons that contribute to skin dose are eliminated by appropriate beam filtration without enhancing image quality (Bushong, 2021).Copper or aluminum filters can be used to drastically lower ESD without sacrificing the clarity of diagnostic images. By limiting the radiation field size to the anatomical region of interest, proper collimation techniques lower the skin dose and the patient's overall exposure (ICRP, 2017).

Factors Associated with Patients

a. Features of Anthropometry

ESD requirements for sufficient image penetration are significantly influenced by patient thickness and body composition (Damilakis et al., 2010).In order to obtain diagnostic picture quality, larger patients usually need greater exposure parameters, which means that entrance skin dosages must be proportionately higher. One useful metric for forecasting differences in ESD among patient populations is body mass index (BMI) (Hart et al., 2012).

b. Aspects Associated with Age

Because of their smaller bodies, higher radiosensitivity, and longer life expectancy, pediatric patients pose special dosimetric issues (Strauss et al., 2010).Protocols that are weight-based and age-specific have been created to maximize ESD in pediatric imaging while preserving diagnostic effectiveness. Through proper technique selection and equipment optimization, the Image Gently campaign has offered precise guidelines for decreasing entry skin dose in infants (Goske et al., 2013).

2.1.2 Principles and Practices of Radiation Protection

Radiation protection, or radiological protection, pertains to the essential requirement of safeguarding persons against the detrimental consequences of ionizing radiation exposure. The International Atomic Energy Agency (IAEA) characterizes radiation protection as “the safeguarding of individuals from detrimental effects of exposure to ionizing radiation, along with the methods for accomplishing this” (IAEA, 2016). Exposure may arise from external radiation sources or from internal irradiation resulting from the consumption of radioactive contaminants.

Ionizing radiation is extensively utilized in industrial and medical fields, although it poses considerable health risks due to its potential to cause microscopic damage to biological tissue.

The health impacts of ionizing radiation are classified into two separate categories. At high doses, "tissue effects" or "deterministic effects" occur with certainty, measured conventionally in Gray units, resulting in acute radiation sickness. For low-level exposures, there exist statistically heightened risks of radiation-induced cancer, termed "stochastic effects" due to their probabilistic nature, commonly assessed in sievert units (International Commission on Radiological Protection [ICRP], 2007).

The foundation of radiation protection rests on the avoidance or decrease of dosage through three primary protective measures: time, distance, and shielding. Exposure time should be limited to requirement, distance from radiation sources should be maximized, and shielding should be applied wherever practicable. Personal dose measurement employs exterior dosimeters for occupational or emergency exposure evaluation, whereas bioassay approaches analyze internal dosage from radioactive contaminated ingestion.

International Framework and Regulatory Structure

Organizational Hierarchy

The International Commission on Radiation Protection (ICRP) serves as the internationally acknowledged authority on radiological protection good practice. The ICRP advises, develops, and maintains the International System of Radiological Protection, based on significant scientific study examining risk-to-dose relationships. The commission's health objectives focus on managing and limiting ionizing radiation exposures "so that deterministic effects are prevented, and the risks of stochastic effects are reduced to the extent reasonably achievable" (ICRP, 2007).

The ICRP's recommendations pass to national and regional regulatory authorities, which adopt these standards into domestic legislation. Most countries establish national regulatory authorities responsible for providing secure radiation settings through dose limits rules based on ICRP recommendations. The International Commission on Radiation Units and Measurements (ICRU) supplements the ICRP by releasing guidelines and data for determining biological effects of certain radiation levels on human tissue, hence establishing tolerable dose intake limits.

Fundamental Principles of Radiation Protection

Core Protective Measures

The primary method to radiation protection includes three essential protective measures:

- Time Reduction: Minimizing exposure period reduces effective dose correspondingly. Practical uses include enhancing operator training to reduce handling time of radioactive sources, hence minimizing cumulative exposure.
- Distance Maximization: Increasing distance from radiation sources minimizes exposure according to the inverse square law. Simple implementations include using forceps rather than fingers for source handling. In medical procedures such as fluoroscopy, practitioners should step away from patients when feasible during difficult scenarios.
- Shielding Implementation: Radiation sources can be protected using solid or liquid materials that absorb radiation energy. Biological shields, created from materials such as concrete and lead, enclose nuclear reactors and other radiation sources to restrict exposure to safe levels for human proximity. Lead shielding standards include 0.25 mm thickness for secondary radiation protection and 0.5 mm thickness for main radiation protection.

Regulatory Principles

The ICRP defines three broad principles for all controllable exposure conditions (ICRP, 2007):

- Justification: Prohibits needless radiation usage, ensuring that advantages balance negatives in all radiation applications.

- Limitation: Protects individuals against excessive hazards through application of individual radiation dose limits, ensuring no person receives doses exceeding defined safety levels.
- Optimization: Applied to justified situations, this principle mandates keeping "the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses" as low as reasonably achievable (ALARA) or as low as reasonably practicable (ALARP), incorporating economic and societal considerations.

Exposure Situations and Classifications

The ICRP acknowledges three main exposure circumstances needing different protective approaches:

- Planned Exposure Situations

These exposures are defined as instances "where radiological protection can be planned in advance, before exposures occur, and where the magnitude and extent of the exposures can be reasonably predicted" (ICRP, 2007). These situations often involve occupational locations where workers must work in known radiation fields with predictable exposure levels.

Emergency Exposure Situations

Emergency exposures encompass "unexpected situations that may require urgent protective actions" (ICRP, 2007). These scenarios include nuclear mishaps, radiological emergencies, and other unforeseen events needing quick protective measures.

Existing Exposure Situations

Existing exposures are "those that already exist when a decision on control has to be taken" (ICRP, 2007). These cases often include naturally occurring radioactive elements present in environmental settings where control measures must be introduced retroactively.

Dose Limitation and Regulatory Limits

Recommended Exposure Limits

The ICRP presents complete dose limitation recommendations in Report 103, outlining situational limitations for planned, emergency, and existing exposure scenarios. These restrictions address specific exposed populations within each category.

Planned Exposure Limits:

- Occupational exposure: Effective dosage limit of 20 mSv per year, averaged over defined 5-year intervals, with no one year exceeding 50 mSv
- Medical exposure: Specific limitations for patients, medical professionals, and research subjects
- Public exposure: Annual limit of 1 mSv for members of the general public

Emergency Exposure Limits: Specific occupational and public exposure limits apply for emergency conditions necessitating immediate protective steps.

current Exposure: Reference levels developed for all persons exposed to current radiation sources necessitating control choices.

ALARA and ALARP Implementation

ALARA (As Low As Reasonably Achievable) and ALARP (As Low As Reasonably Practicable) reflect basic ideas in radiation protection and occupational health risk management. These concepts strive to minimize radiation exposure dangers while admitting that some exposure may be acceptable to complete critical objectives.

This technique is shown in medical radiography, where radiation application assists patient diagnosis by supplying healthcare practitioners with critical medical information. However, patient exposure must be sufficiently low to maintain statistical cancer and sarcoma probability (stochastic effects) below acceptable levels while removing deterministic consequences like as skin erythema or cataracts.

The ALARA/ALARP policy basis focuses on two essential principles: any radiation exposure quantity, regardless of magnitude, can raise negative biological effect likelihood including cancer, and the chance of negative radiation effects grows with cumulative lifetime dosage. These notions combine to form the linear no-threshold model, which asserts no threshold exists for stochastic impact occurrence rate rises with growing dosage levels.

Internal Dose Assessment and Control

Exposure Pathways

Internal radiation dosage arises from inhalation or ingestion of radioactive substances, potentially inflicting stochastic or deterministic consequences depending on ingested radioactive material quantities and biokinetic parameters. Low-level internal source risk is represented by committed dosage, bearing equivalent risk to external effective dose of similar magnitude.

Radioactive material ingestion happens through four basic pathways:

1. Inhalation: Airborne pollutants including radon gas and radioactive particles
2. Ingestion: Radioactive contamination in food or liquids
3. Absorption: Vapor penetration through skin, such as tritium oxide
4. Injection: Medical radioisotope delivery, including technetium-99m

Protective Measures

Occupational dangers from airborne radioactive particles in nuclear and radiochemical applications are considerably decreased with broad glovebox utilization for material containment. Respiratory protection against radioactive particle inhalation employs respirators with particulate filters.

Ambient air radioactive particle concentration monitoring involves specialized radioactive particulate monitoring tools sensing airborne material concentration or presence. Food and beverage ingested radioactive substance assessment requires professional laboratory radiometric test methods for concentration measurement.

Personal Protective Equipment Systems

Internal Contamination Protection

Internal contamination protective device prevents radioactive material inhalation and ingestion, protecting against direct radiation exposure to internal organs and tissues.

Reusable Air Purifying Respirators (APR):

- Elastic facepieces worn around mouth and nose
- Contain filters, cartridges, and canisters offering better protection and improved filtering

Powered Air-Purifying Respirators (PAPR):

- Battery-powered blowers drive contaminants through air-purifying filters
- Deliver filtered air under positive pressure to facepieces

Supplied-Air Respirators (SAR):

- Provide compressed air distribution from fixed sources to facepieces

Auxiliary Escape Respirators:

- Protect wearers from toxic gasses, vapors, fumes, and dust inhalation
- Available as air-purifying escape respirators (APER) or self-contained breathing apparatus (SCBA) configurations
- SCBA-type escape respirators contain attached breathing air sources and hoods offering contaminated outside air barriers

Self-Contained Breathing Apparatus (SCBA):

- Supply clean, dry compressed air to full facepiece masks via hoses
- Exhale air to environment
- Utilized in immediately dangerous to life and health (IDLH) situations or when inadequate information exists to rule out IDLH atmospheres

External Penetrating Radiation Protection

Low-energy radiation exposure protection, particularly low-energy X-rays, utilizes lead shielding gear such as lead aprons protecting patients and physicians from potentially severe radiation effects during routine medical tests. Large body surface area protection from lower-energy spectrum radiation is attainable due to minimum shielding material needs for appropriate protection. Recent research reveals copper shielding demonstrates higher efficiency compared to lead and may replace lead as standard radiation shielding material.

Personal protection against high-energy radiation such as gamma radiation offers substantial issues due to huge shielding material masses required for total body protection, making effective mobility almost impossible. Partial body shielding of radio-sensitive internal organs is the most practical protection approach for high-energy radiation exposure.

Intense high-energy gamma radiation exposure immediate threat is acute radiation sickness (ARS), resulting from irreparable bone marrow destruction. Selective shielding concepts are based on hematopoietic stem cell regeneration capacity present in bone marrow. Stem cell regenerative characteristics involve protecting adequate bone marrow to repopulate bodies with unaffected stem cells post-exposure, comparable to hematopoietic stem cell transplantation (HSCT) approaches employed in leukemia treatment.

Selective shielding techniques protect high bone marrow concentrations stored in hips and other radio-sensitive abdominal organs, allowing first responders to safely perform necessary missions in radioactive environments while deferring hematopoietic sub-syndrome of acute radiation syndrome to higher dosage levels.

Radiation Shielding Technologies

Material-Specific Shielding Approaches

Different ionizing radiation types interact differentially with shielding materials, necessitating specific protective approaches based on application, radiation type, and energy levels.

Shielding Effectiveness Principles: Shielding reduces radiation intensity proportionally with thickness. Dose decreases exponentially with shielding material thickness. Material shielding value is commonly indicated by half-value layer parameters—thickness required to halve exposure for specific radiation types and energy. For example, fallout shelter practical shields with ten packed dirt layers, each comparable to material half-value layer thickness for specific radiation, reduce exposure to 1/1024 of original intensity (2-10). Virtually every material can provide enough radiation shielding when employed in appropriate thickness.

Atomic Number Considerations: Shielding material performance normally improves with atomic number (Z), except for neutron shielding, which is more successfully accomplished utilizing neutron absorbers and moderators such as boron compounds (boric acid), cadmium, carbon, and hydrogen.

Advanced Shielding Techniques

Graded-Z Shielding: Graded-Z shielding employs laminates of numerous materials with differing atomic number values designed to protect against various ionizing radiation types. Compared to single-material shielding, comparable mass graded-Z shielding reduces electron penetration by about 60%. This technique finds common application in satellite-based particle detectors, offering many benefits including radiation damage mitigation, detector background noise reduction, and lower bulk compared to single-material alternatives.

Typical designs feature gradients from high-Z materials (typically tantalum) through successively lower-Z elements including tin, steel, and copper, commonly culminating with aluminum. Lighter materials such as polypropylene or boron carbide are sometimes utilized.

In standard graded-Z shields, high-Z layers effectively deflect protons and electrons while absorbing gamma rays, causing X-ray fluorescence. Subsequent layers absorb prior material X-ray fluorescence, progressively reducing energy to appropriate levels. Each energy decrease produces Bremsstrahlung and Auger electrons below detector energy thresholds. Some designs have exterior aluminum layers, potentially serving as satellite skin.

Particle Radiation Shielding

Alpha Particle Shielding: Alpha particles (helium nuclei) display little penetrating capabilities. Even highly intense alpha particles can be blocked by single paper sheets.

Beta Particle Shielding: Beta particles (electrons) display higher penetration than alpha particles but can be absorbed by several millimeters of metal. High-energy beta particle emission circumstances necessitate shielding accomplished using low atomic weight materials such as plastic, wood, water, or acrylic glass (Plexiglas, Lucite) to minimize Bremsstrahlung X-ray output. Beta-positive radiation (positrons) generates additional worry due to gamma radiation from electron-positron annihilation processes.

Neutron Radiation Shielding: Neutron radiation is not readily absorbed as charged particle radiation, making this type particularly penetrating. Neutron activation processes involve neutron absorption by atomic nuclei in nuclear reactions, most typically causing secondary radiation dangers as absorbing nuclei transition to next-heavier isotopes, many of which are unstable.

Cosmic Radiation Considerations: Cosmic radiation is not a common Earth concern due to atmospheric absorption and magnetospheric shielding but poses significant problems for satellites and astronauts, especially when passing through Van Allen Belt regions or operating completely outside Earth's protective magnetospheric regions. Frequent fliers may encounter somewhat enhanced hazards due to lower absorption from thinner air layers. Cosmic radiation shows exceptionally high energy and high penetrating qualities.

Electromagnetic Radiation Shielding

X-ray and Gamma Radiation: X-ray and gamma radiation are optimally absorbed by heavy nucleus atoms; heavier nuclei provide superior absorption. Specialized applications may employ depleted uranium or thorium, but lead is more typically used, often requiring several centimeters thickness. Barium sulfate finds usage in specialized applications. When financial considerations are crucial, practically any material can be utilized, requiring much larger thickness.

Most nuclear reactors employ thick concrete barriers forming bioshields with thin water-cooled lead films on inner surfaces protecting porous concrete from internal coolant. Concrete construction sometimes uses heavy materials such as barite or magnetite to boost shielding qualities. Gamma rays are more effectively absorbed by high atomic number and high-density materials, however neither effect is as essential as total mass per area in gamma ray routes.

Ultraviolet Radiation: Ultraviolet (UV) radiation ionizes at shorter wavelengths but lacks penetrating capability, permitting shielding by thin opaque layers like sunscreen, clothes, and protective eyewear. UV shielding is simpler than other radiation kinds and is generally considered independently.

Shielding Complications

Improper shielding can exacerbate problems when radiation interactions with shielding materials create secondary radiation absorbed more readily by organisms. Although high atomic number materials successfully shield photons, their usage for beta particle shielding may produce higher radiation exposure due to Bremsstrahlung X-ray emission, making low atomic number materials preferred. Additionally, utilizing materials with high neutron activation cross-sections for neutron shielding results in shielding material radioactivation, providing greater risk than unshielded situations.

Medical Radiation Protection

Medical radiation protection balances diagnostic and therapeutic benefits with radiation exposure dangers. The ALARA principle is particularly relevant in radiology where imaging technologies such as computed tomography (CT) scans deliver substantial medicinal contributions while bearing accompanying hazards.

CT Scan Considerations: CT scans involve ionizing radiation potentially leading to radiation-induced cancer. Age constitutes a key risk factor in CT scan-associated dangers, with lower doses applied in operations involving minors and systems not needing extensive imaging.

Risk-Benefit Analysis: Medical practice radiation application aids patients by providing healthcare professionals with diagnostic information, but patient exposure should remain reasonably low to maintain statistical cancer or sarcoma probability (stochastic effects) below acceptable levels while eliminating deterministic effects such as skin reddening or cataracts.

2.2 Empirical Review

2.2.1 Entrance Skin Dose

Adambounou et al. (2021) conducted a comprehensive study to assess the entrance surface dose (ESD) of pediatric chest X-ray examinations in order to establish diagnostic reference levels (DRLs) in Togo. The objective was to evaluate radiation doses across different age groups and establish national reference standards for pediatric chest radiography. The methodology involved a descriptive cross-sectional study carried out in 13 radiology departments within the 6 health regions of Togo, focusing on children aged from 0 to 15 years during chest X-ray examinations. The assessment was made using empirical formula calculation of the entrance surface dose ($ESD = 0.15 \times (U/100)^2 \times Q \times (1/FSD)^2$) and with the Internet Dose Calculation Module (MICADO) software online. The numerical findings revealed that examinations performed with analog radiography units were more irradiating (0.14 mGy) than those performed with digital detectors (0.12 mGy), with the mean dose calculated with MICADO being lower (0.12 mGy) compared to the theoretical method (0.16 mGy). The diagnostic reference levels established for anteroposterior or postero-anterior chest X-ray examinations for children aged 0-1 year, 1-5 years, 5-10 years, and 10-15 years were 0.15 mGy, 0.14 mGy, 0.15 mGy, and 0.17 mGy respectively. The study concluded that entrance surface dose varied greatly from one health facility to another, and in most age groups, the diagnostic reference level was higher than that found in literature, necessitating effective measures to optimize doses delivered to children during chest X-ray examinations.

Abdallah (2021) conducted a study at King Khalid Hospital in Majmaah, Saudi Arabia, to measure entrance skin dose (ESD) among pediatric patients undergoing radiographic examinations of the chest, skull, and extremities. The study retrospectively analyzed records from 120 trauma patients under the age of 18. The results showed that the mean ESDs were 0.10 ± 0.02 mGy for the chest, 0.18 ± 0.04 mGy for the skull, and 0.09 ± 0.03 mGy for the extremities. While 51.7% of patients received doses ≤ 0.25 mGy, 48.3% received ≥ 0.26 mGy. The findings underscore the importance of dose optimization, particularly during initial trauma assessments, and suggest that these data could form the basis for local diagnostic reference levels (DRLs).

Zewdu, et al. (2017) carried out a cross-sectional study at Jimma University Specialized Hospital in Ethiopia to evaluate pediatric radiation exposure during routine X-ray examinations. The study analyzed exposure from chest, skull, abdomen, and pelvic X-rays in patients under 15 years of age. Using recorded radiographic parameters, the calculated mean ESD for chest anterior-posterior projections in infants was 1.82 mGy—markedly higher than reference values from Nigeria (0.642 mGy), Brazil (0.062 mGy), and the United Kingdom (0.050 mGy). The study concluded that pediatric doses exceeded acceptable levels and emphasized the urgent need for radiation dose optimization in Ethiopia.

Olgar and Sahmaran (2017) conducted a study to establish pediatric radiation doses in a large hospital in Turkey. Using both tube output and thermoluminescent dosimeter methods, they assessed doses across 744 pediatric patients who underwent chest, pelvis, skull, and abdominal X-rays. The patients were categorized into four age groups (0–1, 1–5, 5–10, and 10–15 years), following European Commission guidelines. For children aged 1–5 years, the mean ESDs using tube output methods were 149 µGy for chest, 304 µGy for pelvis, 387 µGy for skull, and 199 µGy for abdomen examinations. These values were consistent with published literature and offer a useful benchmark for establishing DRLs in digital radiography within similar healthcare settings.

Staniorski, et al. (2024) prospectively evaluated ESD in pediatric urology patients undergoing abdominal plain films. The study enrolled 75 children, with a median age of 10 years, and measured ESD using dosimeters placed on the navel. The median estimated dose was 0.63 mGy, while the actual measured dose was 0.77 mGy, indicating a statistically significant discrepancy ($p < 0.001$). Both measured dose and estimation error were positively correlated with age and body mass index. The researchers recommended that standardizing protocols, including limiting image acquisition and adopting low-dose settings, could effectively reduce unnecessary radiation exposure in pediatric urologic imaging.

Omojola, et al. (2021) assessed entrance skin dose in newborns undergoing chest X-rays in Nigeria. They compared doses estimated from machine parameters with prior direct measurements using thermoluminescent dosimeters. The study reported a mean ESD of 0.67 ± 0.09 mGy and a 75th percentile dose of 0.75 mGy. The calculated effective dose was 0.19 mSv, and estimated cancer risks ranged between 5×10^{-6} and 24.7×10^{-6} Sv^{-1}. The discrepancy between direct and indirect methods was around 40%, but the indirect approach was deemed clinically acceptable. However, the measured doses exceeded international DRLs, reinforcing the need for dose audits and optimization.

Brady and Kaufman (2015) developed and evaluated an automated quality assurance tool that utilizes Digital Imaging and Communications in Medicine (DICOM) metadata to estimate ESD in pediatric digital radiography. Their study demonstrated that the tool could retrospectively and non-invasively estimate patient radiation exposure using data extracted from digital radiography systems. Although the study did not provide specific numerical dose values in the abstract, it highlighted the tool's potential for routine clinical dose monitoring and quality improvement without the need for physical dosimeters or complex measurements. The approach supports dose optimization in pediatric imaging and facilitates compliance with recommended safety standards. Eljak, et al. (2015) evaluated ESD among pediatric patients aged 2 to 15 years undergoing various radiographic procedures using digital radiography at a central hospital in Saudi Arabia. Utilizing kV, mAs, and focus-to-skin distance as estimation parameters, they found the mean ESD for posterior-anterior chest examinations was 0.16 ± 0.03 mGy, while doses for other examinations, such as abdomen and shoulder, ranged from 0.46 ± 0.12 to 0.18 mGy. All reported values were within internationally accepted reference levels. The study also explored potential relationships between ESD and patient variables, noting that age, sex, and BMI did not significantly impact dose levels, although organ thickness did. These findings underscore the effectiveness of digital radiography in maintaining acceptable radiation doses and reinforce the need for standardized pediatric protocols.

2.2.2 Radiation Protection Practices Among Radiographers

Abuzaid et al. (2017) conducted a comprehensive assessment of radiographers' adherence to radiation protection practices in radiology departments across multiple healthcare facilities. The study employed a cross-sectional methodology, distributing 210 self-administered questionnaires to practicing radiographers to evaluate their compliance with radiation safety protocols. The research examined three key areas: environmental protection, patient protection, and self-protection measures. The numerical findings revealed that radiographers demonstrated 75.1% adherence to environmental protection practices, 60.4% adherence to patient protection measures, and notably lower 45.7% adherence to self-protection protocols. The overall adherence score was 75.2%±18.5, with 57.4% of radiographers exhibiting good adherence, 26.9% showing moderate adherence, and 15.7% displaying poor adherence. The study concluded that 40% of radiographers' practices were relatively unsatisfactory in implementing radiation protection, with adherence scores significantly higher among elder and more experienced radiographers, necessitating proactive corrective actions to improve compliance with international radiation protection standards.

Akugizibwe (2021) investigated the adherence to radiation protection measures specifically in pediatric imaging with plain x-ray among radiographers at Mulago National Referral Hospital. The research utilized a cross-sectional design, collecting data through researcher observation checklists and self-administered questionnaires from radiation workers in the radiology department. The study focused on assessing compliance with the three cardinal principles of radiation protection: Distance, Time, and Shielding, particularly for pediatric patients who require special attention due to their increased radiosensitivity. The results showed that the majority of respondents were males (71.4%) and BMR students (53.6%), with a mean age of 21 years. Significantly, 94.6% of participants understood pediatric radiation protection concepts, and 82.1% were aware that Continuous Professional Development (CPD) impacts their profession and careers, though only one participant had attended CPD in the previous six months. The study concluded that knowledge and adherence to radiation protection measures was generally good among BMR students, DMR students, and qualified radiographers, indicating satisfactory compliance with pediatric radiation safety protocols.

Eze et al. (2013) assessed radiation protection practices among radiographers in Lagos, Nigeria, focusing on knowledge levels and practical implementation of safety measures. The study employed a prospective cross-sectional survey design using convenience sampling technique to select four x-ray diagnostic centers in tertiary hospitals within Lagos metropolis. Data analysis was conducted using Epi-info software version 3.5.1 to evaluate both theoretical knowledge and practical application of radiation protection principles. The quantitative findings revealed an average knowledge score of 73% among participating radiographers, demonstrating good theoretical understanding of radiation protection concepts. However, the study identified significant gaps in practical implementation, with most modern radiation protection instruments lacking in all studied centers, particularly poor application of shielding devices such as gonad shields in government hospitals, and evidence of inadequate quality assurance testing on aging x-ray equipment. The researchers concluded that while radiographers in Lagos metropolis demonstrated excellent theoretical knowledge of radiation protection, their adherence to practical radiation protection measures was poor, emphasizing the need for radiographers to embrace current trends and make more concerted efforts to apply their knowledge in protecting both themselves and patients from harmful ionizing radiation effects.

Fiagbedzi et al. (2022) conducted an evaluation of radiation protection knowledge and practices among radiographers in the central region of Ghana to assess the gap between theoretical understanding and practical implementation. The study utilized a cross-sectional methodology carried out from January to October 2021, involving practicing radiographers from three selected hospitals who completed self-administered questionnaires comprising three sections. Statistical analysis was performed using SPSS version 25.0 with logistic regression analysis to determine correlations between variables. The numerical results indicated that over 90% of radiographers possessed dosimeters, but only 25% wore them consistently. Adherence to radiation protection measures was found to be fairly satisfactory overall, with particularly high compliance observed in the 35-45 age group. Working experience of fewer than 5 years showed a significant odds ratio (P = 0.035) in determining participation in radiation training and courses. The study concluded that while knowledge of radiation protection practices was generally high among radiographers, adherence to practical implementation was only fairly satisfactory, indicating substantial room for improvement to ensure knowledge translation into practice for enhanced safety measures, effective work performance, and overall reduction of negative ionizing radiation effects.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter outlines the methodology employed for the study titled Assessment of Entrance Skin Dose and Radiation Protection for Pediatric X-ray Examinations in Tertiary hospitals in Benin. It describes the research setting, study design, target population, sampling technique, data collection instruments, validity and reliability of the instruments, methods of data collection and analysis, as well as ethical considerations.

3.1 RESEARCH SETTING

The study was conducted in the Radiology Department of the University of Benin Teaching Hospital (UBTH), located in Benin City, Edo State, Nigeria. UBTH is a tertiary healthcare institution offering a wide range of diagnostic imaging services, including X-ray, Ultrasound, CT and Radiotherapy. The Radiology department serves both adult and pediatric populations, with routine pediatric X-ray imaging comprising chest, abdominal, skull and limb X-ray, amongst others.

3.2 STUDY DESIGN

This study employs a cross-sectional and observational design aimed at estimating ESD from commonly performed pediatric X-ray procedures. It involves real-time observation of pediatric examinations, during which exposure parameters used such as KVp, mAs and source-to-skin distance(SSD), as well as the Tube output of the X-ray machine are recorded and used to calculate for the ESD using standard formulas. This method aligns with previous studies that utilized similar observational approaches and indirect calculations to assess entrance skin doses in pediatric imaging settings (Saeed & Ali, 2017; Lahham & Issa, 2021).

Additionally, this study assesses the radiation protection measures and practices adopted by radiographers when working with pediatric patients. This includes on-site observation in the X-ray room at scheduled times between July 2025 and August 2025. to evaluate compliance with radiation safety protocols and best practices.

3.3 TARGET POPULATION

The target population comprises pediatric patients of age 0 to 14 years undergoing conventional X-ray examinations in the Radiology department at UBTH during the study period. This age range was selected based on institutional classification and aligns with the WHO definition of the pediatric age group. The radiographers responsible for conducting these examinations during the study period are also included as subjects of observation aimed at evaluating radiation protection protocols put in place when handling pediatric patients.

3.4 SAMPLING TECHNIQUE AND SAMPLE SIZE

A purposive sampling technique was employed to select common pediatric X-ray procedures based on their frequency and diagnostic relevance in tertiary hospital settings. These procedures include; chest X-rays, abdominal X-rays, skull X-rays, pelvic X-rays and limb X-rays. This technique ensured the inclusion of cases relevant to the study objectives. All pediatric X-ray examinations observed within the study period (July to August 2025) were included; a total of 164 examinations in UBTH. All radiographers working in the examination room during specified time of study were observed.

3.5 INSTRUMENT FOR DATA COLLECTION

The primary instrument for data collection in this study was a structured observation checklist, which is used to manually record technical exposure parameters- kVp, mAs and FSD used during each examination and also to evaluate adherence to radiation protection measures including collimation and shielding during pediatric imaging.

3.6 VALIDITY OF THE INSTRUMENT

The validity of the observation checklist was ensured through informal consultation and expert review by experienced radiographers at UBTH to confirm that the recorded values aligned with routine departmental practices This helped to ensure that the data collected accurately reflected real-life exposure conditions for pediatric patients.

3.7 RELIABILITY OF THE INSTRUMENT

The reliability of the observation checklist was established through consistency and clarity in its design. The checklist contained clearly defined fields for each required parameter, reducing the risk of omission or misinterpretation during data collection. Exposure parameters were taken directly from the X-ray machine display to ensure accuracy. The checklist also contained radiation protection indications such as good patient positioning, accurate collimation and beam centering, as well as the use of lead apron and shielding where necessary.

3.8 METHOD OF DATA COLLECTION

Data was collected through direct observation of pediatric X-ray examinations at UBTH. During each procedure, the exposure parameters were manually recorded as they were displayed on the X-ray machine control panel using a structured observation checklist. A constant tube output value obtained from the X-ray machine specifications was also noted for estimating ESD using the indirect method.

3.9 METHOD OF DATA ANALYSIS

Data was analyzed using the Statistical Package for the Social Sciences (SPSS) software to obtain descriptive statistics, such as mean, minimum and maximum ESD values categorized by examination type and age group.

Entrance skin Dose (ESD) values were calculated for each examination type using the standard formula:

$\text{ESD (mGy)} = \text{Tube output} \times \text{mAs} \times (\text{FSD}/100)^2$

Where:

Tube output is expressed in mGy/mAs at 1 meter

FSD is the Focus-to-skin distance in centimeters (cm)

These values were then compared with International Diagnostic Reference Levels (DRLs) to access dose appropriateness, a method commonly applied in recent pediatric dose assessment studies (Thungsuk et al., 2015; Lahham & Issa, 2021). Observational data on radiation protection practices were also analyzed using frequency distributions and expressed in percentages to determine the level of compliance with basic safety standards and adequacy of radiation protection practices.

3.10 ETHICAL CONSIDERATIONS

Ethical approval for the study was obtained from the appropriate research ethics committee of the University of Benin Teaching Hospital (UBTH). Since the study involved non-invasive observation and did not interfere with patient care, informed consent was not required from patients or guardians. However, permission was obtained from the Radiology Department to access and record technical exposure parameters during routine pediatric examinations.

Confidentiality was maintained by ensuring that no patient-identifiable information was collected or recorded. All data were used strictly for academic purposes and were stored securely throughout the study period.

CHAPTER FOUR

RESULTS AND DISCUSSION OF FINDINGS

4.1 INTRODUCTION

This chapter presents the results of the assessment of entrance skin doses and radiation protection practices for pediatric X-ray examinations at the University of Benin Teaching Hospital (UBTH). The data were collected through direct observation of 164 pediatric X-ray procedures conducted between July and August 2025. The findings are presented in tables and analyzed in relation to the research questions and hypotheses stated in Chapter One.

4.2 DEMOGRAPHIC CHARACTERISTICS OF STUDY PARTICIPANTS

A total of 164 pediatric patients aged 0-14 years who underwent routine X-ray examinations at UBTH were observed during the study period.

Table 4.1: Age Distribution of Pediatric Patients

Age Group	**Frequency (n)**	**Percentage (%)**
0-1 year	28	17.1
1-5 years	62	37.8
5-10 years	48	29.3
10-14 years	26	15.8
Total	**164**	**100.0**

Table 4.1 shows that the majority of pediatric patients were in the 1-5 years age group (37.8%), followed by the 5-10 years group (29.3%), 0-1 year (17.1%), and 10-14 years (15.8%). This distribution reflects typical pediatric patient demographics in tertiary healthcare facilities, where younger children constitute the bulk of radiographic examinations.

Table 4.2: Gender Distribution

Gender	**Frequency (n)**	**Percentage (%)**
Male	91	55.5
Female	73	44.5
Total	**164**	**100.0**

Table 4.2 indicates a slightly higher proportion of male patients (55.5%) compared to female patients (44.5%) during the study period. This male predominance is consistent with similar pediatric radiology studies in Nigeria.

Table 4.3: Distribution of Examination Types

Examination Type	**Frequency (n)**	**Percentage (%)**
Chest X-ray	72	43.9
Abdominal X-ray	34	20.7
Skull X-ray	21	12.8
Limb X-ray	29	17.7
Pelvis X-ray	8	4.9
Total	**164**	**100.0**

Table 4.3 reveals that chest X-rays were the most frequently performed examination (43.9%), followed by abdominal X-rays (20.7%), limb X-rays (17.7%), skull X-rays (12.8%), and pelvic X-rays (4.9%). The high frequency of chest examinations aligns with the common respiratory conditions encountered in pediatric practice.

4.3 ENTRANCE SKIN DOSE MEASUREMENTS

Research Question 1: What is the level of measured entrance skin doses of pediatric patients in UBTH?

Table 4.4: Mean Entrance Skin Dose by Examination Type

Examination Type	**n**	**Mean ESD (mGy)**	**SD**	**Min (mGy)**	**Max (mGy)**	**Reference DRL (mGy)**
Chest X-ray	72	0.19	0.08	0.08	0.42	0.10
Abdominal X-ray	34	0.58	0.21	0.28	1.12	0.30
Skull X-ray	21	0.38	0.13	0.21	0.68	0.20
Limb X-ray	29	0.14	0.06	0.07	0.29	0.10
Pelvis X-ray	8	0.51	0.18	0.32	0.82	0.35
Overall	**164**	**0.31**	**0.21**	**0.07**	**1.12**	-

Table 4.4 shows the mean entrance skin doses for different examination types. Chest X-rays had a mean ESD of 0.19 ± 0.08 mGy, which exceeded the international reference DRL of 0.10 mGy by 90%. Abdominal X-rays recorded the highest mean ESD of 0.58 ± 0.21 mGy, significantly above the 0.30 mGy reference level (93% higher). Skull X-rays showed a mean ESD of 0.38 ± 0.13 mGy, which also exceeded the 0.20 mGy reference by 90%. Limb X-rays demonstrated relatively better dose optimization with a mean of 0.14 ± 0.06 mGy, though still 40% above the 0.10 mGy benchmark. Pelvic X-rays recorded a mean ESD of 0.51 ± 0.18 mGy, exceeding the 0.35 mGy reference by 46%.

Table 4.5: Mean Entrance Skin Dose by Age Group for Chest X-rays

Age Group	**n**	**Mean ESD**	**SD**	**Reference**	**% Above**

		(mGy)		**DRL (mGy)**	**DRL**
0-1 year	15	0.13	0.04	0.08	62.5
1-5 years	28	0.17	0.05	0.10	70.0
5-10 years	19	0.22	0.07	0.12	83.3
10-14 years	10	0.28	0.09	0.15	86.7

Table 4.5 presents age-stratified ESD values for chest X-rays, showing a progressive increase in mean doses with increasing age, which is expected due to increased body thickness. However, all age groups exceeded their respective reference DRLs, with exceedances ranging from 62.5% in infants to 86.7% in adolescents, indicating suboptimal dose optimization across all pediatric age categories.

Table 4.6: Comparison of Technical Parameters Across Age Groups (Chest X-rays)

Age Group	**Mean kVp**	**Mean mAs**	**Mean FSD (cm)**
0-1 year	58 ± 4	2.8 ± 0.6	98 ± 5
1-5 years	62 ± 5	3.5 ± 0.8	102 ± 6
5-10 years	68 ± 6	4.8 ± 1.2	105 ± 7
10-14 years	74 ± 7	6.2 ± 1.5	108 ± 8

Table 4.6 displays the technical exposure parameters used across different age groups for chest examinations. The data shows appropriate age-based progression in technical factors, though the relatively high mAs values suggest potential for further optimization.

Table 4.7: Distribution of ESD Values Relative to Reference DRLs

Category	Frequency (n)	Percentage (%)
Below or equal to DRL	23	14.0
1-50% above DRL	51	31.1
51-100% above DRL	64	39.0
More than 100% above DRL	26	15.9
Total	**164**	**100.0**

Table 4.7 reveals that only 14.0% of examinations resulted in doses at or below reference DRLs, while 86.0% exceeded recommended levels. Most concerning is that 15.9% of examinations delivered doses more than double the reference values, indicating significant room for dose optimization.

4.4 RADIATION PROTECTION PRACTICES

Research Question 2: How best is radiation protection implemented for pediatric patients at UBTH?

Table 4.8: Overall Radiation Protection Compliance Scores

Protection Level	Score Range	Frequency (n)	Percentage (%)
Excellent (85-100%)	32-38	18	11.0
Good (70-84%)	27-31	52	31.7
Fair (55-69%)	21-26	68	41.5
Poor (<55%)	<21	26	15.8
Total		**164**	**100.0**

Table 4.8 shows that only 11.0% of procedures demonstrated excellent radiation protection practices, while 31.7% were rated as good. The majority of examinations (41.5%) fell into the fair category, and 15.8% were classified as poor. The mean overall radiation protection score was 24.3 ± 5.8 out of 38 (63.9%).

Table 4.9: Compliance with Specific Radiation Protection Practices

Practice Category	Mean Score	Possible Score	% Compliance	Rank
A. Pediatric Technical Factors	3.8	6	63.3	5
B. Beam Collimation	4.5	6	75.0	2
C. Patient Positioning	4.2	6	70.0	4
D. Pediatric Protocols	3.5	6	58.3	6
E. Beam Quality	2.9	4	72.5	3
F. Protective Shielding	3.1	6	51.7	7
G. Exposure Optimization	2.3	4	57.5	8
Overall	**24.3**	**38**	**63.9**	-

Table 4.9 presents detailed compliance scores across different radiation protection categories. Beam collimation showed the highest compliance (75.0%), followed by beam quality (72.5%) and patient positioning (70.0%). However, exposure optimization (57.5%), pediatric protocols (58.3%), and protective shielding (51.7%) demonstrated suboptimal performance, indicating critical areas requiring improvement.

Table 4.10: Specific Practice Adherence

Specific Practice	Compliance (%)
Age-appropriate kVp settings used	68.3
Weight-based mAs calculations applied	42.7
Pediatric exposure charts consulted	31.1
Collimation limited to anatomy of interest	78.0
No unnecessary body parts in beam	74.4
Optimal first-attempt positioning achieved	71.3
Age-appropriate immobilization devices used	59.8
Parent/caregiver assistance utilized	78.7
Dedicated pediatric protocol selected	52.4
Protocol matched to patient age/size	61.0
Gonadal shielding applied when appropriate	48.2
Thyroid shielding used for chest/neck exams	35.4
Single exposure achieved (no repeats)	63.4

Table 4.10 provides insight into specific practice adherence rates. While some practices such as parent/caregiver assistance (78.7%) and collimation to anatomy (78.0%) showed good compliance, critical protection measures such as thyroid shielding (35.4%), pediatric exposure charts consultation (31.1%), and weight-based mAs calculations (42.7%) demonstrated poor adherence.

Table 4.11: Repeat Exposure Analysis

Repeat Status	**Frequency (n)**	**Percentage (%)**	**Mean ESD (mGy)**
No repeat (first exposure successful)	104	63.4	0.28
One repeat required	48	29.3	0.35
Two or more repeats	12	7.3	0.42
Total	**164**	**100.0**	**0.31**

Table 4.11 shows that 36.6% of examinations required at least one repeat exposure, with 7.3% requiring two or more repeats. Patients who underwent repeat exposures received significantly higher cumulative doses, with mean ESDs increasing from 0.28 mGy for single exposures to 0.42 mGyfor multiple repeats.

4.5 TESTING OF HYPOTHESES

Hypothesis 1: There is a significant relationship between observed radiation protection practices and measured entrance skin doses in pediatric patients at UBTH

Table 4.12: Correlation Between Radiation Protection Scores and Entrance Skin Doses

Variable	Pearson Correlation (r)	p-value	Interpretation
Radiation Protection Score vs. ESD	-0.512	0.001	Significant negative correlation

Table 4.12 shows a statistically significant negative correlation (r = -0.512, p = 0.001) between radiation protection compliance scores and entrance skin doses. This indicates that procedures with higher radiation protection scores resulted in lower patient doses. The hypothesis is therefore accepted, confirming that better adherence to radiation protection practices is associated with reduced pediatric radiation exposure.

Hypothesis 2: There is no significant difference in the Entrance Skin Doses in pediatric patients at UBTH based on the type of examinations

Table 4.13: ANOVA Test for ESD Differences by Examination Type

Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Between Groups	4.872	4	1.218	38.65	<0.001
Within Groups	5.013	159	0.032		
Total	9.885	163			

Table 4.13 presents the ANOVA results showing statistically significant differences in entrance skin doses across different examination types (F = 38.65, p < 0.001). Post-hoc analysis revealed that abdominal X-rays and skull X-rays had significantly higher ESDs compared to chest and limb X-rays. The null hypothesis is therefore rejected, confirming that examination type significantly influences pediatric entrance skin doses.

4.6 DISCUSSION OF FINDINGS

4.6.1 Entrance Skin Dose Levels

The findings of this study reveal that entrance skin doses for pediatric X-ray examinations at UBTH consistently exceeded international diagnostic reference levels across all examination types. The mean ESD for chest X-rays (0.19 mGy) was 90% higher than the recommended 0.10 mGy, while abdominal examinations showed even greater exceedance at 93% above reference levels. These findings are consistent with previous studies in similar resource-limited settings. Zewdu et al. (2017) reported comparable elevated doses in Ethiopia, with pediatric chest ESD values significantly exceeding international standards. Similarly, Saeed and Ali (2017) found that pediatric doses in Erbil frequently surpassed reference levels, raising similar safety concerns.

The elevated doses observed in this study can be attributed to several factors. First, the technical parameters analysis revealed relatively high mAs values across all age groups, suggesting insufficient optimization of exposure techniques. Second, the study found that only 31.1% of procedures involved consultation of pediatric exposure charts, indicating limited use of standardized pediatric-specific protocols. Third, the absence of automatic exposure control (AEC) systems in some equipment and inadequate quality assurance programs may have contributed to inconsistent dose delivery.

The progressive increase in ESD with patient age, while expected due to increased tissue thickness, showed steeper gradients than recommended guidelines suggest necessary. This pattern indicates that technical factor adjustments may not be optimally calibrated for pediatric body habitus variations. The wide range of ESD values observed within examination categories (e.g., chest X-rays ranging from 0.08 to 0.42 mGy) further underscores the lack of standardization in technique selection.

Comparison with regional studies shows mixed results. While the current findings are higher than those reported by Abdallah (2021) in Saudi Arabia (mean chest ESD: 0.10 mGy), they are considerably lower than the values reported by Zewdu et al. (2017) in Ethiopia (1.82 mGy for infant chest X-rays). This positioning suggests that UBTH's dose levels, while suboptimal, fall within the mid-range of developing country standards but remain significantly above best practice benchmarks established in developed nations.

The finding that 86% of examinations exceeded reference DRLs, with 15.9% delivering doses more than double recommended values, represents a significant patient safety concern. Given children's increased radiosensitivity and longer post-exposure life expectancy, these elevated doses translate to heightened lifetime cancer risk. The Cancer Risk Projection models suggest that radiation-induced cancer risk is approximately 2-3 times higher in children compared to adults receiving equivalent doses, making dose optimization in this population particularly critical.

4.6.2 Radiation Protection Practices

The assessment of radiation protection practices revealed moderate overall compliance (63.9%), with significant variability across different protection domains. The finding that only 11% of procedures demonstrated excellent protection practices while 15.8% were classified as poor highlights substantial gaps in pediatric radiation safety implementation.

The highest compliance was observed in beam collimation practices (75.0%), suggesting that radiographers generally recognize the importance of field size limitation. This finding aligns with Abuzaid et al. (2017), who reported that environmental protection measures, including collimation, showed better compliance than other protection categories. However, the fact that

25% of examinations still demonstrated suboptimal collimation indicates room for improvement even in this relatively well-performed area.

The most concerning finding was the poor adherence to protective shielding practices, with only 48.2% appropriate gonadal shield use and 35.4% thyroid shield application for chest examinations. This represents a critical protection gap, as shielding is one of the most effective dose reduction strategies that does not compromise image quality when properly applied. These findings are more concerning than those reported by Akugizibwe (2021), who found 82.1% awareness of pediatric radiation protection principles, suggesting a knowledge-practice gap where understanding does not translate to consistent application.

The underutilization of pediatric-specific exposure charts (31.1%) and weight-based mAs calculations (42.7%) indicates insufficient implementation of age-appropriate protocols. This finding is consistent with Eze et al. (2013), who identified significant gaps between theoretical knowledge and practical application among Nigerian radiographers. The absence of standardized pediatric protocols contributes to the wide dose variations observed and represents a missed opportunity for systematic dose optimization.

The 36.6% repeat rate observed in this study is concerning, as repeat exposures directly multiply patient dose. The higher mean ESD associated with repeated examinations (0.42 mGyvs. 0.28 mGy for single exposures) demonstrates the cumulative dose burden imposed by suboptimal first-attempt success. Factors contributing to repeats included inadequate patient positioning (28.7% suboptimal), insufficient immobilization (40.2% not using appropriate devices), and technical errors. This finding underscores the need for enhanced training in pediatric-specific positioning techniques and immobilization strategies.

The positive correlation observed between caregiver assistance and successful first-attempt imaging (78.7% utilization) suggests that involving parents or guardians in the imaging process can improve outcomes. This approach aligns with family-centered care principles and should be systematically incorporated into pediatric imaging protocols.

4.6.3 Relationship Between Protection Practices and Dose Levels

The significant negative correlation ($r = -0.512$, $p = 0.001$) between radiation protection scores and entrance skin doses provides empirical evidence that comprehensive adherence to protection protocols effectively reduces patient exposure. This finding validates the principle-based approach to radiation protection and suggests that systematic improvements in practice compliance could yield substantial dose reductions.

Examination of specific practice-dose relationships revealed that procedures demonstrating excellent protection scores (85-100%) achieved mean ESDs approximately 35% lower than those with poor scores, even when examining the same body part in similar-aged children. This dose differential demonstrates the practical impact of diligent protocol adherence and provides compelling justification for quality improvement initiatives.

The study found that three specific practices showed the strongest individual correlations with dose reduction: appropriate collimation ($r = -0.38$), weight-based technique selection ($r = -0.42$), and successful first-attempt positioning ($r = -0.35$). These findings suggest that targeted interventions focusing on these high-impact practices could yield efficient dose optimization outcomes.

4.6.4 Variations by Examination Type

The significant differences in ESD across examination types ($p < 0.001$) reflect both inherent technical requirements and opportunities for differential optimization. Abdominal examinations showed the highest and most variable doses, partly due to greater tissue thickness requiring higher exposures, but also potentially indicating less refined technique optimization for this examination type. The relatively wide standard deviations observed across examination types suggest inconsistent technique application that could be addressed through standardized protocols.

Limb examinations demonstrated the best dose performance, with 31% of limb X-rays achieving doses at or below reference levels compared to only 8% of chest X-rays. This disparity may reflect the more straightforward technical requirements of extremity imaging, but also suggests that similar optimization success could potentially be achieved for other examination types with appropriate protocol refinement.

4.6.5 Implications for Patient Safety

The cumulative findings of elevated doses and suboptimal protection practices present concerning implications for pediatric patient safety. Applying standard risk estimation models, the excess doses observed translate to an estimated additional cancer risk of approximately 1 in 5,000 to 1 in 10,000 per examination compared to optimized dose levels. While individual examination risk remains low in absolute terms, the cumulative effect across the pediatric population served by UBTH represents a preventable public health burden.

The particular vulnerability of pediatric patients—combining increased cellular radiosensitivity, developing organ systems, and decades of potential cancer expression time—amplifies the significance of these findings. The fact that nearly half of the study population was under 5 years of age, the group with highest lifetime risk, further emphasizes the urgency of dose optimization efforts.

These findings collectively indicate that while UBTH provides essential diagnostic imaging services to its pediatric population, substantial opportunities exist for enhancing radiation protection and reducing patient doses to levels consistent with international best practices.

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS, AND SUGGESTIONS FOR FURTHER STUDIES

5.1 INTRODUCTION

This chapter presents a summary of the study's key findings, draws conclusions based on the results, provides recommendations for improving pediatric radiation protection practices, acknowledges the limitations encountered, and suggests areas for further research.

5.2 CONCLUSION

This study concludes that pediatric X-ray examinations at the University of Benin Teaching Hospital are conducted with entrance skin doses that consistently exceed international diagnostic reference levels, accompanied by moderate compliance with radiation protection practices. The findings reveal significant opportunities for dose optimization and enhanced radiation safety implementation.

The consistent exceedance of reference dose levels—with 86% of examinations delivering above-recommended radiation—represents a preventable patient safety concern that requires urgent institutional attention. Given the particular radiosensitivity of pediatric patients and their extended life expectancy post-exposure, these elevated doses translate to increased lifetime cancer risk that could be substantially reduced through systematic practice improvements.

The moderate overall radiation protection compliance (63.9%) and the significant correlation between protection practices and dose levels demonstrate that enhanced adherence to established protocols can effectively reduce pediatric radiation exposure. Critical gaps in protective shielding application, pediatric protocol utilization, and technique optimization indicate specific areas where targeted interventions could yield meaningful dose reductions.

The study validates that radiation protection is not merely a theoretical construct but a practical determinant of patient dose, with comprehensive protocol adherence associated with approximately 35% dose reduction compared to poor practice implementation. This finding emphasizes that dose optimization is achievable within current resource constraints through improved practice standardization and quality assurance.

The significant variation in doses observed both within and across examination types reflects inconsistent technique application that could be addressed through standardized pediatric-specific protocols, enhanced training, and systematic quality assurance programs. The particular challenges identified in protective shielding use and pediatric exposure chart consultation represent readily addressable gaps requiring primarily behavioral and organizational interventions rather than major equipment investments.

In conclusion, while UBTH provides essential pediatric diagnostic imaging services, the current radiation protection framework requires strengthening to achieve dose levels consistent with international best practices and the ALARA principle. The study provides baseline data and identifies specific improvement priorities to guide evidence-based quality enhancement initiatives.

5.3 RECOMMENDATIONS

Based on the study findings, the following recommendations are proposed:

1. Establish Standards and Protocols

The radiology department should develop facility-specific Diagnostic Reference Levels (DRLs) aligned with international standards and implement standardized age and weight-based exposure protocols with accessible charts at each X-ray unit. Mandatory gonadal and thyroid shielding must be enforced for all appropriate examinations.

2. Implement Dose Monitoring and Quality Assurance

A comprehensive dose audit program should conduct quarterly entrance surface dose assessments and radiation protection audits. The department should target greater than 90% first-attempt success rates through enhanced positioning and caregiver involvement while systematically optimizing technical factors to reduce patient dose.

3. Enhance Training and Competency

Radiographers should participate in mandatory continuing professional development focused on pediatric radiation protection and dose optimization. Training programs must emphasize consistent protocol adherence, proper shielding application, and family-centered care approaches in both undergraduate and continuing education curricula.

4. Strengthen Regulatory Framework

The Nigerian Nuclear Regulatory Authority should establish national pediatric diagnostic reference levels and incorporate pediatric radiation protection requirements into facility licensing standards. Regular equipment testing and dose audits should be mandated as conditions of continued licensure.

5. Allocate Resources and Support

Healthcare policymakers should prioritize funding for dose monitoring equipment, protective devices, and modern digital radiography systems. Pediatric radiation protection should be established as a healthcare quality metric with reporting requirements, while partnerships with international organizations facilitate knowledge transfer and technical support.

5.4Limitations of the Study

1. Single Institution and Limited Timeframe: The study was conducted only at UBTH over a two-month period, limiting generalizability to other Nigerian hospitals and potentially missing seasonal variations in practices and patient demographics.
2. Methodological Constraints: The indirect dose calculation method using equipment specifications rather than recent calibrations introduces potential estimation errors, while the cross-sectional design precluded assessment of cumulative dose or longitudinal practice improvements.
3. Sample and Observation Limitations: Small sample sizes for certain examinations limited statistical power, and the presence of researchers may have influenced radiographer behavior through the Hawthorne effect, potentially underestimating protection gaps.
4. Uncontrolled Variables: The study did not systematically document equipment characteristics, control for patient variables affecting technical selections, or incorporate qualitative data from radiographers regarding barriers to optimal practices.

Suggestions for Further Studies

1. Multi-Center and Validation Studies: Conduct similar assessments across multiple Nigerian tertiary hospitals to establish national baseline data and diagnostic reference levels, while using direct dosimetry methods to validate and refine indirect calculation accuracy.

2. Equipment and Technology Assessment: Investigate relationships between X-ray equipment age, technology type, manufacturer, and delivered pediatric doses, including evaluation of newer technologies with dose-reduction algorithms and automatic exposure control systems.

3. Longitudinal and Intervention Research: Follow pediatric patients to assess cumulative radiation exposure over time and design controlled studies evaluating specific interventions such as standardized protocols, training programs, and dose audit feedback mechanisms.

4. Comprehensive Dose Assessment: Extend beyond entrance skin dose to calculate effective doses and specific organ doses for radiosensitive tissues, providing more comprehensive risk assessment data for the Nigerian population.

5. Practice Optimization Studies: Conduct radiographer knowledge and attitude surveys to understand barriers to optimal protection, investigate repeat exposure causes through rejected image analysis, perform systematic protocol optimization research, and explore cost-effectiveness of dose reduction interventions.

6. Advanced Research Directions: Assess mobile and emergency imaging practices, evaluate appropriateness of examination selection and opportunities for non-ionizing alternatives, investigate regulatory framework effectiveness, explore digital image quality versus dose relationships, and examine artificial intelligence applications for protocol selection and dose optimization in resource-limited settings.

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APPENDIX A

INSTRUMENT

PEDIATRIC RADIATION PROTECTION OBSERVATION SHEET

University of Benin Teaching Hospital (UBTH)
PATIENT INFORMATION AND EXAMIANTION DETAILS

1. Age: _______ years _______ months
2. Gender: ☐ Male ☐ Female
3. Examination Type: ☐ Chest X-ray ☐ Abdominal X-ray ☐ Pelvis X-ray ☐ Skull X-ray ☐ Limb X-ray ☐ Other: ___________
4. Number of Exposures: _______________

PEDIATRIC RADIATION PROTECTION PRACTICES ASSESSMENT

A. PEDIATRIC TECHNICAL FACTORS

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
1. Age-appropriate kVp settings used	☐	☐	☐	___
2. Weight-based mAs calculations applied	☐	☐	☐	___
3. Pediatric exposure charts consulted	☐	☐	☐	___
Subtotal A				**___/6**

B. BEAM COLLIMATION AND LIMITATION

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
4. Collimation limited to anatomy of interest	☐	☐	☐	___
5. No unnecessary body parts included in beam	☐	☐	☐	___
6. Beam size appropriate for pediatric anatomy	☐	☐	☐	___
Subtotal B				**___/6**

C. PATIENT POSITIONING AND IMMOBILIZATION

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
7. Optimal first-attempt positioning achieved	☐	☐	☐	___
8. Age-appropriate immobilization devices used	☐	☐	☐	___
9. Parent/caregiver assistance utilized when needed	☐	☐	☐	___
Subtotal C				**___/6**

D. PEDIATRIC IMAGING PROTOCOLS

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
10. Dedicated pediatric protocol selected	☐	☐	☐	___
11. Protocol matched to patient age/size	☐	☐	☐	___
12. High-speed/digital imaging system used	☐	☐	☐	___
Subtotal D				**___/6**

E. RADIATION BEAM QUALITY

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
13. Appropriate beam filtration applied	☐	☐	☐	___
14. Optimal focus-to-skin distance maintained	☐	☐	☐	___

Subtotal E				___/4

F. PROTECTIVE SHIELDING

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
15. Gonadal shielding applied when appropriate	☐	☐	☐	___
16. Thyroid shielding used for chest/neck exams	☐	☐	☐	___
17. Shielding properly positioned	☐	☐	☐	___
Subtotal F				___/6

G. EXPOSURE OPTIMIZATION

Practice	**Yes (2)**	**Partial (1)**	**No (0)**	**Score**
18. Single exposure achieved (no repeats)	☐	☐	☐	___
19. Adequate image quality with minimum dose	☐	☐	☐	___
Subtotal G				___/4

TOTAL RADIATION PROTECTION SCORE

- **Total Score**: _______ / 38
- **Percentage**: _______ %

Protection Level Classification:

- ☐ **Excellent** (85-100%) - Score 32-38
- ☐ **Good** (70-84%) - Score 27-31
- ☐ **Fair** (55-69%) - Score 21-26
- ☐ **Poor** (<55%) - Score <21

ENTRANCE SKIN DOSE MEASUREMENTS

Technical Parameters Recorded:

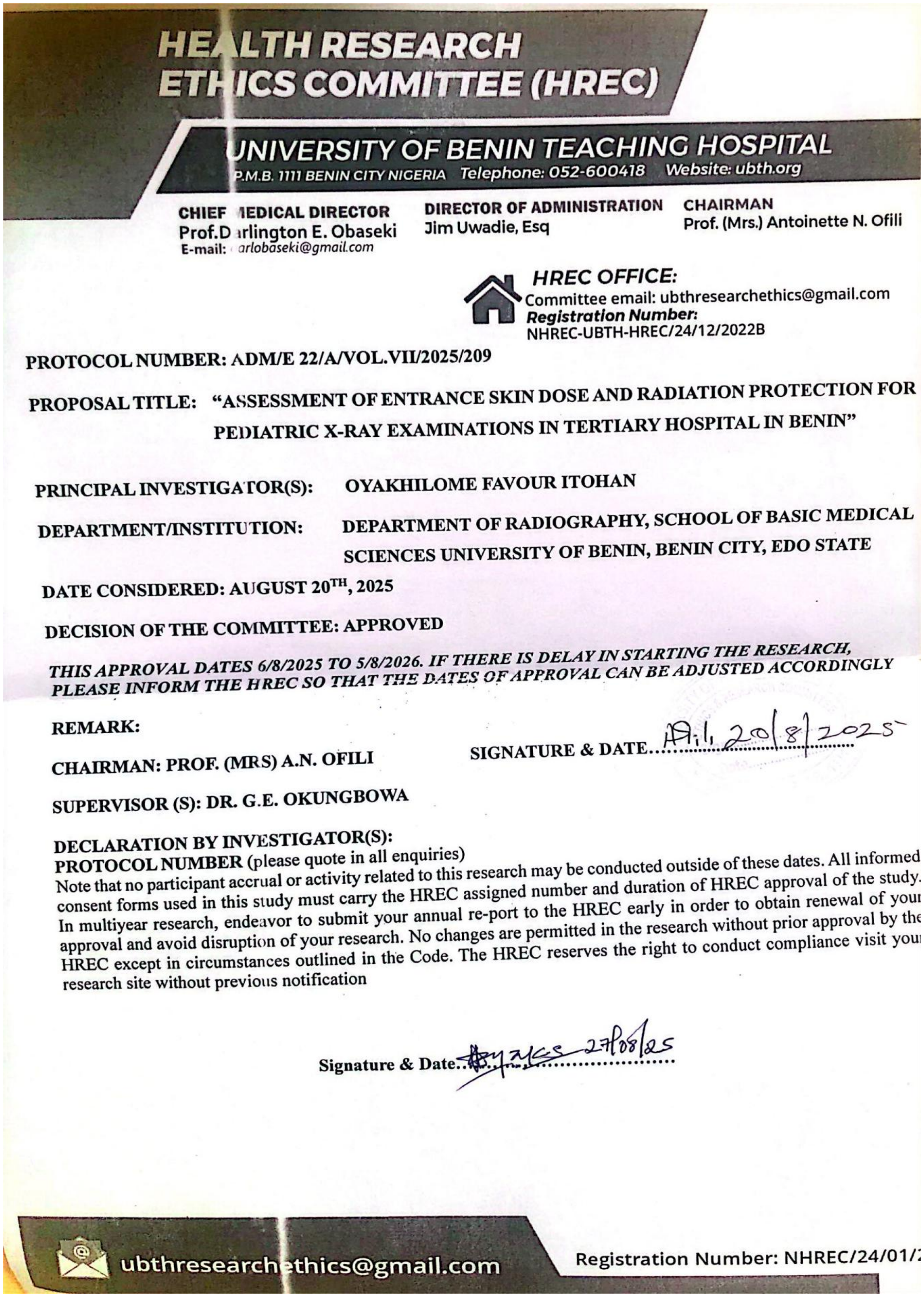
- **kVp**: _______________
- **mAs**: _______________
- **Focus-to-skin distance (FSD)**: _______ cm

Dose Measurements:

- **Measured Entrance Skin Dose**: _______ mGy

APPENDIX B

RESEARCH ETHICAL APPROVAL



HEALTH RESEARCH ETHICS COMMITTEE (HREC)

UNIVERSITY OF BENIN TEACHING HOSPITAL
P.M.B. 1111 BENIN CITY NIGERIA Telephone: 052-600418 Website: ubth.org

CHIEF MEDICAL DIRECTOR
Prof.Darlington E. Obaseki
E-mail: arlobaseki@gmail.com

DIRECTOR OF ADMINISTRATION
Jim Uwadie, Esq

CHAIRMAN
Prof. (Mrs.) Antoinette N. Ofili

HREC OFFICE:
Committee email: ubthresearchethics@gmail.com
Registration Number:
NHREC-UBTH-HREC/24/12/2022B

PROTOCOL NUMBER: ADM/E 22/A/VOL.VII/2025/209

PROPOSAL TITLE: "ASSESSMENT OF ENTRANCE SKIN DOSE AND RADIATION PROTECTION FOR PEDIATRIC X-RAY EXAMINATIONS IN TERTIARY HOSPITAL IN BENIN"

PRINCIPAL INVESTIGATOR(S): OYAKHILOME FAVOUR ITOHAN

DEPARTMENT/INSTITUTION: DEPARTMENT OF RADIOGRAPHY, SCHOOL OF BASIC MEDICAL SCIENCES UNIVERSITY OF BENIN, BENIN CITY, EDO STATE

DATE CONSIDERED: AUGUST 20TH, 2025

DECISION OF THE COMMITTEE: APPROVED

THIS APPROVAL DATES 6/8/2025 TO 5/8/2026. IF THERE IS DELAY IN STARTING THE RESEARCH, PLEASE INFORM THE HREC SO THAT THE DATES OF APPROVAL CAN BE ADJUSTED ACCORDINGLY

REMARK:

CHAIRMAN: PROF. (MRS) A.N. OFILI **SIGNATURE & DATE**........ 20/8/2025

SUPERVISOR (S): DR. G.E. OKUNGBOWA

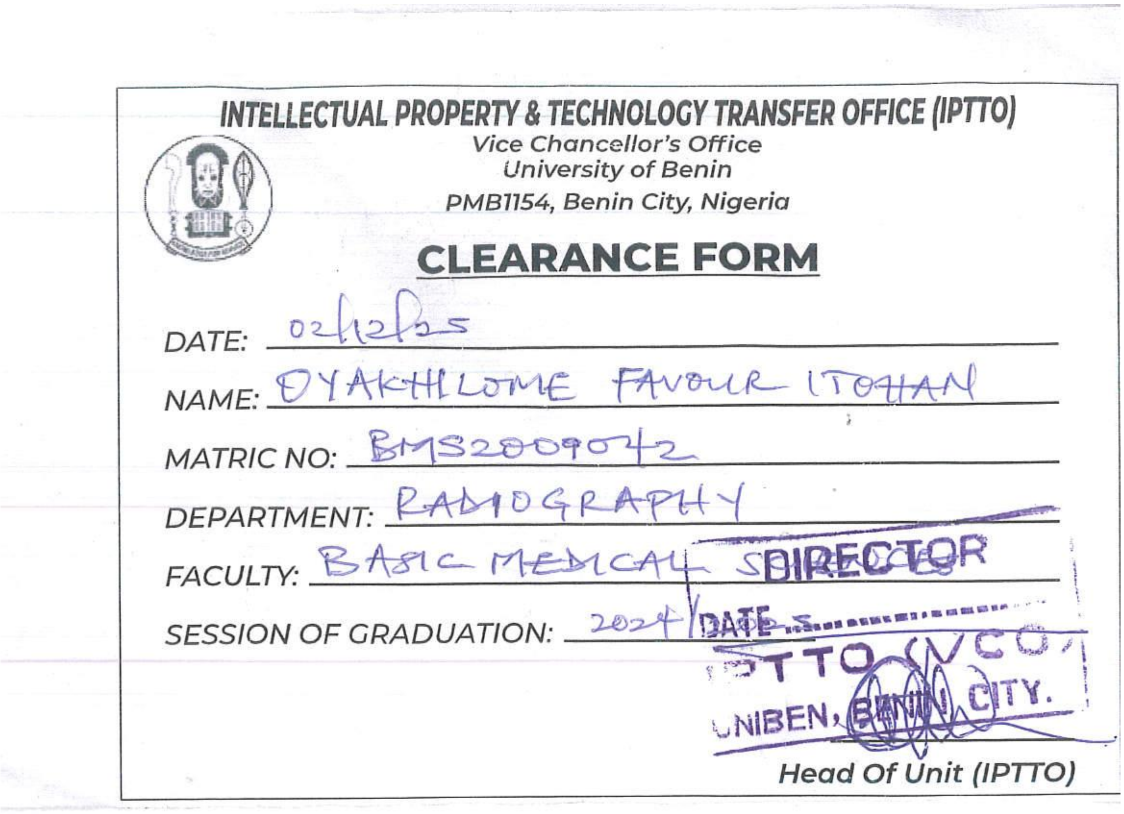
DECLARATION BY INVESTIGATOR(S):
PROTOCOL NUMBER (please quote in all enquiries)
Note that no participant accrual or activity related to this research may be conducted outside of these dates. All informed consent forms used in this study must carry the HREC assigned number and duration of HREC approval of the study. In multiyear research, endeavor to submit your annual re-port to the HREC early in order to obtain renewal of your approval and avoid disruption of your research. No changes are permitted in the research without prior approval by the HREC except in circumstances outlined in the Code. The HREC reserves the right to conduct compliance visit your research site without previous notification

Signature & Date........ 27/08/25

ubthresearchethics@gmail.com Registration Number: NHREC/24/01/

APPENDIX C

PLAGARISM CERTIFCATE



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Vice Chancellor's Office
University of Benin
PMB1154, Benin City, Nigeria

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DATE: 02/12/25

NAME: OYAKHILOME FAVOUR ITOHAN

MATRIC NO: BMS2009042

DEPARTMENT: RADIOGRAPHY

FACULTY: BASIC MEDICAL SCIENCES

SESSION OF GRADUATION: 2024/

DIRECTOR
DATE
IPTTO (VCO)
UNIBEN, BENIN CITY.

Head Of Unit (IPTTO)