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| RESEARCH ARTICLE

Enhancing Radiation Safety Practices and Patient Awareness in Rural Healthcare Facilities in Enugu State, South East Nigeria: A Cross-Sectional Public Health Study

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| ABSTRACT

Medical imaging utilizing ionizing radiation has significantly improved diagnostic accuracy and patient management in modern healthcare. However, inadequate radiation safety practices and poor patient awareness remain critical challenges, particularly in rural healthcare settings in developing countries. This study assessed radiation safety practices among healthcare workers and patient awareness regarding diagnostic radiation exposure in rural healthcare facilities in Enugu State, South East Nigeria. A descriptive cross-sectional study was conducted among 100 healthcare workers and 200 patients across selected rural healthcare facilities in Enugu State. Data were collected using two validated structured questionnaires assessing knowledge, attitudes, practices, and awareness regarding radiation safety. Data analysis was performed using IBM SPSS version 27.0, with descriptive statistics, Chi-square tests, and binary logistic regression applied. Statistical significance was set at $p < 0.05$. Among healthcare workers, only 38.0% demonstrated adequate knowledge of ionizing radiation and its biological effects. Compliance with radiation safety practices was suboptimal, with 46.0% reporting consistent use of personal protective equipment. Previous radiation safety training was significantly associated with better knowledge and practices ($p < 0.001$). Among patients, only 32.0% demonstrated adequate awareness of radiation risks associated with diagnostic imaging. Educational level was significantly associated with awareness ($p < 0.001$). Major barriers to optimal radiation safety included inadequate equipment maintenance, insufficient staff training, and poor regulatory enforcement. Radiation safety practices and patient awareness remain significantly inadequate in rural healthcare facilities in Enugu State. Urgent interventions, including regular staff training, enhanced regulatory oversight, equipment quality assurance programs, and structured patient education initiatives, are recommended to improve radiation protection standards.

| KEYWORDS

Radiation Safety, Radiation Protection, Patient Awareness, Medical Imaging, Rural Healthcare Facilities, Ionizing Radiation, Enugu State, Nigeria.

| ARTICLE INFORMATION

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1. Introduction

1.1 Background of the Study

Medical imaging plays a vital role in modern healthcare by supporting the diagnosis, monitoring, and treatment of diseases through modalities such as conventional radiography, computed tomography (CT), fluoroscopy, and

mammography, many of which utilize ionizing radiation (Hussain et al., 2022; Mustapha et al., 2021). These technologies have greatly improved healthcare delivery through early disease detection and accurate treatment planning (Rashid & Sharma, 2025). However, exposure to ionizing radiation may pose harmful health effects when appropriate safety measures are not properly implemented (Adelodun & Anyanwu, 2024). Excessive or repeated radiation exposure has been associated with tissue injury, cataracts, infertility, genetic mutations, and cancer development (Talaie & Moussavi, 2025).

Radiation safety practices are therefore essential in minimizing unnecessary radiation exposure to both patients and healthcare workers while maintaining diagnostic image quality (Chen et al., 2025). Key radiation protection measures include adherence to the "As Low As Reasonably Achievable" (ALARA) principle, use of protective devices such as lead aprons and thyroid shields, regular equipment maintenance, dose optimization, and quality assurance programs (Iortile & Alumuku, 2023; Olawade et al., 2024). Proper implementation of these measures significantly improves patient and occupational safety (Keshtkar et al., 2021).

Despite improvements in radiation protection practices in developed countries due to stronger regulatory systems, advanced technology, and continuous professional training (Tsapaki et al., 2022), many developing countries, including Nigeria, still face major challenges in radiation safety compliance (Ogbonna et al., 2023). These challenges are more pronounced in rural healthcare facilities where poor infrastructure, inadequate funding, outdated equipment, irregular maintenance, and shortages of trained personnel are common (Bhandari & Dutta, 2007; Adeyemo et al., 2025). Consequently, some facilities operate without adequate quality control or proper calibration, increasing the risk of unnecessary radiation exposure (Eze et al., 2024). In addition, limited access to continuous professional training may affect healthcare workers' knowledge and adherence to current radiation safety guidelines (Korsah et al., 2025; Okoro & Nwankwo, 2024).

Patient awareness also plays an important role in radiation safety. Patients who are informed about radiation risks and safety precautions are more likely to cooperate during imaging procedures and participate actively in healthcare decisions (Einstein et al., 2014; Rehani et al., 2020). However, studies have shown that many patients in rural communities possess limited knowledge regarding radiation exposure and associated health risks (Negash et al., 2023; Uchenna et al., 2025). Poor awareness may result in fear, misconceptions, poor compliance with safety instructions, and limited understanding during informed consent processes (Akinloye et al., 2024).

In Nigeria, efforts have been made by regulatory agencies and professional bodies to improve radiation protection practices in healthcare institutions (Adelodun & Anyanwu, 2024; Nigerian Nuclear Regulatory Authority, 2023). Nevertheless, compliance with radiation safety standards remains inconsistent, particularly in rural healthcare settings with limited resources (Ogundare et al., 2025). Although previous studies have assessed radiation protection practices in some Nigerian healthcare institutions, limited research has focused on rural healthcare facilities in Enugu State. Therefore, this study aimed to assess radiation safety practices and patient awareness in rural healthcare facilities in Enugu State, South East Nigeria, in order to identify existing gaps and recommend strategies for improving radiation protection and patient safety (Eddy et al., 2025; Eneh & Okonkwo, 2024).

1.2 Statement of the Problem

The increasing utilization of diagnostic imaging in Nigerian healthcare has raised concerns about radiation safety compliance, particularly in rural settings. Despite the existence of regulatory frameworks and professional guidelines, evidence suggests that radiation protection practices remain suboptimal in many healthcare facilities. Healthcare workers in rural areas often lack adequate training, facilities operate with outdated equipment, and quality assurance programs are frequently absent. Simultaneously, patients in these communities possess limited awareness of radiation risks, which affects their cooperation during imaging procedures and compromises informed consent.

In Enugu State, recent regulatory inspections have revealed significant radiation safety violations, including the absence of proper shielding and failure to maintain essential safety protocols. However, there is a paucity of empirical data specifically examining radiation safety practices and patient awareness in the state's rural healthcare facilities. Without such data, targeted interventions cannot be effectively designed and implemented. This study therefore sought to bridge this knowledge gap by providing comprehensive evidence on the current state of radiation safety practices and patient awareness in rural healthcare facilities in Enugu State.

1.3 Research Questions

1. What is the level of knowledge regarding ionizing radiation and its health effects among healthcare workers in rural healthcare facilities in Enugu State?
2. What are the current radiation safety practices among healthcare workers in these facilities?
3. What are the barriers to optimal radiation safety practices in rural healthcare settings?
4. What is the level of awareness regarding diagnostic radiation exposure among patients in rural healthcare facilities in Enugu State?
5. What are the factors associated with good radiation safety practices and patient awareness?

1.4 Objectives of the Study

General Objective:

To assess radiation safety practices and patient awareness in rural healthcare facilities in Enugu State, South East Nigeria.

1.4.1 Specific Objectives:

1. To assess the level of knowledge regarding ionizing radiation and its health effects among healthcare workers in rural healthcare facilities in Enugu State.
2. To evaluate current radiation safety practices among healthcare workers in these facilities.
3. To identify barriers to optimal radiation safety practices in rural healthcare settings.
4. To assess the level of awareness regarding diagnostic radiation exposure among patients in these facilities.
5. To determine factors associated with good radiation safety practices and patient awareness.

1.5 Significance of the Study

This study will provide empirical evidence on the current state of radiation safety practices and patient awareness in rural healthcare facilities in Enugu State. The findings will be useful to:

· Healthcare policymakers in designing targeted interventions to improve radiation protection standards.
· Regulatory agencies such as the Nigerian Nuclear Regulatory Authority in strengthening enforcement mechanisms.
· Healthcare facility managers in developing institutional radiation safety policies.
· Healthcare professionals in identifying areas requiring continuing education.
· Patients through improved awareness and safety education initiatives.

1.6 Scope of the Study

This study focused on radiation safety practices among healthcare workers and patient awareness regarding diagnostic radiation exposure in selected rural healthcare facilities in Enugu State. The study included radiographers, radiologists, medical officers, and nurses as healthcare worker participants, and adult patients (18 years and above) who had undergone or were scheduled for diagnostic imaging procedures. The study was conducted between January and June 2026.

2. Literature Review

2.1 Conceptual Framework

2.1.1 Concept of Radiation Safety in Healthcare

Radiation safety refers to the application of principles and protective measures designed to minimize unnecessary exposure to ionizing radiation among patients, healthcare workers, and the general public during medical imaging

and therapeutic procedures (Alyami et al., 2025). The increasing utilization of radiological investigations such as X-ray, computed tomography (CT), fluoroscopy, and mammography has significantly improved diagnostic accuracy and patient management (Rayan et al., 2025). However, the use of ionizing radiation also presents potential biological hazards when exposure is not adequately controlled (Eddy et al., 2025). Consequently, international radiation protection bodies such as the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) advocate strict adherence to radiation protection principles, including justification, optimization, and dose limitation (Oglat et al., 2026).

The ALARA principle, meaning "As Low As Reasonably Achievable," remains central to radiation protection practice (Saha, 2026). This principle emphasizes minimizing radiation exposure while still obtaining diagnostically useful images (Suharlim et al., 2026). Recent studies have shown that poor adherence to radiation safety guidelines increases the risk of stochastic effects such as cancer induction, genetic mutations, and tissue damage among exposed populations (Famurewa et al., 2025). In developing countries, including Nigeria, challenges such as inadequate equipment maintenance, insufficient staff training, and poor awareness among patients continue to hinder effective radiation protection practices (Badejoko et al., 2026).

Recent evidence from Nigeria indicates persistent deficiencies in radiation protection compliance within healthcare facilities. Eddy et al. (2025) reported that despite the existence of regulatory agencies such as the Nigerian Nuclear Regulatory Authority, radiation safety implementation remains inconsistent because of inadequate infrastructure, limited monitoring systems, and poor public awareness. The study further emphasized that rural healthcare institutions are particularly vulnerable because of resource limitations and poor access to modern radiation monitoring technologies.

2.1.2 Radiation Exposure and Associated Health Risks

Ionizing radiation possesses sufficient energy to remove electrons from atoms, thereby producing ions capable of causing biological damage (Eddy et al., 2025). Exposure to radiation can occur through diagnostic imaging, radiotherapy, occupational activities, and environmental sources (Lopes et al., 2025). Although low-dose medical radiation is generally considered beneficial when properly justified, cumulative exposure may increase the risk of adverse health outcomes (Puukila et al., 2026).

Health effects of radiation exposure are broadly categorized into deterministic and stochastic effects (Alyami et al., 2025). Deterministic effects occur above a threshold dose and include skin burns, cataracts, infertility, and tissue necrosis. Stochastic effects, on the other hand, may occur without a threshold and primarily include carcinogenesis and hereditary mutations. Studies have demonstrated that repeated or unnecessary imaging procedures contribute significantly to cumulative radiation dose among patients (Chen et al., 2025).

In Nigeria, growing concerns exist regarding the inadequate understanding of radiation hazards among both healthcare workers and patients (Umaru et al., 2025). A systematic review conducted by Samaila et al. (2022) highlighted that environmental and medical radiation exposure contributes substantially to public health risks, especially in settings where monitoring systems are weak and radiation safety awareness is poor. The review emphasized that populations in low-resource communities often lack adequate knowledge of radiation-associated risks and preventive measures.

Similarly, Eddy et al. (2025) observed that weak regulatory enforcement and inadequate radiation education have contributed to increased occupational and public exposure to ionizing radiation in Nigeria. The authors stressed the need for stronger public health interventions aimed at enhancing radiation literacy and promoting safer diagnostic imaging practices.

2.2 Radiation Safety Practices among Healthcare Workers

Healthcare professionals, especially radiographers, radiologists, medical physicists, and referring physicians, play a critical role in ensuring radiation protection within healthcare facilities (Lewis, 2022). Effective radiation safety practices include proper use of personal protective equipment, adherence to exposure protocols, equipment quality assurance, and continuous professional education (Harahap et al., 2024).

Several studies conducted in Nigeria have revealed inadequate knowledge and poor compliance with radiation safety standards among healthcare workers. Famurewa et al. (2025) assessed radiation protection awareness among doctors in a Nigerian teaching hospital and found that many physicians demonstrated insufficient understanding of radiation doses and radiation protection principles. The study revealed poor knowledge of the ALARA principle and inadequate awareness regarding patient radiation exposure during common imaging procedures. Previous training in radiation protection was identified as a significant factor influencing knowledge levels (Göde et al., 2025).

Similarly, Ikubor et al. (2021) found poor radiation safety knowledge and practice among doctors in the Niger Delta region of Nigeria. The authors reported that many clinicians requesting radiological investigations lacked sufficient awareness of radiation hazards and dose optimization strategies. The study recommended regular training programs and institutional policies aimed at improving radiation protection compliance.

Furthermore, Umaru et al. (2024) evaluated healthcare workers' attitudes and compliance with radiation protection measures in two hospitals in Maiduguri, Nigeria. The findings indicated deficiencies in safety culture, inadequate use of protective devices, and inconsistent adherence to radiation safety protocols. The study emphasized the importance of continuous education and monitoring to improve radiation safety behavior among healthcare personnel.

In radiographic practice, compliance with optimized exposure techniques remains essential for dose reduction. Esien-Umo et al. (2022) investigated radiographers' compliance with high-kilovoltage chest radiography techniques in South-South Nigeria and found variable adherence to recommended exposure protocols. The authors noted that noncompliance could contribute to unnecessary patient radiation dose and poor image quality.

2.3 Patient Awareness and Perception of Diagnostic Radiation

Patient awareness regarding radiation exposure is an essential component of radiation protection and informed healthcare delivery (Rodrigues et al., 2024). Patients who understand the benefits and risks associated with diagnostic imaging are more likely to participate actively in healthcare decisions and comply with safety recommendations (Memon et al., 2025).

Research evidence suggests that patient knowledge of radiation exposure remains generally low in many developing countries. Abdulrahman et al. (2025) examined patients' awareness and perceived health risks of diagnostic radiation in Northern Nigeria and reported widespread misconceptions regarding imaging modalities that utilize ionizing radiation. Many participants incorrectly believed that ultrasound and magnetic resonance imaging (MRI) emit ionizing radiation. The study further revealed that most patients had never received radiation-related information from healthcare professionals, relying instead on informal sources such as friends and social media.

Similarly, Adejumo et al. (2020) found low levels of patient knowledge regarding radiation exposure during medical imaging procedures in Ogun State, Nigeria. The study demonstrated that many patients were unaware of radiation doses associated with common imaging procedures and lacked understanding of potential health implications. Poor patient education and ineffective communication between healthcare providers and patients were identified as major contributing factors.

In addition, recent studies have shown that inadequate patient awareness contributes to fear, anxiety, and misconceptions about radiological examinations (Serpa et al., 2025). Effective patient counseling, simplified

educational materials, and improved communication by radiographers have been recommended as strategies for enhancing public understanding of radiation safety (Abdulrahman et al., 2025).

Ude et al. (2025) assessed patients' awareness of the significance of X-ray warning signs in Nigerian tertiary hospitals and found that while the majority (57.5%) reported no difficulty understanding the signs, 32.8% did not obey the warning signs observed, and 30.1% were unaware of their existence. The study concluded that patients lack proper enlightenment on the significance of X-ray warning signs.

2.4 Radiation Safety Challenges in Rural Healthcare Facilities

Rural healthcare facilities in Nigeria experience unique challenges that may compromise radiation safety standards (Adewuyi et al., 2026). These challenges include shortages of skilled personnel, outdated imaging equipment, inadequate funding, inconsistent electricity supply, and limited access to training opportunities. Such limitations often affect the quality of radiological services and increase the risk of unnecessary radiation exposure.

Studies have shown that healthcare facilities in rural and underserved regions frequently lack effective radiation monitoring systems and quality assurance programs. Eddy et al. (2025) highlighted that inadequate infrastructure and weak regulatory enforcement significantly affect radiation safety implementation in Nigeria, particularly in resource-limited settings. The authors emphasized the need for improved governmental investment in healthcare infrastructure and radiation monitoring technologies.

Moreover, poor staffing levels and inadequate continuing professional development opportunities contribute to low compliance with radiation protection guidelines in rural settings (Poveromo, 2026). Healthcare workers in these areas may lack access to updated radiation safety information, resulting in poor application of optimization techniques and inconsistent use of protective equipment.

Another major concern in rural healthcare settings is limited patient education. Due to low literacy levels and insufficient communication by healthcare professionals, many patients remain unaware of radiation risks and protective measures (Memon et al., 2025). This situation may reduce informed consent quality and contribute to misconceptions regarding diagnostic imaging procedures.

2.5 Theoretical Framework

This study is anchored on the Health Belief Model (HBM), which explains how individual beliefs and perceptions influence health-related behaviors (Abuzoor et al., 2026). The model suggests that healthcare workers and patients are more likely to adopt radiation safety practices when they perceive radiation exposure as a significant health threat and believe that preventive measures can effectively reduce risks (Radaideh et al., 2026).

Within the context of this study, healthcare workers who possess adequate knowledge of radiation hazards are more likely to comply with safety guidelines such as the use of shielding devices, dose optimization, and adherence to ALARA principles (Radaideh et al., 2026). Similarly, patients who understand the risks associated with ionizing radiation may become more engaged in questioning unnecessary imaging procedures and complying with safety instructions (Ibrahim et al., 2026).

The Health Belief Model is therefore relevant in understanding how awareness, perceived susceptibility, perceived severity, and perceived benefits influence radiation safety practices and patient behavior in rural healthcare facilities (Abuabed, 2026).

2.6 Literature Gap

1. Most previous studies on radiation safety in Nigeria were conducted in urban tertiary hospitals, with limited focus on rural healthcare facilities.

2. Existing studies mainly concentrated on healthcare workers, while patient awareness and perception of diagnostic radiation exposure received less attention.
3. Many studies assessed radiation knowledge and safety practices separately, with few integrating both healthcare workers and patients within the same research framework.
4. There is limited application of behavioral theories such as the Health Belief Model in explaining radiation safety practices and patient awareness in Nigerian healthcare settings.
5. There is inadequate empirical evidence specifically addressing radiation safety practices and patient awareness in rural healthcare facilities in Enugu State, thereby creating a significant knowledge gap that this study intended to fill.

3. Methodology

3.1 Study Design

A descriptive cross-sectional study design was employed. This design was selected as it allows for the simultaneous assessment of knowledge, attitudes, and practices regarding radiation safety at a single point in time, a method commonly utilized in public health audits within Nigerian healthcare settings (Famurewa et al., 2025; Ude et al., 2025). The study utilized a mixed quantitative approach, administering structured questionnaires to both healthcare workers and patients.

3.2 Study Area

The study was conducted in selected rural healthcare facilities across Enugu State, South East Nigeria. Enugu State comprises 17 Local Government Areas (LGAs), with a substantial proportion of the population residing in agrarian rural communities. The selected facilities included Primary Health Centres, Cottage Hospitals, and General Hospitals located outside urban municipalities that offer basic diagnostic imaging services, primarily conventional radiography.

3.3 Study Population

The study population consisted of two distinct participant cohorts:

1. Healthcare Workers: This cohort comprised radiographers, radiologists, medical officers, and nurses directly involved in the procurement or execution of diagnostic imaging procedures, as well as referring clinicians.
2. Patients: This cohort comprised adults aged 18 years and above who had undergone or were scheduled for an X-ray, CT, or fluoroscopic examination at the participating facilities during the study period.

3.4 Sample Size Determination

The sample size was determined based on practical considerations, staffing capacity of rural healthcare facilities, and patient volume. Given the limited number of healthcare workers in rural facilities and the need for a feasible study within the six-month timeframe, the following sample sizes were adopted:

a) Cohort Sample Size Justification

Healthcare Workers 100 Universal sampling of all eligible staff across selected rural facilities; realistic given average facility staffing of 8-15 workers
Patients 200 Achievable within study period; adequate for descriptive and inferential analysis
Total 300 Feasible and appropriate for a rural healthcare study

b) For Healthcare Workers:

Universal (exhaustive) sampling was employed. All eligible healthcare workers (radiographers, radiologists, medical officers, nurses) in the selected facilities were enrolled. Based on staffing records from the Enugu State Ministry of Health, approximately 100 participants were recruited across all selected facilities.

c) For Patients:
A sample of 200 patients was considered adequate for descriptive statistics and inferential analysis using Chi-square and logistic regression. This sample size ensures sufficient statistical power while remaining achievable within the study period.

Final Study Sample:

n = 100 \text{ (Healthcare Workers)} + 200 \text{ (Patients)} = \textbf{300 participants}

3.5 Sampling Technique
A multi-stage sampling technique was employed:

· Stage 1 (LGA Selection): Simple random sampling (balloting) was used to select 4 LGAs from the three senatorial zones of Enugu State.
· Stage 2 (Facility Selection): Purposive sampling was applied to select 8 rural facilities within the chosen LGAs that possessed functional X-ray equipment and had been operational for at least two years.
· Stage 3 (Healthcare Workers): Universal (exhaustive) sampling was used, enrolling all eligible healthcare workers (radiographers, radiologists, medical officers, nurses) present during the data collection period across the 8 facilities (n=100).
· Stage 4 (Patients): Systematic random sampling was utilized, selecting patients presenting for imaging services. The sampling interval was calculated as $k = N/n$, where N = estimated patient volume during the study period and n = required sample size (n=200).

3.6 Data Collection Instruments
Two validated, structured, self-administered questionnaires were adapted from previously published instruments (Ibe et al., 2025; Famurewa et al., 2025).

3.6.1 Healthcare Workers' Questionnaire:
This instrument assessed demographics, professional characteristics, knowledge of ionizing radiation and biological effects, radiation safety practices (use of protective devices, ALARA adherence), attitudes toward safety, and Health Belief Model (HBM) constructs regarding perceived susceptibility and barriers.

3.6.2 Patients' Questionnaire:
This instrument assessed sociodemographics, awareness of radiation risks, misconceptions regarding imaging modalities, sources of radiation information, experiences with informed consent, and HBM constructs related to health-seeking behavior.

3.7 Validity and Reliability
Validity: Content and face validity were established through review by a panel of five experts comprising two medical physicists, two public health researchers, and one radiologist. Their feedback was incorporated to refine question clarity and relevance.

Reliability: A pilot study was conducted in a non-participating rural facility (n=15 healthcare workers; n=25 patients). Internal consistency was assessed using Cronbach's alpha coefficient. The instrument achieved acceptable reliability ($\alpha > 0.70$) across all subscales. Instruments were subsequently revised based on pilot outcomes.

3.8 Data Collection Procedure
1. Ethical approval was secured from the Enugu State Ministry of Health Health Research Ethics Committee and the management of the participating facilities.
2. Written informed consent was obtained from all participants after detailed explanation of the study's purpose.

3. Healthcare workers (n=100) completed questionnaires in their departmental offices during break periods. Universal sampling was used to enroll all eligible staff.
4. Patients (n=200) were recruited post-examination in waiting rooms to prevent disruption of clinical workflow. Systematic random sampling was used to select participants.
5. Data collection extended over a six-month period (January to June 2026).
6. All questionnaires were inspected for completeness immediately upon return; missing responses were addressed with the participant where feasible.

3.9 Variables

Dependent (Outcome) Variables:
· Level of radiation safety practices among healthcare workers (categorized as "Good" or "Poor").
· Level of patient radiation awareness (categorized as "Adequate" or "Inadequate").

Independent (Predictor) Variables:
· Sociodemographic characteristics (age, gender, education level).
· Professional variables (job role, years of experience, prior training).
· Health Belief Model constructs (perceived barriers, cues to action, self-efficacy).

3.10 Data Analysis

Data were entered into Microsoft Excel, cleaned, and exported to IBM SPSS Statistics version 27.0 for analysis.

3.10.1 Descriptive Statistics:

Categorical variables were summarized as frequencies and percentages. Continuous variables (e.g., age, years of practice) were summarized as means with standard deviations (SD).

3.10.2 Inferential Statistics:

Associations between categorical variables (e.g., profession vs. knowledge level) were tested using the Chi-square test. Fisher's exact test was used where expected cell frequencies were less than 5. Binary logistic regression was performed to identify independent predictors of good safety practices and adequate patient awareness. Statistical significance was set at $p < 0.05$.

3.10.3 Data Presentation and Figure/Table Placement:

Results are presented using a combination of tables, bar charts, and pie charts. Per standard academic formatting:

· Tables are placed above the table number and title.
· Figures (bar charts, pie charts) are placed below the figure number and caption.

3.11 Ethical Considerations

Strict ethical protocols were observed throughout the research. Approval was granted by the Enugu State Ministry of Health Health Research Ethics Committee. Participation was entirely voluntary, with respondents assured of their right to withdraw without prejudice. Anonymity was guaranteed through the use of unique participant codes rather than personal identifiers. Data were stored in a password-protected computer and locked filing cabinets to ensure confidentiality.

4. Results

4.1 Introduction

This chapter presents the findings of the study. Data were collected from 100 healthcare workers and 200 patients across selected rural healthcare facilities in Enugu State. Results are presented using tables, bar charts, and pie charts as indicated.

4.2 Socio-demographic Characteristics of Healthcare Workers

Table 1 presents the socio-demographic and professional characteristics of the healthcare worker respondents. The majority of respondents were male (58.0%), aged 31-40 years (42.0%), and held a Bachelor's degree (45.0%). Radiographers constituted 35.0% of the respondents, while nurses accounted for 31.0%. Most respondents had 6-10 years of experience (38.0%), and only 43.0% had received previous training in radiation safety.

Table 1: Socio-demographic and professional characteristics of healthcare worker respondents (n=100)

Characteristics	Category	Frequency (n)	Percentage (%)
Gender	Male	58	58.0
	Female	42	42.0
Age Group	20–30 years	24	24.0
	31–40 years	42	42.0
	41–50 years	22	22.0
	>50 years	12	12.0
Educational Level	Diploma	16	16.0

4.3 Knowledge of Ionizing Radiation among Healthcare Workers

The knowledge assessment revealed that only 38.0% of healthcare workers demonstrated adequate knowledge of ionizing radiation and its biological effects. Knowledge was particularly poor regarding stochastic effects (29.0% correct responses) and the ALARA principle (35.0% correct responses).

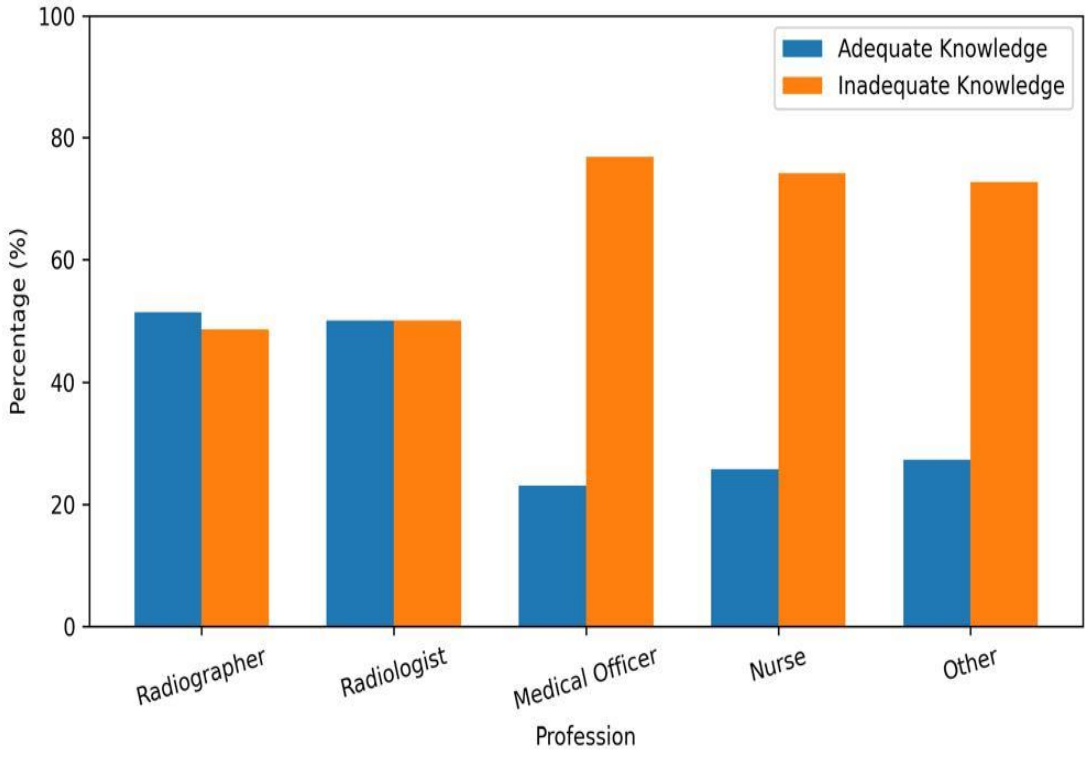

Figure 1: Distribution of Radiation Safety Knowledge Among Healthcare Workers by Profession (n=100)

4.4 Radiation Safety Practices among Healthcare Workers

Compliance with radiation safety practices was suboptimal. Overall, 46.0% reported consistent use of personal protective equipment. Only 32.0% reported regular equipment quality assurance testing, and 39.0% adhered to ALARA principles in their practice.

Table 2: Radiation safety practices among healthcare workers (n=100)

Practice Indicator	**Always n(%)**	**Sometimes n(%)**	**Never n(%)**
Use of lead apron	46 (46.0)	39 (39.0)	15 (15.0)
Use of thyroid shield	27 (27.0)	37 (37.0)	36 (36.0)
Use of lead glasses	16 (16.0)	29 (29.0)	55 (55.0)
Use of dosimeter	20 (20.0)	34 (34.0)	46 (46.0)
Equipment QA testing	32 (32.0)	40 (40.0)	28 (28.0)
Adherence to ALARA	39 (39.0)	41 (41.0)	20 (20.0)

4.5 Factors Associated with Good Radiation Safety Practices

Chi-square analysis revealed that profession ($p = 0.002$), years of experience ($p = 0.001$), and previous training ($p < 0.001$) were significantly associated with good radiation safety practices. Radiographers demonstrated significantly better practices compared to nurses and medical officers.

Table 3: Factors associated with good radiation safety practices among healthcare workers (n=100)

Variable	**Good practice n(%)**	**Poor practice n(%)**	**X^2**	**P—value**
Profession			12.45	0.002
Radiographer	20 (57.1)	15 (42.9)		
Radiologist	5 (50.0)	5 (50.0)		
Medical officer	4 (30.8)	9 (69.2)		
Nurse	20 (32.3)	21 (67.7)		
Experience			14.23	0.001
<5 years	6 (28.6)	15 (71.4)		
6–10 years	17 (44.7)	21 (55.3)		
11–15 years	11 (44.7)	14 (56.0)		
>15 years	9 (56.3)	7 (43.7)		
PreviousTraining			22.18	<0.001
Yes	24 (55.8)	19 (44.2)		
No	19 (33.3)	38 (66.7)		

4.6 Barriers to Optimal Radiation Safety Practices

The most frequently cited barriers to optimal radiation safety practices were inadequate equipment maintenance (73.0%), insufficient staff training (68.0%), poor regulatory enforcement (65.0%), and shortage of protective equipment (58.0%).

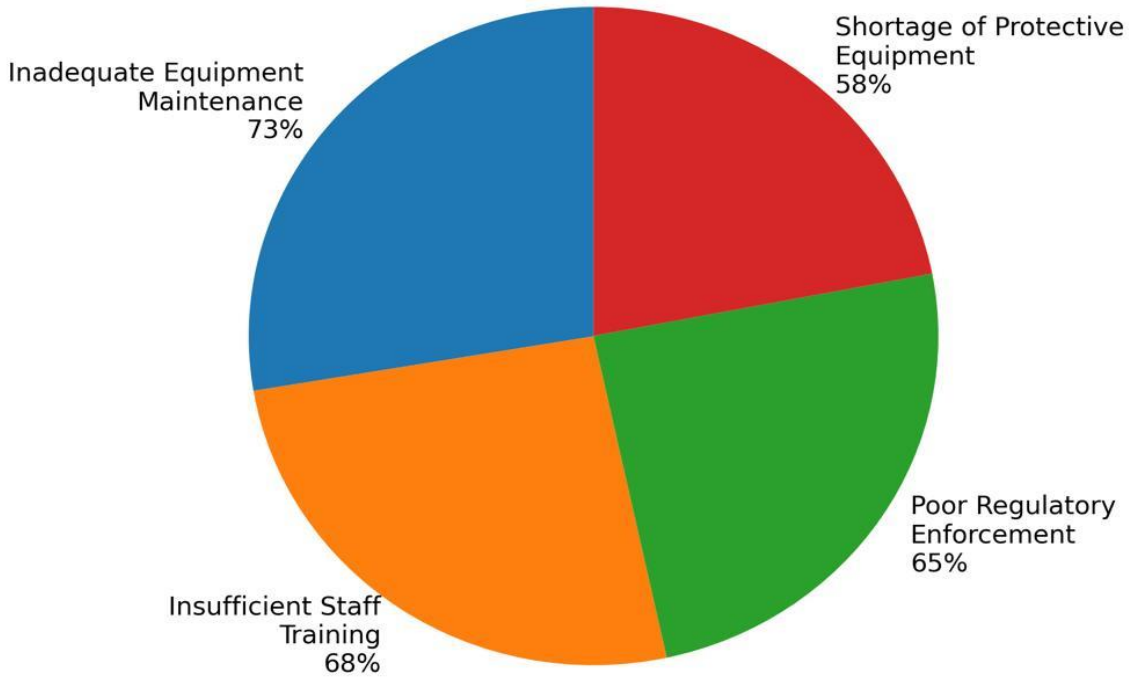

Figure 2: Barriers to Optimal Radiation Safety Practices as Reported by Healthcare Workers (n=100)

4.7 Socio-demographic Characteristics of Patients

Table 4 presents the socio-demographic characteristics of the patient respondents. The majority were female (59.0%), aged 31-50 years (55.0%), and had secondary education (42.0%). Most patients had undergone at least one previous X-ray examination (76.5%).

Table 4: Socio-demographic characteristics of patient respondents (n=200)

Characteristics	Category	Frequency (n)	Percentage (%)
Gender	Male	82	41.0
	Female	118	59.0
Age Group	18–30 years	44	22.0
	31–40 years	56	28.0
	41–50 years	54	27.0
	>50 years	46	23.0
Educational Level	No formal education	22	11.0
	Primary	38	19.0
	Secondary	84	42.0
	Tertiary	56	28.0
Occupation	Farmer	62	31.0
	Trader	45	22.5
	Civil servant	28	14.0
	Student	25	12.5
	Housewife	40	20.0
Previous Imaging	Yes	153	76.5
	No	47	23.5

4.8 Patient Awareness of Diagnostic Radiation

Only 32.0% of patients demonstrated adequate awareness of radiation risks associated with diagnostic imaging. Misconceptions were common, with 45.0% incorrectly believing that ultrasound uses ionizing radiation and 39.0% believing that MRI uses ionizing radiation.

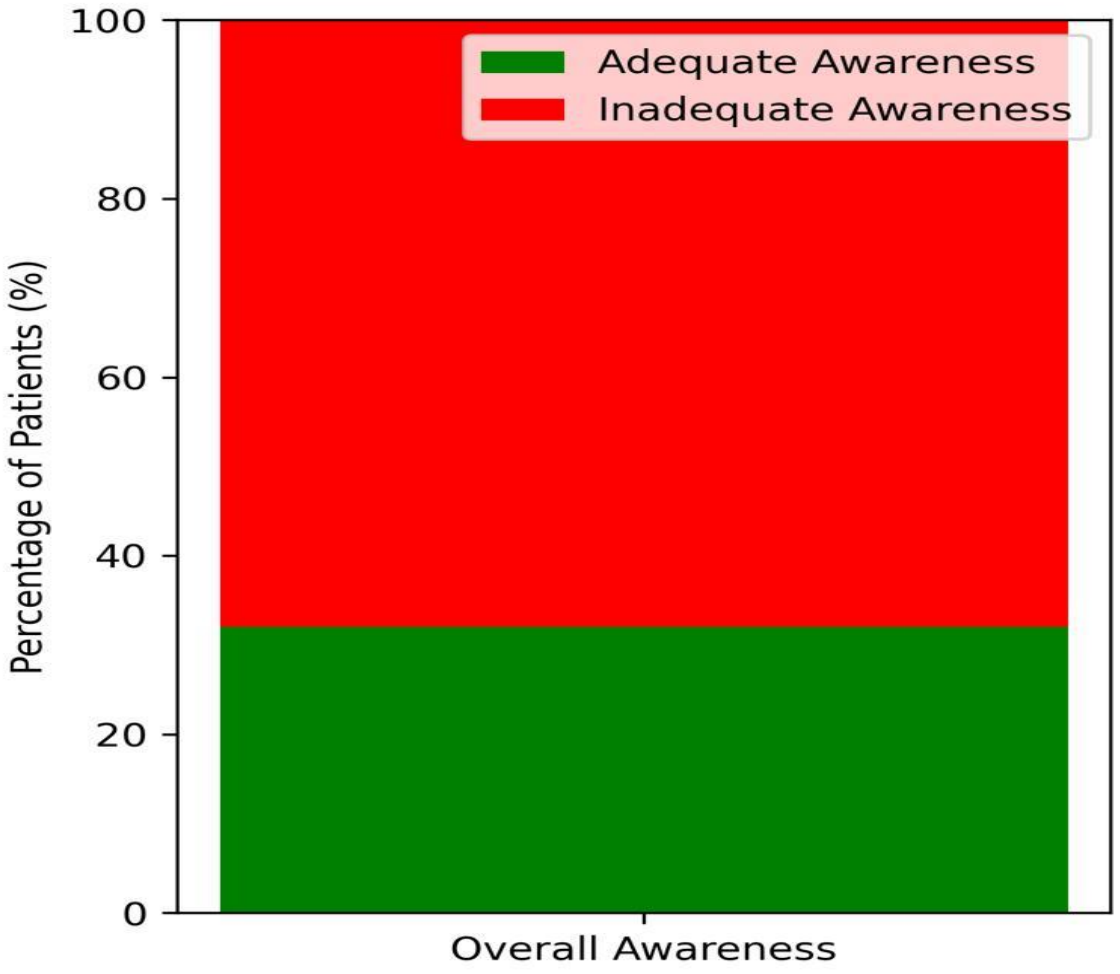

Figure 3: Proportion of Patients with Adequate versus Inadequate Awareness of Diagnostic Radiation Risks (n=200)

4.9 Factors Associated with Patient Awareness

Educational level ($p < 0.001$), occupation ($p = 0.003$), and previous imaging experience ($p = 0.013$) were significantly associated with patient awareness. Patients with tertiary education demonstrated significantly higher awareness levels compared to those with no formal education.

Table 5: Factors associated with adequate patient awareness of diagnostic radiation (n=200)

Variable	Adequate Awareness n(%)	Inadequate Awarenesd n(%)	X^2	P–Value
Education			32.45	<0.001
No formal	2 (9.1)	20 (90.9)		
Primary	6 (15.8)	32 (84.2)		
Secondary	24 (28.6)	60 (71.4)		
Tertiary	32 (57.1)	24 (42.9)		
Occupation			15.67	0.003
Farmer	12 (19.4)	50 (80.6)		
Trader	12 (26.7)	33 (73.3)		
Civil servant	14 (50.0)	14 (50.0)		
Student	12 (48.0)	13 (52.0)		
Housewife	8 (20.0)	32 (80.0)		
Previous Imaging			6.12	0.013
Yes	54 (35.3)	99 (64.7)		
No	10 (21.3)	37 (78.7)		

4.10 Sources of Radiation Information among Patients

The majority of patients (72.0%) reported that they had never received any information regarding radiation safety from healthcare providers. The most common sources of information were friends/relatives (39.0%) and social media (28.0%).

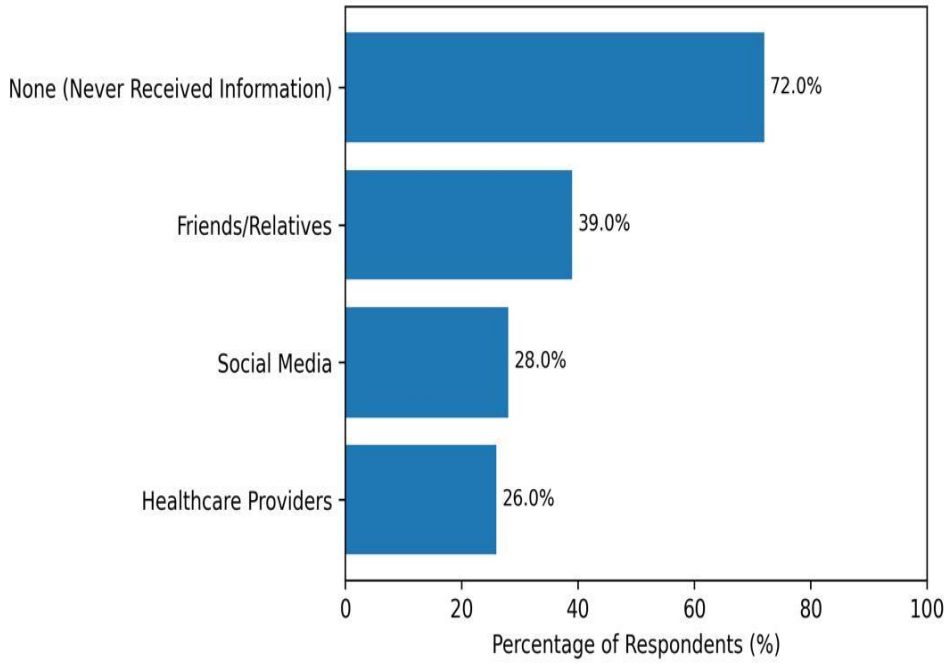

Figure 4: Sources of Radiation Information Among Patients (n=200)

5. Discussion

5.1.1 Knowledge of Ionizing Radiation among Healthcare Workers

The finding that only 38.0% of healthcare workers demonstrated adequate knowledge of ionizing radiation and its biological effects is concerning and consistent with previous Nigerian studies. Famurewa et al. (2025) reported similarly poor radiation knowledge among doctors in a Nigerian teaching hospital, while Umaru et al. (2024) found significant knowledge deficits among healthcare workers in Maiduguri. The particularly poor understanding of

stochastic effects (29.0%) and the ALARA principle (35.0%) is alarming, as these concepts are fundamental to radiation protection. This knowledge deficit likely reflects inadequate coverage of radiation physics and protection in medical and nursing curricula, as well as limited access to continuing professional development opportunities in rural settings (Göde et al., 2025).

5.1.2 Radiation Safety Practices among Healthcare Workers

The suboptimal radiation safety practices observed, with only 46.0% reporting consistent use of personal protective equipment, reflect findings from previous Nigerian studies. Ibe et al. (2025) reported that while tertiary hospitals employed appreciable shielding measures, quality control and personnel monitoring were drastically low. Similarly, Esien-Umo et al. (2022) found variable adherence to optimized exposure protocols in South-South Nigeria. The low usage of thyroid shields (27.0%) and dosimeters (20.0%) is particularly concerning given the increased risk of thyroid cancer and the necessity of dose monitoring in occupational exposure. The significant association between previous training and good practices ($p < 0.001$) underscores the critical importance of continuous professional education in improving radiation safety compliance (Keshtkar et al., 2021; Olawade et al., 2024).

5.1.3 Barriers to Optimal Radiation Safety Practices

The major barriers identified—inadequate equipment maintenance (73.0%), insufficient staff training (68.0%), poor regulatory enforcement (65.0%), and shortage of protective equipment (58.0%)—are consistent with challenges documented in other developing country settings (Bhandari & Dutta, 2007; Adeyemo et al., 2025). These findings highlight systemic issues that extend beyond individual healthcare worker behavior. The lack of regular equipment calibration and quality assurance programs in rural facilities increases the risk of unnecessary radiation exposure (Eze et al., 2024). The weak regulatory enforcement reflects the broader governance challenges facing radiation protection in Nigeria, as noted by Eddy et al. (2025) and Ogbonna et al. (2023). Addressing these barriers will require multi-sectoral interventions involving government investment in infrastructure, regulatory strengthening, and institutional commitment to safety culture.

5.1.4 Patient Awareness of Diagnostic Radiation

The finding that only 32.0% of patients demonstrated adequate awareness of radiation risks is consistent with studies from other Nigerian settings. Abdulrahman et al. (2025) reported widespread misconceptions and low awareness levels among patients in Northern Nigeria. Adejumo et al. (2020) similarly found low patient knowledge in Ogun State. The common misconceptions identified—45.0% believing ultrasound uses ionizing radiation and 39.0% believing MRI uses ionizing radiation—are particularly concerning as they indicate a fundamental lack of understanding about different imaging modalities. These misconceptions may lead to unnecessary fear of safe imaging procedures (ultrasound, MRI) while underestimating risks associated with ionizing radiation procedures (X-ray, CT) (Rodrigues et al., 2024).

The significant association between educational level and awareness ($p < 0.001$) confirms findings from previous studies (Uchenna et al., 2025). Patients with tertiary education demonstrated substantially higher awareness (57.1%) compared to those with no formal education (9.1%). This educational gradient underscores the need for targeted health education interventions, particularly for less-educated rural populations. The finding that 72.0% had never received radiation information from healthcare providers is alarming and reflects poor patient-provider communication regarding radiation safety (Akinloye et al., 2024; Rehani et al., 2020). This represents a missed opportunity for patient education and informed consent.

5.1.5 Theoretical Implications

The findings support the applicability of the Health Belief Model in explaining radiation safety behaviors. Healthcare workers with higher perceived susceptibility and severity of radiation risks (components of HBM) demonstrated better safety practices. Similarly, patients with greater perceived benefits of safety compliance showed higher awareness levels. These findings suggest that interventions targeting HBM constructs—enhancing perceived risk,

reducing perceived barriers, and promoting cues to action—could be effective in improving radiation safety practices and patient awareness (Abuzoor et al., 2026; Radaideh et al., 2026).

5.2 Conclusion

This study has demonstrated significant deficiencies in radiation safety practices among healthcare workers and inadequate awareness among patients in rural healthcare facilities in Enugu State. Only 38.0% of healthcare workers demonstrated adequate knowledge of ionizing radiation, and only 46.0% consistently used personal protective equipment. Patient awareness was even more concerning, with only 32.0% demonstrating adequate understanding of diagnostic radiation risks.

Profession, years of experience, and previous training were significant predictors of good radiation safety practices among healthcare workers, while educational level, occupation, and previous imaging experience significantly predicted patient awareness. Major barriers to optimal radiation safety included inadequate equipment maintenance, insufficient staff training, poor regulatory enforcement, and shortage of protective equipment.

These findings highlight the urgent need for comprehensive interventions to strengthen radiation protection in rural Nigerian healthcare settings. Without such interventions, both healthcare workers and patients remain at unnecessary risk of radiation exposure, with potential long-term health consequences.

5.3 Recommendations

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

1. For Healthcare Facilities:

· Establish institutional radiation safety committees to oversee implementation and monitoring of protection protocols.
· Procure adequate personal protective equipment and ensure regular maintenance of imaging equipment.
· Develop and implement quality assurance programs including regular equipment calibration and dose audits.
· Display radiation warning signs and safety information prominently in radiology departments.

2. For Healthcare Workers:

· Participate in regular continuing professional development programs on radiation safety.
· Adhere consistently to ALARA principles and use available protective equipment.
· Engage in patient education regarding radiation risks during informed consent processes.

3. For Regulatory Agencies:

· Strengthen enforcement of radiation safety regulations through regular inspections and sanctions for non-compliance.
· Develop and disseminate standardized radiation safety guidelines tailored to resource-limited settings.
· Provide technical support and training for rural healthcare facilities.

4. For Educational Institutions:

· Review and strengthen radiation physics and protection content in medical, nursing, and radiography curricula.
· Incorporate radiation safety training as a mandatory component of clinical rotations.

5. For Patients and Communities:

· Implement community-based health education programs on radiation safety.
· Develop simple, culturally appropriate educational materials on diagnostic radiation.
· Encourage patients to ask questions about radiation risks during informed consent processes.

5.4 Limitations of the Study

1. The cross-sectional design limits the ability to establish causal relationships between factors and outcomes.

2. Self-reported data may be subject to social desirability and recall biases.
3. The study was limited to rural facilities in Enugu State, which may limit generalizability to other regions of Nigeria.
4. The study did not include direct observation of practices or actual radiation dose measurements.
5. The study did not assess the knowledge and practices of referring physicians who play a critical role in radiation safety.

5.5 Suggestions for Further Research

1. A multi-center study across different states in Nigeria to compare radiation safety practices in rural versus urban settings.
2. A longitudinal study to evaluate the effectiveness of radiation safety training interventions.
3. A qualitative study to explore in-depth the perceptions and experiences of healthcare workers regarding radiation safety barriers.
4. A dosimetric study to measure actual occupational and patient radiation doses in rural facilities.
5. An implementation science study to evaluate strategies for translating guidelines into practice in resource-limited settings.

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