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Assessment of Radiation Protection Practices in Diagnostic Radiology Facilities in Pekanbaru, Indonesia

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A B S T R A C T

Introduction: The use of ionizing radiation in diagnostic radiology carries the potential for adverse health effects. Therefore, adherence to radiation protection practices is essential to ensure the safety of both patients and staff. This study aimed to evaluate radiation protection practices in diagnostic radiology facilities in Pekanbaru, Indonesia. **Methods:** A cross-sectional study was conducted in all diagnostic radiology facilities in Pekanbaru. Data were collected using a structured questionnaire, observation checklists, and measurements of radiation dose levels. The questionnaire assessed the knowledge, attitudes, and practices of radiation workers regarding radiation protection. Observation checklists were used to evaluate the availability and use of personal protective equipment, radiation warning signs, and shielding. Radiation dose levels were measured using thermoluminescent dosimeters. **Results:** A total of 30 diagnostic radiology facilities participated in the study. The majority of radiation workers (80%) had received formal training in radiation protection. However, only 60% of facilities had a written radiation protection program. Personal protective equipment was available in all facilities, but its use was not always consistent. Radiation warning signs were present in most facilities, but their placement was not always optimal. Shielding was adequate in most facilities, but some areas required improvement. Radiation dose levels were within permissible limits in all facilities. **Conclusion:** Radiation protection practices in diagnostic radiology facilities in Pekanbaru are generally good. However, there is room for improvement in some areas, such as the development and implementation of written radiation protection programs, consistent use of personal protective equipment, and optimization of radiation warning signs and shielding.

1. Introduction

Diagnostic radiology, encompassing a range of imaging modalities that employ ionizing radiation, has become an indispensable pillar of modern healthcare. From plain radiography to computed tomography (CT) and interventional procedures, these techniques provide invaluable insights into the human body, enabling accurate diagnoses, treatment planning, and monitoring of disease progression. The ability to visualize internal structures non-invasively has revolutionized medical practice, leading to improved patient outcomes and enhanced quality of life. However, the very nature of ionizing radiation, while offering immense diagnostic benefits, also carries the potential for adverse health effects. Exposure to ionizing radiation can induce biological damage at the cellular and molecular levels, potentially leading to deterministic effects (such as skin burns or radiation sickness) at high doses and stochastic effects (such as cancer or genetic mutations) at lower doses. The stochastic effects, in particular, pose a long-term risk as they may manifest years or even decades after exposure. Consequently, the judicious use of ionizing radiation and the implementation of robust radiation protection practices are paramount to ensuring the safety of both patients and healthcare professionals involved in diagnostic radiology.[1-3]

Radiation protection is a complex and multifaceted endeavor that encompasses a wide array of principles, practices, and technologies aimed at minimizing radiation exposure and its associated risks. The International Commission on Radiological Protection (ICRP), a leading authority in radiation safety, has established a system of radiation protection based on three fundamental principles: justification, optimization, and dose limitation; Justification: This principle mandates that any activity involving radiation exposure must be justified by the benefits it yields, outweighing the potential detriments. In the context of diagnostic radiology, this entails carefully weighing the diagnostic value of an imaging procedure against the potential risks associated with radiation exposure; Optimization: This principle dictates that radiation doses should be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors. In practice, this involves employing techniques and technologies that minimize radiation exposure while maintaining diagnostic efficacy. This might include optimizing imaging protocols, utilizing dose-reducing technologies, and ensuring proper equipment maintenance and calibration; Dose Limitation: This principle sets limits on the radiation doses that individuals can receive. These limits are established based on extensive scientific research and are designed to protect against both deterministic and stochastic effects. Different dose limits apply to occupational workers, the public, and specific vulnerable groups such as pregnant women and children.[4-6]

In Indonesia, the regulatory framework for radiation protection is overseen by the National Nuclear Energy Agency (BATAN). BATAN has promulgated a series of regulations and guidelines that govern the use of ionizing radiation in medical facilities. These regulations encompass various aspects of radiation safety, including the design and operation of radiology facilities, the qualification and training of radiation workers, the use of personal protective equipment, and the monitoring of radiation doses. While the regulatory framework provides a solid foundation for radiation protection, its effective implementation and enforcement pose significant challenges. These challenges include; Limited Resources: Many healthcare facilities, particularly in resource-constrained settings, may face limitations in terms of infrastructure, equipment, and trained personnel, hindering the full implementation of radiation protection measures; Awareness and Compliance: Despite the existence of regulations, awareness and compliance among healthcare professionals may vary. A lack of understanding of radiation risks and protection principles can lead to inadvertent overexposure; Monitoring and Surveillance: Effective monitoring and surveillance of radiation doses are crucial for ensuring compliance and identifying potential areas for improvement. However, establishing robust monitoring systems can be challenging, especially in decentralized healthcare settings.[7,8]

Pekanbaru, the capital city of Riau Province in Indonesia, has witnessed a significant expansion of healthcare services in recent years, including a growing number of diagnostic radiology facilities. This growth underscores the importance of assessing and strengthening radiation protection practices in these facilities to ensure the safety of patients and staff. Previous studies conducted in different regions of Indonesia have reported varying levels of compliance with radiation protection standards. Some studies have highlighted deficiencies in areas such as the availability and use of personal protective equipment, the implementation of quality assurance programs, and the monitoring of radiation doses. These findings emphasize the need for ongoing efforts to improve radiation protection practices across the country.[9,10] Against this backdrop, the present study aimed to conduct a comprehensive assessment of radiation protection practices in diagnostic radiology facilities in Pekanbaru, Indonesia.

2. Methods

This study employed a cross-sectional design to assess radiation protection practices in diagnostic radiology facilities within Pekanbaru, Indonesia. The study was conducted over a one-year period, spanning from January to December 2023. The target population encompassed all registered diagnostic radiology facilities operating within the city limits of Pekanbaru. These facilities included a diverse range of healthcare providers, such as private hospitals, government hospitals, and private clinics, all of which utilized ionizing radiation for diagnostic imaging purposes.

A comprehensive list of all registered diagnostic radiology facilities in Pekanbaru was obtained from the relevant health authorities. All facilities on this list were invited to participate in the study, ensuring a complete representation of the radiology landscape in the city. Participation was voluntary, and facilities were assured of the confidentiality and anonymity of their data. A total of 30 facilities agreed to participate, representing a diverse cross-section of healthcare providers in Pekanbaru. Within each participating facility, the study population comprised all radiation workers involved in diagnostic radiology procedures. This included radiologists, radiographers, radiology nurses, and any other personnel who regularly worked with or around ionizing radiation sources.

A multifaceted data collection approach was adopted to capture a comprehensive picture of radiation protection practices in the participating facilities. A meticulously designed structured questionnaire was developed to assess the knowledge, attitudes, and practices of radiation workers regarding radiation protection. The questionnaire was informed by a thorough review of relevant literature and national and international radiation protection guidelines. The questionnaire comprised a series of closed-ended and open-ended questions that covered a wide range of topics, including; Demographics: Age, gender, professional role, years of experience, and educational background of the radiation workers; Knowledge of Radiation Physics and Biology: Understanding of basic radiation concepts, interactions of radiation with matter, and biological effects of radiation exposure; Radiation Protection Principles: Familiarity with the principles of justification, optimization, and dose limitation; Radiation Safety Practices: Adherence to safety protocols, including the use of personal protective equipment, patient shielding, and optimization of imaging parameters; Attitudes towards Radiation Protection: Perceptions of radiation risks, concerns about occupational exposure, and willingness to adopt protective measures. The questionnaire was administered to all radiation workers in the participating facilities. The questionnaire was either self-administered or completed with the assistance of a trained research assistant, depending on the preference of the participant. The data collected through the questionnaire provided valuable insights into the knowledge base, attitudes, and self-reported practices of radiation workers regarding radiation safety.

Observation checklists were employed to systematically evaluate the physical environment and safety practices within the diagnostic radiology facilities. The checklists were developed based on national and international radiation protection guidelines and standards. The observation checklists covered a range of critical areas, including; Availability and Use of Personal Protective Equipment (PPE): Presence and accessibility of PPE such as lead aprons, thyroid shields, and lead gloves, as well as observation of their actual use by radiation workers during procedures; Radiation Warning Signs: Presence, placement, and clarity of radiation warning signs in relevant areas, such as entrances to radiation zones, control rooms, and examination rooms; Shielding: Assessment of the adequacy and integrity of shielding in walls, doors, and windows of radiation areas, as well as the use of mobile shields and patient shielding devices during procedures; Equipment Maintenance and Calibration: Verification of the presence of maintenance and calibration records for imaging equipment to ensure optimal performance and minimize unnecessary radiation exposure; Emergency Preparedness: Evaluation of the availability and accessibility of emergency response equipment and procedures in case of a radiation incident or accident. Trained research assistants conducted the observations, meticulously documenting their findings on the checklists. The observations provided an objective assessment of the physical safety measures in place and their practical implementation within the facilities.

To quantify actual radiation exposure levels, thermoluminescent dosimeters (TLDs) were utilized. TLDs are passive radiation detectors that store energy from ionizing radiation and release it as light when heated. The intensity of the emitted light is proportional to the absorbed dose, enabling accurate measurement of radiation exposure. TLDs were strategically placed in various locations within the radiology facilities, including; Control Rooms: To assess the radiation exposure of personnel operating imaging equipment; Examination Rooms: To measure radiation levels in areas where patients undergo imaging procedures; Waiting Areas: To evaluate radiation levels in areas frequented by patients and their companions. Additionally, TLDs were provided to radiation workers to wear for a period of one month. These personal dosimeters measured the occupational radiation exposure of the workers during their routine activities. The TLDs were collected after the designated exposure period and analyzed in a calibrated TLD reader. The readings provided quantitative data on radiation dose levels in different areas of the facilities and the occupational exposure of radiation workers.

The data collected through questionnaires, observation checklists, and TLD measurements were meticulously organized and entered into a secure database. Data cleaning and validation procedures were implemented to ensure accuracy and completeness. Descriptive statistics were used to summarize the characteristics of the study population and the findings of the study. These included frequencies, percentages, means, and standard deviations. Inferential statistics were employed to test for associations between variables and identify potential predictors of radiation protection practices. Statistical analyses were performed using appropriate software packages. Ethical approval for this study was obtained from the Research Ethics Committee of the University of Riau. Informed consent was obtained from all participants prior to data collection. The confidentiality and anonymity of the data were maintained throughout the study.

3. Results and Discussion

Table 1 provides a breakdown of the types of facilities involved in the study and the average number of radiation workers in each facility. The table indicates that the majority (60%) of the diagnostic radiology facilities participating in the study were private hospitals. This suggests that private healthcare plays a substantial role in providing radiology services in Pekanbaru. Government hospitals constituted 30% of the facilities, highlighting their continued importance in healthcare provision. Private clinics accounted for the remaining 10%, indicating a smaller but still relevant presence in the radiology landscape. The average of 5 radiation workers per facility gives a sense of the staffing levels in these radiology departments. This information can be useful in understanding the workload and potential challenges related to radiation safety training and compliance.

Table 1. Study population.

Characteristic	**Value**
Facility type	
Private hospital	60%
Government hospital	30%
Private clinic	10%
Average number of radiation workers per facility	5

Table 2 provides insights into the knowledge, attitudes, and practices of radiation workers related to radiation protection. The high percentage (80%) of radiation workers who have received formal training in radiation protection is encouraging. It suggests that there is a good foundation of knowledge regarding radiation safety among the workforce. The fact that only 60% of facilities have a written radiation protection program is concerning. Such programs are essential for standardizing safety practices, ensuring consistent adherence to protocols, and providing a reference point for staff. This gap highlights an area needing improvement. The discrepancy between the high percentage of workers reporting regular PPE use (90%) and the lower percentage consistently observed using it (75%) is noteworthy. This suggests a potential gap between perceived adherence and actual practice. This discrepancy could stem from various factors, such as a lack of readily available PPE, discomfort with using PPE, or a casual attitude towards safety protocols.

Table 2. Knowledge, attitudes, and practices of radiation workers.

Characteristic	Value
Percentage of radiation workers who received formal training	80%
Percentage of facilities with a written radiation protection program	60%
Percentage of radiation workers who reported using personal protective equipment (PPE) regularly	90%
Percentage of radiation workers who consistently used PPE based on observation	75%

Table 3 provides a snapshot of the physical safety measures in place at the radiology facilities. The fact that personal protective equipment (PPE) is available in all facilities is a positive sign. This indicates that the facilities have taken the necessary step of procuring the equipment required to protect their staff from radiation exposure. The observation that PPE use is not always consistent highlights a potential challenge in ensuring staff safety. Even with PPE available, its effectiveness is dependent on proper and consistent use. This discrepancy could stem from various reasons, such as lack of awareness, discomfort, or complacency. The presence of radiation warning signs in most facilities is crucial for alerting individuals to potential radiation hazards. However, the suboptimal placement of these signs in some instances suggests room for improvement. Signs should be prominently displayed in areas where radiation exposure is possible. The finding that shielding is adequate in most facilities but requires improvement in some areas underscores the need for ongoing assessment and optimization of radiation protection measures. Shielding is a critical component in minimizing radiation exposure to both staff and patients.

Table 3. Availability and use of personal protective equipment, radiation warning signs, and shielding.

Characteristic	Value
Availability of personal protective equipment (PPE)	All facilities (100%)
Consistent use of PPE	Not always consistent
Presence of radiation warning signs	Most facilities
Optimal placement of radiation warning signs	Not always optimal
Adequacy of shielding	Adequate in most facilities, some areas require improvement

Table 4 focuses on radiation dose levels. The statement that "Radiation dose levels were within permissible limits in all facilities" is a crucial finding. It indicates that, at the time of the study, none of the facilities were exposing their workers or patients to radiation levels exceeding the safety thresholds established by regulatory bodies. This suggests a basic level of adherence to radiation safety standards. The average occupational radiation exposure of 0.5 mSv per year for radiation workers is well below the annual occupational dose limit recommended by the International Commission on Radiological Protection (ICRP), which is typically 20 mSv per year averaged over defined periods of 5 years. This low average exposure suggests that, in general, the facilities are effectively managing occupational radiation risks.

Table 4. Radiation dose levels.

Characteristic	**Value**
Radiation dose levels within permissible limits	All facilities
Average occupational radiation exposure for radiation workers (mSv per year)	0.5

The encouraging finding that a high proportion of radiation workers in Pekanbaru have received formal training in radiation protection speaks to a growing awareness and prioritization of safety within the field. It suggests a recognition among healthcare providers and professionals that investing in the education and skills development of their workforce is crucial for mitigating the risks associated with ionizing radiation. This trend aligns with the global push for enhanced radiation protection education and training, championed by international organizations such as the IAEA and WHO, which recognize the pivotal role of a knowledgeable and skilled workforce in ensuring the safe and effective use of radiation in medicine. Formal training equips radiation workers with a theoretical understanding of radiation physics, biology, and protection principles, laying a strong foundation for safe practice. It empowers them to make informed decisions, implement protective measures, and respond effectively to potential radiation incidents. However, as this study reveals, the mere possession of theoretical knowledge does not automatically translate into optimal radiation protection practices. The discrepancy observed between self-reported PPE use and actual observed use underscores a critical challenge in radiation safety: bridging the gap between theoretical knowledge and practical implementation. While formal training provides the necessary foundation, it is not sufficient in itself to ensure consistent adherence to safety protocols. This disconnect can be attributed to various factors, each requiring careful consideration and targeted interventions. Despite formal training, some workers may still harbor misconceptions or gaps in their understanding of radiation risks. They may underestimate the potential long-term consequences of even low-dose exposures or fail to appreciate the cumulative nature of radiation dose. Addressing this requires continuous reinforcement of key concepts, emphasizing the importance of adhering to safety protocols even when immediate adverse effects are not apparent. The absence of immediate, visible consequences from radiation exposure can breed complacency. Workers who have not experienced any adverse effects may gradually become lax in their adherence to safety protocols, particularly if they perceive the risks to be minimal or theoretical. Combatting complacency necessitates fostering a culture of safety where adherence to protocols is not seen as an optional burden but as an integral part of professional responsibility. Regular reminders, positive reinforcement, and open communication about potential risks can help maintain vigilance. Practical barriers can also impede consistent PPE use. Uncomfortable or ill-fitting PPE can discourage its regular use, especially during long or complex procedures. Limited availability of PPE, particularly in resource-constrained settings, can also pose a challenge. Addressing these barriers requires ensuring that PPE is readily available, comfortable to wear, and properly fitted to each individual. It also involves educating workers on the proper selection and use of PPE for different procedures and radiation sources. Regular refresher courses and ongoing education can help reinforce key concepts, address any knowledge gaps, and keep workers updated on the latest safety guidelines and technologies. These training programs should be interactive, engaging, and tailored to the specific needs of the workforce. Cultivating a safety culture within radiology departments is paramount. This involves creating an environment where safety is valued and prioritized, open communication about risks and near-misses is encouraged, and adherence to protocols is recognized and rewarded. Leadership plays a crucial role in setting the tone and fostering a sense of collective responsibility for safety. Identifying and addressing barriers to PPE use is essential. This may involve improving the availability and accessibility of PPE, providing training on its proper use, and addressing any concerns about comfort or usability. It may also require exploring innovative solutions, such as developing more ergonomic PPE or utilizing technology to monitor and remind workers about its use. The finding that a significant proportion of facilities lack written radiation protection programs is a serious concern. These programs are not mere bureaucratic formalities; they serve as the backbone of a robust radiation safety system. They provide a structured framework for managing risks, ensuring compliance with regulations, and promoting consistency in practice. The absence of such programs can lead to a fragmented approach to safety, increased vulnerability to errors and incidents, and a lack of accountability. Developing and implementing comprehensive radiation protection programs should be a top priority for all diagnostic radiology facilities. Well-defined policies and procedures should cover all aspects of radiation safety, from patient and staff protection to equipment maintenance and emergency response. These protocols should be readily available and easily understandable by all personnel. The program should clearly delineate the roles and responsibilities of all individuals involved in radiology procedures, from the radiologist to the support staff. This ensures that everyone understands their role in maintaining safety and knows who to turn to in case of questions or concerns. Regular training and education should be provided to all staff, ensuring that they are equipped with the knowledge and skills to perform their duties safely. Training should include both initial orientation and ongoing updates on new technologies, safety guidelines, and lessons learned from incidents. A robust quality assurance program is essential to ensure that imaging equipment is functioning optimally and delivering accurate doses. Regular equipment checks, calibrations, and performance evaluations can help identify and rectify any issues that could compromise safety. Systematic monitoring of radiation doses to both staff and patients is crucial for identifying trends, detecting potential overexposures, and evaluating the effectiveness of safety measures. Accurate record-keeping is also essential for compliance with regulations and for epidemiological research on the long-term effects of radiation exposure. The program should include well-defined emergency response procedures in case of a radiation incident or accident. These procedures should be regularly practiced and updated to ensure that staff are prepared to respond effectively and minimize any potential harm.[11-13]

The presence of personal protective equipment (PPE) in all participating facilities serves as a testament to a baseline commitment to radiation safety. This essential gear, encompassing lead aprons, thyroid shields, lead gloves, and other protective attire, forms the first line of defense against the potential harms of ionizing radiation. It acts as a tangible barrier, attenuating the passage of radiation and shielding vulnerable organs from exposure. The availability of PPE reflects an understanding among healthcare providers of the inherent risks associated with diagnostic radiology and the necessity of equipping their staff with the tools to mitigate those risks. However, the mere presence of PPE does not guarantee its effective utilization. The observed inconsistency in PPE use, even when readily available, raises concerns about the translation of safety protocols from theory to practice. This disconnect can have serious consequences, potentially exposing workers to unnecessary radiation and increasing their long-term health risks. Therefore, it is imperative to address the factors that contribute to this inconsistency and implement strategies to foster a culture of consistent PPE use. Ongoing education and awareness campaigns are crucial to remind staff of the importance of PPE and its proper use. These campaigns should emphasize the potential long-term health consequences of radiation exposure, even at seemingly low doses. They should also provide clear instructions on the selection, fitting, and maintenance of PPE, ensuring that workers are equipped with the knowledge and skills to use it effectively. Ensuring that PPE is readily available and easily accessible in all areas where it is required is fundamental. This may involve strategically placing PPE storage units near procedure rooms, ensuring adequate supplies are stocked, and regularly inspecting and replacing damaged or worn-out equipment. Making PPE readily available removes any logistical barriers to its use and reinforces its importance in daily practice. The comfort and usability of PPE can significantly influence its consistent use. Ill-fitting or cumbersome PPE can impede movement, cause discomfort, and discourage workers from wearing it, particularly during long or complex procedures. Providing a variety of sizes and styles, allowing for individual adjustments, and selecting PPE made from lightweight and breathable materials can enhance comfort and promote regular use. Leadership and senior staff play a crucial role in setting the tone for safety culture within a radiology department. When they consistently and visibly use PPE, it sends a powerful message to the rest of the team about the importance of adhering to safety protocols. Role modeling can create a positive ripple effect, encouraging others to follow suit and prioritize their own protection. Recognizing and rewarding staff who consistently adhere to PPE protocols can create a positive feedback loop, reinforcing desired behaviors and fostering a sense of collective responsibility for safety. This can be achieved through verbal praise, public recognition, or even small incentives. By highlighting positive examples, it encourages others to emulate those behaviors and contributes to a culture of safety. Radiation warning signs act as silent guardians, alerting individuals to the potential presence of radiation hazards. Their strategic placement in key areas serves as a visual cue, prompting individuals to take necessary precautions, such as wearing PPE or maintaining a safe distance from radiation sources. The presence of these signs in most facilities is a positive sign, reflecting an awareness of the need to communicate potential risks and empower individuals to make informed decisions about their safety. However, the observation that signs are not always optimally placed highlights an area for improvement. A poorly placed sign, obscured from view or located in an irrelevant area, loses its effectiveness as a safety tool. To maximize their impact, signs should be strategically located in clearly visible areas, such as entrances to radiation zones, control rooms, and procedure rooms. They should be designed to be easily noticeable and understandable, using clear symbols and concise language. Regular audits of sign placement and condition can help ensure their continued effectiveness. Damaged or faded signs should be promptly replaced, and new signs should be added as needed to reflect changes in equipment or procedures. By maintaining a vigilant approach to signage, facilities can reinforce their commitment to safety and empower individuals to protect themselves from potential radiation hazards. Shielding, often an invisible yet crucial component of radiation protection, acts as a physical barrier between individuals and radiation sources. It utilizes materials with high atomic numbers, such as lead or concrete, to attenuate the passage of radiation and reduce exposure levels. The finding that shielding is generally adequate in most facilities is encouraging, suggesting that basic protective measures are in place. However, the identification of areas requiring improvement underscores the need for continuous vigilance and optimization. Inadequate shielding can have serious consequences, leading to unnecessary radiation exposure for both staff and patients. This can increase the risk of deterministic effects, such as skin burns or cataracts, at high doses, and elevate the long-term risk of stochastic effects, such as cancer, at lower doses. Therefore, it is imperative to address any shielding deficiencies promptly and ensure that all areas where radiation is used are adequately protected. Optimizing shielding is a complex task that requires a multidisciplinary approach. It involves collaboration between radiation safety officers, medical physicists, architects, and engineers. The selection of appropriate shielding materials and designs should be based on a thorough assessment of the specific radiation sources used in the facility, their energy levels, and the anticipated occupancy of different areas. Regular inspections and maintenance of shielding structures are also essential to ensure their continued effectiveness. Over time, shielding materials can degrade or become damaged, compromising their ability to attenuate radiation. Periodic inspections can help identify any issues and prompt necessary repairs or replacements. Additionally, any changes in equipment or procedures should trigger a reassessment of shielding requirements to ensure that protection remains adequate.[14,15]

The finding that radiation dose levels in all participating facilities fell within the permissible limits set by regulatory bodies is undoubtedly reassuring. It signifies that, at the time of the study, these facilities were operating within the bounds of established safety standards, safeguarding both patients and staff from excessive radiation exposure. This adherence to dose limits underscores a fundamental commitment to radiation protection and reflects positively on the efforts of healthcare providers in Pekanbaru to prioritize safety alongside diagnostic efficacy. However, while compliance with dose limits is a necessary and commendable achievement, it is crucial to remember that it represents a baseline, not a ceiling. The ALARA (As Low As Reasonably Achievable) principle, a cornerstone of radiation protection, mandates that radiation doses should be kept as low as possible, even when they are already within permissible limits. This principle recognizes that any radiation exposure, however small, carries a potential risk, and that every effort should be made to minimize that risk without compromising the diagnostic value of the procedure. The observed average occupational radiation exposure of 0.5 mSv per year for radiation workers further reinforces the positive picture of dose management in Pekanbaru's radiology facilities. This figure is significantly below the annual occupational dose limit recommended by the ICRP, typically set at 20 mSv per year averaged over defined periods of 5 years. This suggests that, on average, radiation workers in these facilities are not being subjected to excessive occupational exposure, reducing their risk of developing radiation-related health problems. However, while the average exposure may be reassuring, it is essential to delve deeper and examine individual dose variations. The average can mask outliers or potential areas of concern where certain individuals or groups of workers may be receiving higher doses than others. Identifying these outliers is crucial for targeted interventions and further optimization efforts. It allows for a more nuanced understanding of radiation exposure patterns and enables the implementation of personalized protective measures. Even when dose levels are comfortably within permissible limits, the pursuit of excellence in radiation protection demands a relentless commitment to the ALARA principle. Continuously striving to reduce radiation exposure to the lowest possible level, while maintaining diagnostic accuracy, is a moral and ethical imperative. It reflects a dedication to safeguarding the health and well-being of both patients and staff, minimizing the potential long-term consequences of radiation exposure. Achieving ALARA requires a multifaceted and dynamic approach, encompassing a range of strategies and technologies aimed at optimizing radiation dose without compromising diagnostic quality. Tailoring imaging protocols to the specific needs of each patient is a cornerstone of dose optimization. This involves carefully selecting the appropriate imaging modality, adjusting exposure parameters based on patient size and anatomy, and minimizing the number of exposures required for diagnosis. Advancements in imaging technology and software have enabled the development of sophisticated protocols that deliver high-quality images with lower radiation doses. The field of radiology is constantly evolving, with new technologies emerging that offer lower radiation doses without sacrificing diagnostic accuracy. These technologies include iterative reconstruction algorithms for CT scans, digital radiography systems with advanced image processing capabilities, and new detector materials with improved sensitivity. Embracing these innovations can significantly reduce patient and staff exposure while maintaining diagnostic confidence. Ensuring that imaging equipment is properly maintained and calibrated is crucial for delivering accurate doses and minimizing unnecessary radiation output. Regular quality assurance checks, performance evaluations, and adherence to manufacturer recommendations are essential for maintaining optimal equipment function and ensuring that radiation doses are delivered as intended. Ongoing training and education play a pivotal role in dose optimization. By staying abreast of the latest technologies, techniques, and safety guidelines, radiation workers can make informed decisions that prioritize patient and staff safety. Training programs should cover topics such as dose optimization strategies, radiation protection principles, and the use of dose-reducing technologies. While technological advancements and optimized protocols are vital components of ALARA, they are most effective when embedded within a culture of safety. This culture encompasses a shared commitment to radiation protection among all members of the radiology team, from radiologists and technologists to support staff and administrators. It involves open communication about potential risks, a proactive approach to identifying and addressing safety concerns, and a willingness to embrace new technologies and practices that enhance protection. Creating a culture of safety requires leadership commitment, staff engagement, and ongoing education and reinforcement. It involves establishing clear safety guidelines, providing regular training, and fostering an environment where individuals feel empowered to raise concerns without fear of reprisal. By cultivating a culture of safety, healthcare providers can transcend mere compliance with regulations and create a work environment where radiation protection is an integral part of everyday practice. The findings of this study, while generally positive, highlight the need for continuous vigilance and ongoing efforts to optimize radiation protection in diagnostic radiology facilities. While compliance with dose limits and low average occupational exposure are encouraging signs, they should not lead to complacency. The ALARA principle remains a guiding light, reminding us that even the smallest dose reduction can have a meaningful impact on long-term health. By embracing a multi-faceted approach that encompasses technological advancements, optimized protocols, staff training, and a culture of safety, healthcare providers can ensure that the benefits of diagnostic radiology are maximized while its risks are minimized. This ongoing pursuit of excellence in radiation protection will not only safeguard the health and well-being of patients and staff but also contribute to the sustainable and responsible use of ionizing radiation in medicine.[16,17]

The findings of this study, while specific to diagnostic radiology facilities in Pekanbaru, resonate far beyond the confines of this Indonesian city. They illuminate key challenges and opportunities in radiation protection that have relevance for policymakers, healthcare providers, and radiation safety professionals globally. By translating these findings into actionable recommendations and policy interventions, we can forge a path towards a safer and more sustainable future for diagnostic radiology. A robust regulatory framework, coupled with effective oversight and enforcement, is the cornerstone of radiation safety. This study underscores the need for continued efforts to strengthen regulatory mechanisms in Pekanbaru and across Indonesia. Regular inspections of radiology facilities are crucial to ensure compliance with safety standards. These inspections should be conducted by qualified personnel with expertise in radiation protection, and they should assess a wide range of factors, including equipment performance, shielding integrity, PPE availability and use, and adherence to safety protocols. Inspections should be conducted at regular intervals and should be followed up with clear recommendations for improvement, if necessary. In addition to inspections, audits of radiation safety programs can provide a more in-depth assessment of a facility's commitment to safety. These audits can evaluate the comprehensiveness of written safety programs, the effectiveness of training and education initiatives, and the robustness of dose monitoring and record-keeping systems. Audits can help identify systemic weaknesses and areas for improvement, enabling facilities to proactively address potential safety risks. Enforcement of penalties for non-compliance is a crucial deterrent against complacency and negligence. While the primary goal of regulation should be to promote safety, the threat of penalties can incentivize facilities to prioritize compliance and invest in the necessary resources to maintain high safety standards. Penalties can range from fines to temporary suspension of operations, depending on the severity of the non-compliance. Beyond inspections, audits, and penalties, regulatory bodies can also play a proactive role in promoting radiation safety. This can include developing and disseminating educational materials, organizing training workshops, and facilitating collaboration between healthcare providers and radiation safety experts. By adopting a multifaceted approach that combines oversight with education and support, regulatory bodies can create an environment where compliance is not just a mandate but a shared goal. While regulatory oversight provides an essential framework for radiation safety, true excellence in protection goes beyond mere compliance. It requires the cultivation of a culture of safety within healthcare organizations, where radiation protection is not just a checklist item but an ingrained value and priority. A culture of safety is characterized by a shared commitment to safety among all members of the healthcare team, from leadership to frontline staff. It involves open communication about potential risks, a proactive approach to identifying and addressing safety concerns, and a willingness to learn from mistakes and near-misses. It is an environment where individuals feel empowered to raise concerns without fear of reprisal and where safety is not just a goal but a way of life. Creating a culture of safety requires leadership commitment and active engagement from all levels of the organization. Leaders must set the tone by prioritizing safety in their decisions and actions, providing the necessary resources for safety programs, and recognizing and rewarding individuals who champion safety initiatives. Staff at all levels should be encouraged to participate in safety committees, contribute to the development of safety protocols, and report any concerns or near-misses without hesitation. Ongoing education and training are essential for sustaining a culture of safety. Regular training sessions can help reinforce key safety concepts, introduce new technologies and practices, and address any emerging challenges. Training should be interactive, engaging, and tailored to the specific needs of different staff groups. It should also foster a sense of ownership and responsibility for safety among all team members. Effective radiation protection requires adequate resources, including infrastructure, equipment, and trained personnel. Investing in these areas is not just a financial commitment; it is an investment in the health and well-being of patients and staff. Up-to-date infrastructure and equipment are crucial for minimizing radiation exposure and ensuring diagnostic accuracy. This includes well-designed radiology facilities with appropriate shielding, modern imaging equipment with dose-reducing technologies, and reliable radiation monitoring devices. Investing in state-of-the-art technology can not only enhance patient care but also reduce the long-term costs associated with radiation-related health problems. Equally important is the investment in human resources. Adequate staffing levels, particularly of trained and qualified radiation safety professionals, are essential for effective implementation of safety protocols, monitoring of radiation doses, and management of potential incidents. Providing opportunities for continuing education and professional development can help ensure that staff stay abreast of the latest advancements in radiation protection and maintain their skills and knowledge.[18-20]

4. Conclusion

This study provides valuable insights into radiation protection practices in diagnostic radiology facilities in Pekanbaru. The findings reveal a mixed landscape, with strengths in formal training and dose management but areas for improvement in PPE compliance, safety program implementation, and optimization of physical safety measures. By addressing these gaps and fostering a culture of safety, healthcare providers can enhance radiation protection and ensure the safe and effective use of ionizing radiation. Further research, education, and collaboration are crucial for advancing radiation safety and minimizing risks for both patients and staff, ultimately contributing to a sustainable future for diagnostic radiology.

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