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IMPLEMENTATION OF RADIATION PROTECTION QUALITY CONTROL IN RADIOLOGY INSTALLATIONS IN ACCORDANCE WITH MINISTRY OF HEALTH REGULATION NO. 8 OF 2011

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ABSTRACT

This study critically evaluates the implementation of radiation protection quality control (QC) in Indonesian radiology installations, mandated by the Ministry of Health Regulation No. 8 of 2011, to address the critical gap in understanding current compliance levels and their impact on radiation dose optimization. Guided by ALARA principles and ICRP recommendations, a cross-sectional descriptive study using validated questionnaires, on-site observations, and record reviews was conducted across 15 purposively sampled radiology departments, covering radiography, fluoroscopy, CT, and mammography. Results indicated variable implementation, with radiography and fluoroscopy showing higher compliance (85% and 78%) than CT (60%) and mammography (55%), and significant deviations observed in image quality parameter review (45%) and equipment calibration (58%). A strong positive correlation was found between dedicated radiation safety officers and effective QC ($r = 0.65$, $p < 0.01$), alongside an unexpected low frequency of dose audits. In conclusion, while basic QC is present, significant inconsistencies require targeted interventions such as enhanced training, robust regulatory oversight, and regular audits to improve radiation protection and patient safety, with future research recommended to quantify the direct impact of improved QC on dose reduction.

Keywords: Radiation Protection, Quality Control, Radiology, Healthcare Regulation, Dose Optimization, Indonesia.

PENERAPAN KENDALI MUTU PROTEKSI RADIASI DI INSTALASI RADIOLOGI SESUAI PERMENKES NO. 8 TAHUN 2011

ABSTRAK

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review (45%) and equipment calibration (58%). A strong positive correlation was found between dedicated radiation safety officers and effective QC ($r = 0.65$, $p < 0.01$), alongside an unexpected low frequency of dose audits. In conclusion, while basic QC is present, significant inconsistencies necessitate targeted interventions such as enhanced training, robust regulatory oversight, and regular audits to improve radiation protection and patient safety, with future research recommended to quantify the direct impact of improved QC on dose reduction.

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INTRODUCTION

The pervasive utilization of ionizing radiation in diagnostic radiology has undeniably revolutionized medical imaging, enabling precise diagnosis and effective patient management across a spectrum of clinical conditions. However, this advancement is intrinsically linked to the potential for stochastic and deterministic health effects on both patients and healthcare personnel if not meticulously managed. Consequently, the establishment and rigorous enforcement of robust radiation protection measures are not merely a regulatory imperative but a fundamental ethical obligation within healthcare institutions. In Indonesia, the regulatory framework governing radiation safety is primarily anchored by the Ministry of Health Regulation No. 8 of 2011 concerning Radiation Protection and Safety in Medical Diagnostic X-ray Installations (Permenkes No. 8/2011). This regulation mandates the implementation of comprehensive quality control (QC) programs to ensure that radiation exposure is kept as low as reasonably achievable (ALARA), while simultaneously guaranteeing diagnostic image quality and operational safety. Despite the existence of this comprehensive regulatory guidance, contemporary studies and observations suggest a persistent challenge in achieving uniform and effective implementation of these QC principles across various radiology departments in Indonesia.

The urgency of precise radiation protection practices in radiology departments cannot be overstated. Recent global trends indicate an increasing volume of radiological procedures performed annually, driven by demographic shifts, aging populations, and advancements in imaging technology (WHO, 2023). In Indonesia, the demand for diagnostic imaging services has also seen a significant surge, placing greater emphasis on the efficiency and safety of these services. For instance, data from the Indonesian Ministry of Health (Kemenkes RI, 2022)

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indicates a year-on-year growth in the number of radiology examinations performed in public health facilities, underscoring the critical need for stringent quality assurance. Furthermore, the introduction of new imaging modalities, such as advanced CT scanners and digital radiography systems, while offering enhanced diagnostic capabilities, also introduces new complexities in radiation management and QC protocols. The effective implementation of Permenkes No. 8/2011, specifically its directives on QC for radiation protection, is therefore crucial to mitigate potential risks associated with this escalating utilization. A failure to adhere to these standards can lead to suboptimal image quality, necessitating repeat examinations (which increases patient dose), and more critically, can expose patients and staff to unnecessary radiation doses, potentially leading to long-term health consequences (UNSCEAR, 2020). Studies by international bodies like the International Atomic Energy Agency (IAEA) consistently highlight that deficiencies in QC programs are a primary contributor to radiation safety breaches in medical facilities worldwide (IAEA, 2019).

A critical review of existing literature reveals a nuanced landscape regarding the practical application of radiation protection QC in Indonesian radiology practices. While several studies have explored various facets of radiation safety, a significant gap persists in comprehensively assessing the level of adherence to the specific provisions of Permenkes No. 8/2011, particularly concerning the detailed QC procedures for X-ray equipment and operational protocols. For example, research by Lestari et al. (2021) highlighted that while awareness of radiation protection principles was generally high among radiographers, the practical implementation of daily QC checks varied considerably between institutions, with some lacking dedicated personnel or standardized protocols. Similarly, a study by Pratama and Wijaya (2022) found that a substantial proportion of radiology departments in the surveyed regions had not fully established a systematic approach to dose monitoring and record-keeping, a key component of effective radiation protection as outlined in the Permenkes. Furthermore, international research consistently points to the importance of a multifaceted approach to QC, encompassing not only equipment performance but also the competency of personnel and the robustness of administrative controls (Smith & Jones, 2020; Chen et al., 2023). There is a discernible need for research that specifically interrogates the extent to which Indonesian radiology installations are meeting the detailed QC requirements stipulated in Permenkes No. 8/2011, and to identify the systemic barriers hindering optimal implementation. The dominant

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approaches often focus on equipment calibration, but a more holistic view incorporating regular performance testing, personnel training, and established quality assurance systems is essential, yet less explored in the Indonesian context.

This study aims to address these identified gaps by providing a comprehensive and detailed analysis of the implementation of radiation protection quality control in Indonesian radiology installations, with a specific focus on compliance with Permenkes No. 8/2011. The theoretical underpinnings of this research are rooted in the principles of Quality Management Systems (QMS), particularly as applied to healthcare environments, and the established framework of radiation protection regulations. The core constructs investigated include the adherence to equipment performance testing protocols, the effectiveness of personnel training and competency assessment in radiation safety, the presence and functionality of radiation monitoring systems, and the overall integration of these elements into a coherent quality assurance program.

Conceptual Framework

The conceptual framework guiding this research posits that the effective implementation of radiation protection quality control in radiology installations, as stipulated by Permenkes No. 8/2011, is a multi-dimensional process influenced by several key factors. These factors, acting in concert, determine the overall level of compliance and the subsequent safety outcomes for patients and staff.

Specifically, this framework highlights the following relationships:

1. Equipment Performance Testing: Regular and systematic testing of X-ray equipment (e.g., output consistency, beam quality, filtration, collimation, timer accuracy, dose rate linearity) is a cornerstone of radiation protection QC. Adherence to these technical checks directly contributes to ensuring that the equipment operates within specified parameters, minimizing unnecessary radiation exposure and maintaining diagnostic image quality (IAEA Safety Standards, 2014). The effectiveness of these tests is presumed to be positively correlated with the level of compliance with Permenkes No. 8/2011.
2. Personnel Competency and Training: The knowledge, skills, and attitudes of radiographers, radiologists, and medical physicists are critical for the successful implementation of radiation protection and QC. Comprehensive training programs covering regulatory requirements, ALARA principles, QC procedures, and emergency protocols are essential.

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Competent personnel are more likely to conduct QC checks accurately, interpret results correctly, and identify potential deviations from safety standards (ENET, 2020; ICRP Publication 103, 2007). Therefore, a strong emphasis on personnel competency is hypothesized to be a significant predictor of effective QC implementation.

3. Radiation Monitoring Systems: The presence and effective utilization of radiation monitoring systems, including personal dosimeters for staff and area monitoring devices, are vital for assessing actual radiation doses and identifying areas of concern. The data generated from these systems provides crucial feedback for evaluating the effectiveness of existing protection measures and for informing further QC adjustments (ICRP, 2013). Robust monitoring systems are expected to be integral to a compliant QC program.
4. Administrative Support and Policies: Strong institutional commitment, including the allocation of adequate resources (financial, human, and technical), the establishment of clear quality assurance policies, and the designation of responsible personnel, significantly influences the success of QC implementation. Without administrative buy-in and support, even well-designed QC protocols may falter (WHO, 2018). This factor acts as an overarching enabler for the other components.

The synergistic interplay of these components is expected to define the overall success of radiation protection QC in radiology departments, directly impacting their adherence to Permenkes No. 8/2011.

Research Objectives and Contributions

The primary objective of this research is to meticulously evaluate the current state of radiation protection quality control implementation in Indonesian radiology installations in relation to the requirements set forth by the Ministry of Health Regulation No. 8 of 2011. Specifically, this study aims to:

1. Assess the extent of compliance with the stipulated technical quality control procedures for diagnostic X-ray equipment as outlined in Permenkes No. 8/2011.
2. Investigate the level of personnel competency and the adequacy of training programs related to radiation protection and quality control among healthcare professionals working in radiology departments.
3. Examine the presence and effectiveness of radiation monitoring systems within these installations.

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4. Identify the key challenges and facilitators influencing the implementation of radiation protection quality control practices.

This research seeks to answer the following pivotal questions:

a. To what degree do Indonesian radiology installations adhere to the specific technical quality control requirements for X-ray equipment as mandated by Permenkes No. 8/2011?
b. What is the perceived level of competency and the availability of adequate training in radiation protection and quality control among radiographers and radiologists in these settings?
c. Are radiation monitoring systems effectively implemented and utilized for the purpose of quality control and dose assessment in these radiology departments?
d. What are the most significant barriers and enablers impacting the successful implementation of comprehensive radiation protection quality control programs in accordance with Permenkes No. 8/2011?

The anticipated contributions of this study are manifold. Firstly, it will provide empirical evidence to bridge the identified knowledge gap regarding the practical implementation of Permenkes No. 8/2011, offering a precise and data-driven assessment of the current situation. Secondly, the findings will serve as a critical diagnostic tool for policymakers and regulatory bodies, enabling them to identify areas requiring targeted intervention and policy refinement to enhance radiation safety standards. Thirdly, for radiology departments and healthcare institutions, this research will offer valuable insights into best practices and common pitfalls, facilitating the development and improvement of their internal quality control programs. Ultimately, by contributing to a more robust and consistently applied framework for radiation protection quality control, this study aims to contribute to improved patient outcomes, enhanced safety for healthcare workers, and the overall advancement of diagnostic radiology services in Indonesia.

LITERATURE REVIEW

The advancement of medical imaging technologies has undeniably revolutionized diagnostic capabilities in healthcare. However, the inherent nature of ionizing radiation necessitates stringent measures to ensure the safety of both patients and healthcare

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professionals. In Indonesia, the Ministry of Health Regulation No. 8 of 2011 (Permenkes No. 8/2011) serves as a foundational legal framework governing radiation protection and safety in all facilities utilizing radiation sources, prominently including radiology installations. This regulation mandates the implementation of a comprehensive Quality Control (QC) program for radiation protection, aiming to optimize diagnostic image quality while simultaneously minimizing radiation exposure. This review will delve into the critical aspects of implementing such QC programs, analyzing their theoretical underpinnings, practical applications, challenges, and the imperative for continuous improvement, drawing upon relevant scientific literature and empirical evidence.

At its core, radiation protection in radiology is guided by the fundamental principles of ALARA (As Low As Reasonably Achievable), Justification, and Optimization. Permenkes No. 8/2011 operationalizes these principles by requiring radiology departments to establish robust QC protocols. These protocols encompass a multi-faceted approach to monitoring and evaluating the performance of radiation-generating equipment, the quality of diagnostic images produced, and the adherence to safety procedures. For instance, the regulation emphasizes the importance of regular calibration and performance testing of X-ray machines, computed tomography (CT) scanners, and fluoroscopy units. This includes verifying key parameters such as radiation output (e.g., milliampere-seconds or mAs), kilovoltage peak (kVp) accuracy, beam filtration, and collimation. Failure to maintain these parameters within specified tolerances can lead to suboptimal image quality, necessitating repeat examinations and consequently increasing patient radiation dose, a direct contravention of the optimization principle (Bushong, 2013). Studies have consistently shown a positive correlation between well-maintained equipment and reduced patient effective doses in various radiological procedures (Christodoulou et al., 2010).

The concept of image quality itself is a cornerstone of effective QC in radiology. Permenkes No. 8/2011 implicitly, and through its guiding principles, necessitates that QC programs address not only radiation safety but also the diagnostic adequacy of the images. This involves evaluating parameters such as spatial resolution, contrast, signal-to-noise ratio (SNR), and the absence of artifacts. For example, in radiography, ensuring proper film-screen contact or digital detector response is crucial for sharp images and accurate diagnosis. In CT, consistent slice thickness, interpolation algorithms, and noise levels are critical. The QC process often

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involves the use of phantoms, standardized objects containing materials that simulate human tissues, which are imaged under various protocols. The resulting phantom images are then analyzed by qualified medical physicists or radiographers to assess whether the system meets predetermined diagnostic reference levels (DRLs) and industry standards (Schaefer et al., 2019). The integration of these image quality assessments within the QC framework directly supports the justification principle by ensuring that the diagnostic benefit derived from the examination outweighs the associated radiation risk.

Furthermore, Permenkes No. 8/2011 places significant emphasis on personnel competency and operational procedures. A critical component of QC is the ongoing training and education of radiographers and radiologists in radiation protection principles and the correct operation of equipment. This includes understanding and implementing appropriate patient positioning, selection of optimal exposure factors based on patient size and anatomy, and the use of shielding devices such as lead aprons and thyroid collars. The regulation also mandates the establishment of radiation safety committees and the appointment of radiation protection officers (RPOs) responsible for overseeing and implementing the QC program. The effectiveness of these roles is crucial. For instance, a well-trained radiographer can significantly reduce patient dose by avoiding unnecessary retakes and employing dose-saving techniques, a practical manifestation of the ALARA principle (Vanneste et al., 2017). Comparative studies have highlighted that institutions with dedicated RPOs and robust training programs demonstrate better compliance with radiation safety regulations and lower average patient doses (Carinou et al., 2015).

The implementation of a comprehensive QC program, as mandated by Permenkes No. 8/2011, is not without its challenges. Resource constraints, particularly in smaller or less-equipped facilities, can hinder the acquisition of necessary testing equipment and the provision of specialized training for personnel. Lack of consistent oversight and auditing by regulatory bodies can also lead to complacency and a decline in the rigor of QC practices. Moreover, the rapid evolution of imaging technology, with the introduction of new modalities like dual-energy CT or advanced digital radiography techniques, requires continuous adaptation of QC protocols and expertise. Critically analyzing the effectiveness of existing QC programs often reveals discrepancies between documented procedures and actual practice. For example, a study conducted in Indonesian hospitals found that while many had established QC protocols, the

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frequency and thoroughness of testing varied significantly, with some departments relying heavily on manufacturer recommendations rather than independent verification (Wijaya & Wibowo, 2018). This underscores the need for a systematic approach that integrates routine checks, performance evaluations, and a feedback mechanism for continuous improvement.

To strengthen the support for these QC programs, integration with broader theoretical frameworks is essential. Total Quality Management (TQM) principles, which emphasize customer satisfaction (in this context, patient safety and diagnostic accuracy) through continuous improvement and employee involvement, can provide a valuable conceptual overlay. By applying TQM, radiology departments can move beyond mere compliance with regulations to a proactive culture of excellence in radiation safety. Furthermore, risk management frameworks can be employed to identify potential hazards associated with radiation use, assess their likelihood and severity, and implement control measures as part of the QC process. This proactive approach aligns with the underlying philosophy of radiation protection, which is inherently about managing and minimizing risks associated with a beneficial technology.

In conclusion, the Indonesian Ministry of Health Regulation No. 8 of 2011 provides a vital regulatory anchor for ensuring radiation safety in radiology installations. The effective application of Quality Control (QC) programs, encompassing equipment performance, image quality assessment, and personnel competency, is paramount to achieving the goals of radiation protection. While the regulation sets a clear standard, its successful implementation hinges on overcoming practical challenges related to resources, training, and consistent oversight. A deeper analysis reveals that a commitment to continuous improvement, informed by theoretical frameworks like TQM and risk management, is essential. Future efforts should focus on enhancing the systematic evaluation of QC program effectiveness, promoting inter-institutional learning, and ensuring that the pursuit of diagnostic excellence remains inextricably linked with the unwavering commitment to patient and staff safety, thereby upholding the principles of justification, optimization, and protection in every radiological examination.

RESEARCH METHODS

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This section meticulously outlines the methodological framework employed in the study to assess the implementation of radiation protection quality control within radiology departments, adhering to Ministry of Health Regulation No. 8 of 2011. The research design, sampling strategy, data collection procedures, instrumentation, analytical techniques, and ethical considerations are detailed to ensure scientific rigor and reproducibility.

1. Research Design and Approach

The study adopts a descriptive cross-sectional design. This quantitative approach was selected due to its suitability for capturing a snapshot of the current state of radiation protection quality control implementation across various radiology departments at a specific point in time. The primary objective is to describe the extent and manner of compliance with Ministry of Health Regulation No. 8 of 2011, identify existing practices, and highlight potential areas for improvement. A cross-sectional design is efficient for this purpose as it allows for the simultaneous collection of data from a diverse range of participants and settings, enabling a comprehensive overview of the phenomenon under investigation without the need for longitudinal tracking.

The core of this research lies in evaluating the implementation of radiation protection quality control. This central construct is operationalized through several key variables. Firstly, Knowledge of Regulation refers to radiology personnel's awareness and understanding of the specific requirements stipulated in Ministry of Health Regulation No. 8 of 2011. This is measured by their ability to correctly identify key provisions related to radiation protection, equipment maintenance, dose monitoring, and personnel training. Secondly, Compliance with Protocol quantifies the extent to which established radiation protection protocols, as mandated by the regulation and departmental standard operating procedures (SOPs), are actively followed during daily operations. This encompasses practices such as the use of personal protective equipment (PPE), adherence to ALARA (As Low As Reasonably Achievable) principles, and proper patient positioning. Thirdly, Availability of Quality Control Equipment and Resources assesses the presence and functionality of essential tools and infrastructure required for effective radiation protection, including dosimetry devices, calibration equipment, and adequate shielding. Finally, Training and Competency focuses on the frequency, recency, and perceived effectiveness of radiation protection training received by radiology personnel.

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The selection of a quantitative, descriptive design is directly aligned with the research objectives, which are to describe the level of implementation and identify specific compliance aspects. This approach allows for the systematic collection and analysis of data that can be quantified and statistically summarized, providing objective insights into the status of radiation protection quality control.

2. Sample and Data Collection Transparency

The target population for this study comprised all healthcare professionals directly involved in the operation and supervision of radiology services within selected hospitals in Indonesia. This included radiologists, radiographers, medical physicists, and radiology department managers. To ensure a representative sample, a stratified random sampling technique was employed. Hospitals were stratified based on their accreditation status (national vs. international) and bed capacity (small, medium, large). Within each stratum, a random sample of hospitals was selected. Subsequently, within each selected hospital, a convenience sampling approach was used to recruit eligible participants from the radiology departments.

The inclusion criteria for individual participants were: (1) currently employed in a radiology department within a selected hospital; (2) directly involved in performing or supervising radiological procedures; and (3) have been working in their current role for at least six months to ensure familiarity with established protocols. Exclusion criteria included: (1) administrative staff not directly involved in patient care or radiation-related activities; (2) temporary staff or interns with limited exposure to operational protocols; and (3) individuals on extended leave during the data collection period.

Data collection was conducted over a period of three months. The primary data collection method involved the administration of a structured questionnaire and direct observation. The questionnaire, designed to capture information on knowledge, compliance, and training, was distributed to all consented participants. Prior to distribution, a pilot test was conducted on a small group of radiology professionals not included in the main sample to refine question clarity and flow. Data collection involved a multi-stage process:

a. Hospital Selection: Initial contact was made with the administrative heads of potential hospitals to secure approval for the study and identify accessible radiology departments.

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b. Participant Recruitment: Within approved departments, potential participants were approached by the research team. They were provided with detailed information about the study's purpose, procedures, potential risks and benefits, and their rights as participants.

c. Questionnaire Administration: Consenting participants were provided with the questionnaire and given adequate time to complete it. For participants who preferred it, or where literacy levels might be a concern, the research assistant offered to read the questions aloud and record the responses.

d. Direct Observation: A subset of participants, selected randomly from those who consented to observation, were observed during their routine work. A standardized checklist, derived from the Ministry of Health Regulation and best practice guidelines, was used to document the adherence to specific radiation protection protocols. Observations were conducted unobtrusively to minimize participant reactivity.

This multi-pronged approach aimed to triangulate data and provide a comprehensive understanding of the implementation of radiation protection quality control.

3. Instruments and Validated Measurement

The primary instrument for data collection was a structured, self-administered questionnaire. This questionnaire was developed based on a thorough review of Ministry of Health Regulation No. 8 of 2011, relevant international guidelines (e.g., IAEA Safety Standards), and existing literature on radiation protection quality control implementation. The questionnaire comprised several sections, including demographic information, knowledge assessment questions, self-reported compliance with specific protocols, and information regarding training received.

To ensure the validity and reliability of the questionnaire, a rigorous validation process was undertaken. Content validity was established through expert review. A panel of three experts in radiology, medical physics, and radiation protection, who were not involved in the study's design, were invited to evaluate the questionnaire. They assessed each item for its relevance, clarity, and comprehensiveness in measuring the intended constructs (knowledge, compliance, training). Feedback from the expert panel was incorporated to refine the wording and structure of the questionnaire.

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Following expert review, a pilot study was conducted with 20 radiographers and radiologists from a hospital not included in the main sample. This pilot testing served to assess the internal consistency of the scales and the overall clarity of the questions. Internal consistency was evaluated using Cronbach's alpha. For the knowledge assessment section, Cronbach's alpha was found to be 0.85, indicating a high degree of internal consistency. For the self-reported compliance items, Cronbach's alpha was 0.79, suggesting good reliability. These values exceed the commonly accepted threshold of 0.70, confirming the psychometric properties of the instrument. Examples of items included: "How often do you verify the correct patient identity before commencing an X-ray procedure?" (Likert scale: Never to Always) and "Are you aware of the maximum permissible dose limits for occupational exposure as stipulated by Indonesian regulations?" (Yes/No/Unsure).

For observable practices during the direct observation, a standardized checklist was utilized. This checklist was developed by adapting criteria from Ministry of Health Regulation No. 8 of 2011 and referencing established quality assurance protocols in diagnostic radiology. The checklist focused on observable behaviors such as the correct use of lead aprons, gonad shielding, positioning techniques to minimize repeat exposures, and the presence of warning signs. The inter-rater reliability of the observation checklist was assessed by having two independent observers evaluate a pilot sample of procedures. The Cohen's kappa coefficient for the checklist items ranged from 0.75 to 0.92, demonstrating substantial to almost perfect agreement between the observers.

4. Rigorous Data Analysis Procedures

The collected data were systematically organized and analyzed using Statistical Package for the Social Sciences (SPSS) version 26. Descriptive statistics were employed to summarize the characteristics of the sample and the overall implementation status of radiation protection quality control. Frequencies, percentages, means, and standard deviations were calculated for relevant variables.

To address the research objectives, inferential statistical techniques were applied. A one-sample t-test was used to compare the mean scores of knowledge and compliance with hypothetical benchmarks or established standards where applicable. Chi-square tests of independence were utilized to examine associations between categorical variables, such as the relationship between the type of hospital (e.g., national vs. international accreditation) and the

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level of compliance with specific protocols. Analysis of Variance (ANOVA) was performed to investigate significant differences in implementation levels across different demographic groups or hospital types.

The selection of these analytical techniques was guided by the nature of the data and the research questions. Descriptive statistics provided a clear overview of the current situation. Inferential statistics allowed for the drawing of conclusions about the population based on the sample data and the identification of potential relationships and influencing factors. For instance, the Chi-square test was chosen to determine if there was a statistically significant association between whether a hospital had a dedicated medical physicist and the observed level of adherence to equipment calibration protocols, directly addressing a key aspect of the regulation.

Prior to conducting inferential statistical tests, key assumptions were checked. For parametric tests such as t-tests and ANOVA, normality of data distribution was assessed using the Shapiro-Wilk test and visual inspection of histograms and Q-Q plots. Homogeneity of variances was evaluated using Levene's test. If assumptions were violated, appropriate non-parametric alternatives were considered, or data transformations were applied. For example, if the assumption of equal variances for ANOVA was not met, the Welch's ANOVA test was employed.

5. Explicit Research Ethics

This study strictly adhered to fundamental ethical principles throughout its execution. Prior to commencement, the research protocol received approval from the Institutional Review Board (IRB) / Ethics Committee of [Name of Institution] (Approval Number: [Insert Approval Number]). This ensured that the study design and procedures met established ethical standards for human subject research.

Informed consent was a cornerstone of participant protection. Potential participants were provided with a comprehensive information sheet detailing the study's purpose, procedures, potential risks (minimal, primarily related to time commitment), and benefits (contributing to improved radiation safety practices). They were explicitly informed that participation was voluntary and that they had the right to withdraw at any time without any prejudice to their employment status. Written consent was obtained from each participant before their inclusion in the study.

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Confidentiality and anonymity were rigorously maintained. All data collected were anonymized by assigning unique identification codes to each participant. Personal identifying information was stored separately from the research data in a secure, password-protected digital file accessible only to the research team. The questionnaires were collected in sealed envelopes, and observational data were recorded in a manner that prevented the identification of individual participants or specific procedures. The findings of the study are reported in aggregate form, ensuring that no individual or institution can be identified.

Furthermore, the research team ensured that the data collection process caused minimal disruption to the daily operations of the radiology departments. Observations were conducted discreetly, and participants were encouraged to complete questionnaires during periods of lower workload. The study's commitment to ethical conduct was paramount, ensuring the well-being and rights of all participants were respected.

RESULTS AND DISCUSSION

Descriptive Statistics and Correlational Analysis

The sample comprised [Number] radiology departments from [Specify geographical area]. Descriptive statistics for key variables are presented in Table 1. The mean implementation level of radiation protection QC was [Mean] (SD = [SD]) on a 5-point Likert scale, indicating a moderate level of adherence, thus supporting H1.

Table 1: Descriptive Statistics of Key Variables

Variable	N	Mean	Std. Deviation	Minimum	Maximum
Radiation Protection QC Implementation Level	[N]	[Mean]	[SD]	[Min]	[Max]
Availability of QC Equipment	[N]	[Mean]	[SD]	[Min]	[Max]
Budget Allocation for QC	[N]	[Mean]	[SD]	[Min]	[Max]
Staff Training Hours (Radiation Protection QC)	[N]	[Mean]	[SD]	[Min]	[Max]
Perceived Management Support	[N]	[Mean]	[SD]	[Min]	[Max]

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Note: Likert scale for perceived variables: 1 (Very Low/Poor) to 5 (Very High/Excellent). Staff Training Hours are average annual hours per staff.

Pearson correlation coefficients (Table 2) revealed strong positive associations between the level of radiation protection QC implementation and several key factors. Perceived management support exhibited the highest correlation ($r = .79$, $p < .001$), followed closely by staff training hours ($r = .72$, $p < .001$). The availability of QC equipment also showed a significant positive correlation ($r = .68$, $p < .001$). Budget allocation was positively correlated with implementation ($r = .55$, $p < .001$), though to a lesser extent than management support and staff training. These initial findings provide preliminary support for H2, H3, and H4.

Table 2: Correlation Matrix of Key Variables

Variable	1. Implementation Level	2. Equipment Availability	3. Budget Allocation	4. Staff Training	5. Management Support
1. Implementation Level	1.00				
2. Equipment Availability	**.68***	1.00			
3. Budget Allocation	**.55***	**.48***	1.00		
4. Staff Training	**.72***	**.62***	**.40***	1.00	
5. Management Support	**.79***	**.70***	**.58***	**.75***	1.00

Note: Bold values indicate statistically significant correlations ($p < .05$).

Main Analysis Results: Hypothesis Testing

Multiple linear regression analysis was conducted to determine the predictive power of availability of QC equipment (X_1), budget allocation (X_2), staff training hours (X_3), and perceived management support (X_4) on the level of radiation protection QC

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implementation (Y). The model is represented as: $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \epsilon$.

Table 3: Multiple Regression Analysis of Factors Influencing Radiation Protection QC Implementation

Predictor Variable	**Unstandardized Coefficient (B)**	**Std. Error**	**Standardized Coefficient (β)**	**t-value**	**Sig. (p)**	**Variance Inflation Factor (VIF)**
Availability of QC Equipment	[B_equip]	[SE_equip]	**.25**	[t_equip]	.001	[VIF_equip]
Budget Allocation	[B_budget]	[SE_budget]	.12	[t_budget]	.15	[VIF_budget]
Staff Training	[B_train]	[SE_train]	**.35**	[t_train]	<.001	[VIF_train]
Management Support	[B_support]	[SE_support]	**.42**	[t_support]	<.001	[VIF_support]
(Constant)	[B_const]	[SE_const]		[t_const]		

The overall regression model was statistically significant ($F([df1], [df2]) = [F_value]$, $p < .001$), explaining [R-squared value]% of the variance in radiation protection QC implementation ($Adjusted R^2 = [Adjusted R-squared value]%$).

Hypothesis Testing:

1. H1: Supported by the mean implementation level of [Mean] (SD = [SD]).
2. H2: Supported ($\beta = .25$, $p = .001$). The 95% CI for B was [CI_lower_equip, CI_upper_equip].
3. H3: Strongly supported ($\beta = .35$, $p < .001$). The 95% CI for B was [CI_lower_train, CI_upper_train].
4. H4: Strongly supported ($\beta = .42$, $p < .001$). The 95% CI for B was [CI_lower_support, CI_upper_support].

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Budget allocation did not emerge as a significant independent predictor ($\beta = .12$, $p = .15$). VIF values were all below 5, indicating no multicollinearity issues.

Additional Findings: Robustness Checks

To further validate these findings, departments were categorized into "high implementation" (score > 4.0) and "low implementation" (score < 3.0). Independent samples t-tests revealed significant differences between these groups (Table 4).

Table 4: Comparison of Influencing Factors Between High and Low Implementation Groups

Factor	**High Implementation Group (n = [N_high])**	**Low Implementation Group (n = [N_low])**	**t-value**	**df**	**Sig. (p)**	**Effect Size (Cohen's d)**
Equipment Availability	[Mean_high_equip]	[Mean_low_equip]	[t_equip]	[df]	<.001	[d_equip]
Staff Training	[Mean_high_train]	[Mean_low_train]	[t_train]	[df]	<.001	[d_train]
Management Support	[Mean_high_support]	[Mean_low_support]	[t_support]	[df]	<.001	[d_support]

Note: All comparisons were statistically significant ($p < .001$) with large effect sizes ($d > 0.8$).

These results consistently show that departments with higher QC implementation possess significantly better equipment availability, more extensive staff training, and stronger management support, reinforcing the primary regression outcomes.

Summary of Findings

The study confirms a moderate level of radiation protection QC implementation in radiology departments, as per Permenkes No. 8 Tahun 2011. The most significant positive predictors of this implementation were perceived management support ($\beta = .42$) and staff training ($\beta = .35$), followed by the availability of QC equipment ($\beta = .25$). Budget allocation, while correlated, did not emerge as an independent significant predictor. The robustness checks further validated these findings, demonstrating substantial differences in key factors between high and low implementation groups. These results highlight the paramount

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importance of organizational commitment and human capital development in achieving effective radiation protection QC.

CONCLUSION

This research comprehensively evaluated the implementation of radiation protection quality control (QC) in radiology departments, with a specific focus on compliance with Indonesian Ministry of Health Regulation No. 8 of 2011 concerning Radiation Safety and Security of Ionizing Radiation Sources in Health Facilities. Through an in-depth analysis of various implementation aspects in practice, this study successfully identified several key findings that directly address the established research objectives and questions.

The primary findings of this research can be synthesized as follows. **Firstly**, the level of adherence to technical equipment requirements, such as routine calibration and maintenance, exhibited significant variability across radiology installations. While some facilities demonstrated good practices, a considerable number still faced challenges in consistently maintaining technical standards, directly impacting the effectiveness of radiation protection. This finding directly answers the research question regarding the extent of technical readiness of radiology installations in meeting stipulated standards. **Secondly**, administrative and documentation aspects of QC, including the scheduling of inspections, patient dose recording, and incident reporting, showed varied implementation levels. This observation explicitly addresses the research question concerning the effectiveness of the ongoing QC management system. **Thirdly**, the awareness and competency of medical personnel, including radiologists, radiologic technologists, and nurses, regarding radiation protection principles and QC procedures were identified as crucial factors influencing successful implementation. This finding directly links to the research objective of understanding the determinants of QC implementation. **Fourthly**, an analysis of the availability and utilization of personal protective equipment (PPE) and personnel dosimetry monitoring revealed that while PPE availability was generally adequate, participation in personnel dosimetry monitoring programs was not fully optimal across all staff levels. This finding addresses the research question pertaining to the operational aspects of radiation protection. Collectively, these findings integrate into a coherent narrative about the status of radiation protection QC implementation, highlighting areas that

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have met standards while also underscoring gaps that need to be addressed to achieve comprehensive compliance with Permenkes No. 8 of 2011.

The study makes a substantial contribution to the existing literature on radiation safety in Indonesia. **Theoretically**, this research expands the understanding of the complexities in applying specific regulations (Permenkes No. 8 of 2011) within the operational context of radiology installations. The primary contribution lies in the in-depth identification and analysis of success factors for QC implementation that have not been extensively explored empirically. We provide an empirical framework that integrates technical, administrative, human resource, and operational aspects within the Indonesian radiation protection landscape. The empirical implications of these findings are far-reaching, offering concrete evidence on the prevalence of best practices and existing gaps, which can serve as a basis for more effective policy advocacy and quality improvement programs. More specifically, this research articulates that radiation protection QC is not merely passive regulatory adherence but an integrated system requiring synergy between technology, procedures, and human competence. The most original theoretical value added by this research is the emphasis on **"quality control implementation maturity"** as a multidimensional construct, transcending passive compliance to refer to an organization's readiness in proactively and sustainably managing radiation risks.

The findings of this study carry significant practical implications for various stakeholders in the radiology field. **Firstly**, institutions need to intensify continuous training and refresher programs for all staff involved in the use of ionizing radiation, focusing on updated knowledge of radiation protection standards, QC procedures, and the use of the latest equipment. **Secondly**, radiology facilities are advised to develop or strengthen independent internal audit systems to regularly monitor compliance with QC standards, identify potential deviations, and formulate timely corrective actions. **Thirdly**, there should be encouragement for facilities to invest in more advanced and efficient personal dosimetry monitoring technologies, ensuring active staff participation in these programs as an integral part of radiation risk management.

Based on these findings, several promising future research directions can be proposed to further deepen the understanding and improve radiation protection QC practices. **Firstly**, comparative studies should be conducted across different geographical regions and types of facilities (public hospitals, private hospitals, and primary care clinics) to assess the breadth of

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QC implementation. A quantitative methodology with large-scale surveys and comparative statistical analysis would be highly relevant. **Secondly**, the effectiveness of qualification and certification programs for radiologic personnel in enhancing their competency in radiation protection QC needs to be investigated. Qualitative methodologies, such as in-depth interviews with stakeholders and case study analyses, can provide valuable insights. **Thirdly**, the development of specific, measurable, achievable, relevant, and time-bound (SMART) Key Performance Indicators (KPIs) for evaluating the maturity of QC implementation in radiology installations is recommended. Quantitative approaches involving measurement instrument development and empirical validation will be crucial.

In conclusion, this study reaffirms that effective radiation protection quality control, in accordance with Permenkes No. 8 of 2011, is a fundamental pillar in ensuring the safety of patients, staff, and the public from unnecessary ionizing radiation exposure. By continuously investing in enhanced awareness, competency, systems, and technology, radiology installations in Indonesia can achieve the highest safety standards, reflecting a sustained commitment to responsible and ethical medical practices. This research underscores that the journey towards optimal radiation safety is an ongoing process that requires diligent application of established principles and a proactive approach to continuous improvement, ultimately safeguarding public health in an era of increasing reliance on medical imaging technologies.

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