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SOSIALISASI INTEGRASI FISIKA DASAR RADIOGRAFI DALAM SISTEM JAMINAN MUTU KESEHATAN DI RUMAH SAKIT DAN PUSKESMAS DI KABUPATEN TOBA

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Abstrak

Akurasi dan keamanan dalam prosedur diagnostik radiologi merupakan elemen fundamental dalam jaminan mutu layanan kesehatan modern. Pemahaman yang baik mengenai fisika dasar radiografi termasuk prinsip pencitraan, interaksi radiasi dengan jaringan, serta aspek proteksi radiasi sangat penting untuk menghasilkan kualitas gambar optimal sekaligus meminimalkan paparan radiasi bagi pasien maupun tenaga medis. Namun, observasi di beberapa fasilitas kesehatan di Kabupaten Toba menunjukkan adanya perbedaan pemahaman dan penerapan konsep fisika dasar radiografi di kalangan tenaga radiologi. Kondisi ini menjadi isu krusial seiring meningkatnya penggunaan modalitas pencitraan dan tuntutan regulasi keselamatan pasien. Penelitian ini mengevaluasi efektivitas program sosialisasi integrasi fisika dasar radiografi terhadap pemahaman dan praktik tenaga radiologi di rumah sakit dan puskesmas Kabupaten Toba. Kerangka teoretis menggunakan Social Learning Theory Bandura yang menekankan observasi, imitasi, dan penguatan dalam pembelajaran. Hipotesis yang diajukan adalah bahwa program sosialisasi terstruktur dapat meningkatkan pengetahuan dan kepatuhan terhadap praktik terbaik. Desain penelitian bersifat kuasi-eksperimental dengan pre-test dan post-test pada dua kelompok, yaitu intervensi (mengikuti sosialisasi) dan kontrol. Sebanyak 60 tenaga radiologi dipilih melalui purposive sampling. Instrumen berupa kuesioner terstruktur yang telah divalidasi (Cronbach's Alpha > 0,85). Analisis menggunakan uji-t independen dan berpasangan. Hasil penelitian menunjukkan peningkatan signifikan pada kelompok intervensi, dari skor rata-rata pre-test 62,3 menjadi 85,2 pada post-test ($p < 0,001$; Cohen's $d = 2,65$). Kelompok kontrol tidak menunjukkan peningkatan berarti, dengan skor post-test rata-rata 65,1 ($p < 0,001$ dibanding intervensi). Selain itu, pemahaman yang lebih baik terbukti berkorelasi positif dengan penerapan proteksi radiasi. Aspek paling berdampak adalah simulasi praktis kalibrasi peralatan yang meningkatkan kepercayaan diri partisipan. Kesimpulannya, program sosialisasi fisika dasar radiografi efektif meningkatkan pengetahuan dan praktik tenaga radiologi di Kabupaten Toba. Temuan ini menegaskan relevansi Social Learning Theory dalam pengembangan profesional berkelanjutan, serta merekomendasikan integrasi modul serupa dalam program nasional untuk meningkatkan mutu layanan radiologi.

***Kata Kunci**: Fisika Radiografi, Jaminan Mutu Kesehatan, Sosialisasi, Radiologi, Proteksi Radiasi.*

SOCIALIZATION OF THE INTEGRATION OF BASIC RADIOGRAPHY PHYSICS IN THE HEALTH QUALITY ASSURANCE SYSTEM IN HOSPITALS AND COMMUNITY HEALTH CENTERS IN TOBA REGENCY

Abstract

Accuracy and safety in radiological diagnostic procedures are fundamental pillars of modern healthcare quality assurance, where a solid understanding of the basic physics of radiography—covering imaging principles, radiation interactions with human tissues, and radiation protection—is essential to ensure optimal diagnostic image quality and minimize unnecessary radiation exposure to both patients and healthcare personnel. Observations conducted at healthcare facilities in Toba Regency revealed variability in the comprehension and application of these fundamental physics concepts among radiology professionals, an issue of growing concern given the increasing use of imaging modalities and stricter regulatory demands on patient safety. This study seeks to evaluate the effectiveness of an integrated radiographic physics socialization program in enhancing the knowledge and practices of radiology personnel in hospitals and community health centers in Toba Regency. The research framework is grounded in Bandura's Social Learning Theory, which emphasizes observation, imitation, and reinforcement in acquiring knowledge and skills. The central hypothesis posits that structured socialization programs significantly improve understanding and compliance

with best practices in radiographic physics compared to a control group. Employing a quasi-experimental design with pre-test and post-test groups, the study involved 60 radiology personnel selected through purposive sampling from three regional hospitals and five health centers. A validated structured questionnaire (Cronbach's Alpha > 0.85) was used to assess participants' understanding of radiographic physics and related radiation protection practices. Data were analyzed using paired and independent t-tests. Findings demonstrated a statistically significant improvement in the intervention group's post-test scores (85.2 ± 7.5) compared to pre-test scores (62.3 ± 9.2), with a mean difference of 22.9 (p < 0.001; Cohen's d = 2.65). Post-test comparisons with the control group (65.1 ± 8.8) also showed significant differences (p < 0.001; Cohen's d = 2.50). Notably, practical simulation of equipment calibration had the strongest impact, boosting participants' confidence and reinforcing learning outcomes. In conclusion, the program effectively improved radiology personnel's knowledge and practices in Toba Regency, affirming the relevance of Social Learning Theory in professional development. The study recommends integrating similar modules into national continuing education frameworks to strengthen radiology service quality.
***Keywords**:* Radiographic Physics, Health Quality Assurance, Socialization, Radiology.

1. INTRODUCTION

The advancement of medical imaging technologies, particularly in diagnostic radiology, has fundamentally reshaped the landscape of modern healthcare, offering unprecedented insights into the human body for accurate disease detection, staging, and treatment monitoring (Khoo et al., 2023). At the core of these sophisticated imaging modalities lies the discipline of radiographic physics, which governs the principles of radiation generation, interaction with matter, image formation, and radiation safety (Bushberg et al., 2012). Ensuring the optimal application and consistent quality of radiographic services is not merely a technical imperative but a critical component of a robust healthcare system, directly impacting patient outcomes and public health. In this context, the integration of fundamental radiographic physics principles into the broader framework of healthcare quality assurance (QA) systems is paramount, especially within the diverse settings of hospitals and primary healthcare centers (Puskesmas). This research specifically investigates the socialization and implementation of fundamental radiographic physics within the quality assurance systems of healthcare facilities in Kabupaten Toba, Indonesia, a region where understanding and adherence to these principles are crucial for enhancing diagnostic efficacy and patient safety.

The urgency for precise and effective quality assurance in diagnostic radiology is underscored by several global and national trends. The World Health Organization (WHO) consistently highlights the critical role of medical imaging in achieving Universal Health Coverage (UHC), emphasizing that access to safe and quality diagnostic services is a cornerstone of effective healthcare delivery (WHO, 2021). In many low- and middle-income countries, including Indonesia, the increasing demand for diagnostic imaging services, driven by demographic shifts, rising prevalence of non-communicable diseases, and greater health-seeking behaviors, places significant strain on existing infrastructure and expertise (Global Health Observatory data, 2022). For instance, the utilization of X-ray services in Southeast Asia has seen a steady increase, necessitating a commensurate focus on quality control to mitigate risks associated with radiation exposure and to ensure diagnostic accuracy (UNSCEAR, 2017). Furthermore, advancements in imaging technology, such as the widespread adoption of digital radiography (DR) and computed radiography (CR) systems, while offering benefits in terms of image quality and workflow efficiency, also introduce new challenges in calibration, quality control, and staff training, requiring a solid understanding of underlying physics principles (Huda, 2019; Neri et al., 2022). The Indonesian Ministry of Health has also recognized the importance of quality in medical imaging, issuing regulations that mandate adherence to radiation safety standards and quality control protocols for all medical imaging facilities (Permenkes No. 58 Tahun 2017). However, the practical implementation and effective socialization of these mandates, particularly at the grassroots level within Puskesmas, often face hurdles related to resource limitations, personnel capacity, and varying levels of technical understanding (Purwanto & Susanto, 2020).

Despite the recognized importance of radiographic physics in ensuring quality and safety, empirical evidence suggests a persistent gap in its effective integration and dissemination within healthcare quality assurance frameworks, particularly in resource-constrained settings. A review of recent literature reveals that while studies on quality assurance in medical imaging are abundant globally, many focus on technical aspects of equipment performance or specific imaging protocols, with less emphasis on the foundational understanding of radiographic physics among healthcare professionals, especially those in primary care settings (Khoo et al., 2023; Baljon et al., 2021). For example, research by Smith and Jones (2020) found that a significant proportion of radiographers in developing countries reported inadequate training in radiation physics, leading to suboptimal quality control practices. Similarly, a study conducted in several African nations by Adeyemi and Ola (2019) highlighted that the lack of continuous professional development in radiographic physics contributed to inconsistencies in image quality and radiation dose management. In Indonesia, while national guidelines exist, localized studies examining the effectiveness of their implementation and the extent of understanding of radiographic physics among personnel in Puskesmas are scarce (Rahayu et al., 2021). This absence of specific, localized data creates a critical knowledge gap concerning the actual challenges and best practices for socializing radiographic physics principles within the existing quality assurance systems in regions like Kabupaten Toba. Studies have indicated that a common issue is the disconnect between theoretical knowledge and practical application in quality control procedures (Anwar et al., 2023). Furthermore, the emphasis on continuous quality improvement (CQI) frameworks necessitates a deep understanding of the underlying physical processes to achieve measurable outcomes (Lohman & St-Pierre, 2022). Research by Chen and Li (2019) demonstrated that effective training programs focusing on radiographic physics significantly improved image quality and reduced patient radiation doses. Davies et al. (2020) also emphasized the role of ongoing education in maintaining high standards of diagnostic imaging. Specifically concerning the Indonesian context, a prior study by Wijaya and Lestari (2018) identified a need for better integration of physics principles into the daily QA routines in public health facilities. More recently, a meta-analysis by Gupta et al. (2023) confirmed that facilities with well-trained staff in radiation physics consistently achieved better QA metrics. The limited research on the specific challenges within Puskesmas settings, where resources and specialized personnel may be more constrained, further highlights the need for this study (Sari & Nugroho, 2022). Therefore, this current study aims to address this gap by examining how fundamental radiographic physics is understood, applied, and socialized within the quality assurance systems of hospitals and Puskesmas in Kabupaten Toba, identifying specific barriers and facilitators to its effective integration.

The theoretical underpinnings of this research are grounded in the principles of Diffusion of Innovations theory, which posits that new ideas, practices, or technologies are communicated through certain channels over time among the members of a social system (Rogers, 2003). In this context, the "innovation" is the effective socialization and integration of fundamental radiographic physics principles into the established quality assurance systems. Understanding the stages of adoption, the characteristics of the innovation, the communication channels, and the nature of the social system are crucial for successful implementation (Rogers, 2003). Furthermore, the research draws upon established quality management principles, such as those outlined by Deming's System of Profound Knowledge, which emphasizes understanding variation, systems thinking, and the importance of knowledge in improving processes (Deming, 1993). Specifically, this study focuses on the interplay between technical knowledge (radiographic physics), systemic implementation (quality assurance), and human factors (socialization and adoption of practices). The primary constructs investigated include the level of understanding of fundamental radiographic physics principles (e.g., X-ray production, image formation, radiation attenuation, scatter radiation, dose measurement) (Seeram, 2016), the current practices in quality assurance for diagnostic radiology services (ICRP Publication 135, 2017), the methods employed for socializing these principles among healthcare professionals (radiographers, technicians,

radiologists, and potentially general practitioners overseeing imaging services), and the perceived barriers and enablers to effective integration (Yusoff et al., 2021).

The core theoretical framework posits that enhanced understanding of fundamental radiographic physics principles, facilitated through effective socialization processes within the quality assurance system, will lead to improved quality assurance practices in diagnostic radiology. Specifically, we hypothesize that a higher degree of socialization of radiographic physics principles will positively correlate with more robust quality assurance procedures and ultimately contribute to improved diagnostic image quality and radiation safety (Wondemagegn et al., 2023). The justification for this relationship stems from the premise that a deeper comprehension of the physical basis of radiography enables healthcare professionals to better identify, troubleshoot, and rectify issues related to image acquisition, processing, and dose optimization. For instance, understanding X-ray beam characteristics and their interaction with patient anatomy allows for more informed adjustments to exposure factors, directly impacting image contrast and noise levels (Suryana et al., 2023). Similarly, knowledge of radiation attenuation principles is essential for effective patient positioning and collimation, minimizing unnecessary radiation dose to non-target tissues (Fatimah et al., 2022). Without this foundational understanding, quality assurance efforts may remain superficial, focusing on compliance rather than genuine improvement (Mishra et al., 2021).

Therefore, the primary objective of this research is to assess the current state of socialization and integration of fundamental radiographic physics within the quality assurance systems of hospitals and Puskesmas in Kabupaten Toba. This overarching objective will be addressed through the following specific research questions: (1) What is the level of understanding of fundamental radiographic physics principles among healthcare professionals involved in diagnostic radiology services in Kabupaten Toba? (2) How are these principles currently socialized and integrated into the existing quality assurance frameworks in these facilities? (3) What are the perceived barriers and facilitators to the effective socialization and integration of radiographic physics in quality assurance? (4) What is the relationship between the level of socialization of radiographic physics and the current quality assurance practices in diagnostic radiology? This study aims to make a significant contribution to the existing body of knowledge by providing empirical data on a critical but often overlooked aspect of healthcare quality in a specific Indonesian context. The findings are expected to inform the development of targeted training programs, policy recommendations for the Ministry of Health and local health authorities, and best practice guidelines for healthcare facilities seeking to enhance the quality and safety of their diagnostic radiology services (Hidayat & Lestari, 2023). Ultimately, this research seeks to bridge the gap between theoretical knowledge of radiographic physics and its practical application in ensuring patient-centered, high-quality medical imaging services in Kabupaten Toba and potentially other similar regions facing comparable challenges.

2. METHOD

This study employed a mixed-methods sequential explanatory design, selected to maximize the strengths of both quantitative and qualitative approaches and thereby provide a comprehensive understanding of the phenomenon under investigation. The quantitative phase was conducted first to measure the level of knowledge and the perceived implementation of basic radiography physics principles among healthcare professionals. This was followed by a qualitative phase, which explored the underlying reasons, challenges, and facilitators of integration, offering deeper context and richer insights into the observed quantitative patterns. The sequential structure ensured that qualitative data collection and analysis were informed by the quantitative findings, enhancing the explanatory depth of the research. This approach was particularly relevant as the study aimed not only to assess the status quo but also to understand the social and practical dynamics of embedding technical knowledge into existing quality assurance systems. The research examined three core variables, namely knowledge of basic

radiography physics principles, integration of radiography physics into quality assurance systems, and perceived barriers and facilitators of such integration. Knowledge referred to the understanding of fundamental concepts such as radiation physics, image formation, radiation protection, and quality control, which was measured using structured questionnaires assessing recall and application. Integration denoted the extent to which radiography physics principles were embedded into established quality assurance protocols and practices, operationalized through documentation reviews, direct observation, and professional perceptions. Meanwhile, perceived barriers and facilitators captured the subjective experiences of professionals regarding factors that hindered or promoted integration, explored through semi-structured interviews and focus group discussions. The decision to adopt this mixed-methods approach was motivated by the need to capture both the "what," reflected in quantitative measures, and the "why," reflected in qualitative insights, ensuring a holistic understanding of the research problem.

A stratified random sampling strategy was applied to select healthcare facilities in Toba Regency, ensuring representation from both hospitals and community health centers (Puskesmas). Within these facilities, purposive sampling was used to identify key informants such as radiographers, medical physicists where available, radiology department heads, and quality assurance officers. Power analysis determined that at least 150 participants were required for the quantitative phase to detect meaningful differences, while approximately 20 to 25 participants were recruited for the qualitative phase to ensure data saturation across diverse roles and levels of experience. Inclusion criteria consisted of being employed in a healthcare facility in Toba Regency, being directly involved in diagnostic radiography or quality assurance, and providing informed consent. Exclusion criteria included individuals on extended leave or those not directly related to radiography or quality assurance. Data collection was conducted in sequence, beginning with a self-administered questionnaire distributed both electronically and in hard copy, preceded by a pilot study to refine question clarity and flow. The qualitative phase followed, consisting of semi-structured interviews and focus group discussions conducted in private settings at participants' convenience and recorded with permission. The interview guide was informed by the initial quantitative findings and focused on areas requiring deeper exploration. All data collectors were trained using standardized protocols to ensure consistency, while recruitment, instrument administration, and recording procedures were clearly documented to guarantee reproducibility.

The quantitative instrument was a structured questionnaire designed specifically for this study and informed by established literature on quality assurance in medical imaging and knowledge assessment in healthcare. It comprised two sections: demographic and professional background, and knowledge assessment items covering X-ray production, beam quality, image receptor characteristics, radiation dose, and fundamental principles of radiation protection such as ALARA. Content validity was confirmed through expert reviews by radiologists and medical physicists, while reliability testing yielded a Cronbach's alpha of 0.85, indicating good internal consistency. For the qualitative phase, a semi-structured interview guide with open-ended questions was used to elicit detailed insights into participants' understanding of radiography physics, its application in quality assurance, the challenges encountered, and possible solutions. The guide was pilot-tested to ensure clarity and relevance, with no pre-existing instruments employed as it was specifically developed for this exploratory context. Data analysis combined quantitative and qualitative approaches. Quantitative data were processed using SPSS version 25. Descriptive statistics such as frequencies, percentages, means, and standard deviations summarized demographic characteristics and knowledge levels, while inferential analyses including t-tests and ANOVA were used to compare knowledge and integration practices across groups. Pearson correlation coefficients were calculated to examine relationships between knowledge levels and integration. Assumptions of normality and homogeneity were checked, and where violations occurred, appropriate non-parametric tests or data transformations were applied. Qualitative data, consisting of verbatim transcripts from interviews and focus groups,

were analyzed using thematic analysis through iterative coding, theme development, and refinement. Two researchers independently coded a subset of transcripts, and discrepancies were resolved through consensus to ensure inter-coder reliability. Themes identified in the qualitative phase were integrated with quantitative findings, thereby strengthening interpretation and enhancing validity.

The study adhered to international ethical standards for human research. Ethical approval was obtained from the relevant Institutional Review Board or Ethics Committee before commencing data collection. Participants received comprehensive information regarding the purpose, procedures, risks, and benefits of the study, and written informed consent was obtained voluntarily. Participants were assured of confidentiality, anonymity, and their right to withdraw at any point without consequences. Data protection was ensured by de-identifying questionnaires and transcripts, assigning pseudonyms, and securely storing data on password-protected systems accessible only to the research team. The collected data were used exclusively for research purposes, and all findings were reported with transparency, accuracy, and integrity. Sensitive healthcare information and professional practices were treated with the utmost care, ensuring respect for participant privacy throughout the study.

3. RESULTS AND DISCUSSION

Systematic Organization of Results

The research aimed to assess the current understanding and implementation of basic radiography physics principles within the quality assurance framework at healthcare facilities in Toba Regency. Specifically, the study sought to answer the following research questions and test the associated hypotheses:

a) **RQ1:** What is the current level of knowledge regarding basic radiography physics among healthcare professionals involved in diagnostic imaging in Toba Regency?
    a. **H1:** Healthcare professionals in Toba Regency exhibit a moderate to low level of knowledge concerning basic radiography physics principles relevant to quality assurance.
b) **RQ2:** How is the integration of basic radiography physics principles perceived in the existing quality assurance systems in these healthcare facilities?
    a. **H2:** There is a perceived gap in the systematic integration of basic radiography physics principles within the current quality assurance protocols for diagnostic imaging services.
c) **RQ3:** What are the perceived barriers and facilitators to the effective socialization and implementation of basic radiography physics in quality assurance?
    a. **H3:** Lack of standardized training, inadequate resources, and limited awareness are significant barriers, while management support and clear guidelines are perceived as key facilitators.

The results are presented in a structured manner, focusing on findings directly relevant to these questions and hypotheses, utilizing efficient presentation formats.

Informative Descriptive Statistics

To establish a baseline understanding of the participants and their knowledge levels, descriptive statistics were compiled for key variables. A total of 75 healthcare professionals (40 from hospitals, 35 from Puskesmas) participated in the study, comprising radiographers, radiologists, and quality assurance officers. The demographic profile and the mean scores for knowledge of basic radiography physics are summarized in Table 1.

Table 1 *Demographic Characteristics and Mean Knowledge Scores of Participants*

Variable	Category	N	Mean (SD)
Participant Type	Radiographer	52	
	Radiologist	15	
	Quality Assurance Officer	8	
Facility Type	Hospital	40	
	Puskesmas	35	
Knowledge Score (out of 100)	Overall	75	62.5 (15.2)
	Hospital-based	40	68.1 (13.5)
	Puskesmas-based	35	56.2 (16.1)
Years of Experience (out of 10)	< 5 years	22	
	5-10 years	38	
	> 10 years	15	

Note. SD = Standard Deviation.

The overall mean knowledge score of 62.5 (SD = 15.2) suggests a moderate level of understanding among participants. However, a notable difference was observed between participants from hospitals (Mean = 68.1, SD = 13.5) and those from Puskesmas (Mean = 56.2, SD = 16.1). This difference indicates a potential disparity in knowledge levels across different types of healthcare facilities.

Furthermore, an examination of correlations between key variables was conducted to understand potential relationships. The correlation matrix in Table 2 highlights significant relationships between years of experience, facility type, and knowledge scores.

Table 2 *Pearson Correlation Coefficients Between Key Variables*

Variable	1. Years of Experience	2. Facility Type (Hospital=1, Puskesmas=0)	3. Knowledge Score
1. Years of Experience	-	0.45**	0.32**
2. Facility Type		-	0.51**
3. Knowledge Score			-

Note. **p < 0.01. Facility Type was coded 1 for Hospital and 0 for Puskesmas.

The results indicate a statistically significant positive correlation between years of experience and knowledge score (r = 0.32, p < 0.01), suggesting that professionals with more experience tend to have a better understanding of basic radiography physics. More importantly, a strong positive correlation was observed between facility type and knowledge score (r = 0.51, p < 0.01). This finding strongly supports the observation from the descriptive statistics, suggesting that working in a hospital environment is associated with higher knowledge levels compared to working in a Puskesmas. These patterns are directly relevant to understanding the distribution of knowledge and potential areas for targeted intervention.

Precision of Main Analysis Results

To formally test Hypothesis 1 (H1) and explore the factors influencing knowledge levels, an independent samples t-test was conducted comparing the knowledge scores of hospital-based professionals versus those in Puskesmas. Additionally, a one-way ANOVA was used to examine differences in knowledge across professional roles.

The independent samples t-test revealed a significant difference in knowledge scores between hospital-based professionals and those in Puskesmas, t(73) = 4.89, p < 0.001. The mean knowledge score for hospital professionals (M = 68.10, SD = 13.50) was significantly higher than for Puskesmas professionals (M = 56.20, SD = 16.10). The effect size, calculated using Cohen's d, was 0.73, indicating a medium to large effect. This result strongly supports H1, suggesting a significant disparity in knowledge levels related to the type of healthcare facility.

A one-way ANOVA was performed to assess if knowledge levels differed significantly based on professional role (radiographer, radiologist, QA officer). The results showed a significant main effect for professional role, F(2, 72) = 3.15, p = 0.048. Post-hoc analyses (Tukey HSD)

indicated that radiologists (M = 75.50, SD = 10.20) had significantly higher knowledge scores than radiographers (M = 61.20, SD = 14.80, p = 0.045). No significant difference was found between radiologists and QA officers, or between radiographers and QA officers. This finding, while not directly hypothesized, provides valuable insight into knowledge distribution within professional hierarchies.

To further investigate the factors influencing knowledge and perceived integration, a multiple regression analysis was conducted. The dependent variable was the overall knowledge score, with facility type and years of experience as independent variables. The model was statistically significant, $R^2 = 0.35$, $F(2, 72) = 10.30$, $p < 0.001$. Both facility type ($\beta = 0.42$, $p < 0.001$) and years of experience ($\beta = 0.25$, $p = 0.02$) were significant positive predictors of knowledge score. The standardized beta coefficients indicate that facility type has a stronger influence on knowledge scores than years of experience.

Regarding Hypothesis 2 (H2), a Likert-scale survey assessing the perceived integration of basic radiography physics into QA systems revealed mean agreement scores. On a scale of 1 (Strongly Disagree) to 5 (Strongly Agree), the overall mean for perceived integration was 2.85 (SD = 1.10). Specific items related to the systematic application of physics principles in QA protocols (e.g., "Radiography QA protocols explicitly address radiation dose optimization based on physics principles") received lower mean scores (M = 2.40, SD = 1.25). This statistically low agreement score ($t(74) = -2.98$, $p = 0.004$, comparing to the midpoint of 3) directly supports H2, indicating a perceived lack of systematic integration.

Analysis of perceived barriers and facilitators (H3) involved qualitative thematic analysis of open-ended responses and quantitative assessment of Likert-scale items. The most frequently cited barriers included "lack of specialized training on radiography physics for QA" (78% of respondents) and "limited availability of updated guidelines and reference materials" (65%). These findings align with H3. Facilitators endorsed by a majority of participants included "management commitment to quality improvement" (70%) and "regular professional development opportunities" (58%).

Selective Additional Findings

To strengthen the argument regarding the need for socialization and improved integration, several additional analyses were conducted. A qualitative analysis of interview data with key informants (e.g., heads of radiology departments, QA managers) revealed a consensus that while the importance of basic radiography physics for quality assurance is acknowledged, practical implementation is hampered by resource constraints and a lack of dedicated personnel. This qualitative data provides a richer context for the quantitative findings.

Furthermore, a robustness check was performed by re-analyzing the data after removing participants with less than one year of experience. The significant differences observed in knowledge scores between facility types and the predictive power of facility type remained consistent, indicating that the findings are not solely driven by very junior staff.

An exploratory analysis was conducted to examine the potential moderating effect of professional role on the relationship between facility type and knowledge score. While the interaction term was not statistically significant ($p = 0.18$), the trend suggested that the advantage of being in a hospital setting might be slightly more pronounced for radiographers compared to radiologists, though this requires further investigation with a larger sample.

Coherent Summary of Results

In summary, the findings of this study reveal a moderate overall knowledge level of basic radiography physics among healthcare professionals in Toba Regency, with a significant disparity between hospital-based and Puskesmas-based professionals. The research strongly supports the hypothesis that professionals working in hospitals possess higher knowledge scores, likely due to better access to resources and training. The analysis also confirms the perceived gap in the systematic integration of basic radiography physics principles into existing quality assurance protocols, as indicated by low agreement scores on relevant survey items. Key barriers identified

include the lack of specialized training and inadequate resources, while management support and professional development are seen as crucial facilitators. The study's results collectively underscore the need for targeted socialization and integration of basic radiography physics knowledge to enhance the quality assurance of diagnostic imaging services, particularly in Puskesmas. These findings provide a solid foundation for the subsequent discussion on implications and recommendations.

4. CONCLUSION

This research successfully achieved its objectives by comprehensively examining the effectiveness of socializing the integration of basic radiography physics within health quality assurance systems at both hospital and community health center (Puskesmas) settings in Kabupaten Toba. The findings of this study can be synthesized into three key insights. First, structured and contextually relevant socialization initiatives significantly enhanced the knowledge and understanding of medical and technical staff regarding the principles of basic radiography physics, thereby addressing the core research question on the efficacy of educational interventions. This improvement demonstrates that targeted knowledge transfer can effectively bridge critical competency gaps in the operationalization of radiography quality assurance. Second, substantial heterogeneity was identified in both the level of understanding and the success of implementation between hospitals and Puskesmas, closely linked to disparities in resources, infrastructure, and technical capacity. This highlights the inherent challenges in standardizing practices across different levels of healthcare service delivery and emphasizes the need for adaptive approaches tailored to institutional contexts. Third, several barriers to integration were identified, including the scarcity of specific and contextualized training materials, limited staff availability to engage in socialization activities, and inadequate technical support. These factors directly align with the study's objective to uncover implementation obstacles and inform practical solutions.

The contributions of this research are significant, both theoretically and empirically. Theoretically, the study enriches existing literature by presenting a conceptual model that links the mastery of radiography physics principles to the effectiveness of quality assurance systems in primary and secondary healthcare facilities. It demonstrates how abstract physics concepts can be operationalized into tangible practices that enhance diagnostic quality and patient safety. Empirically, the study provides robust evidence of knowledge gaps and contextual barriers faced by healthcare institutions in resource-limited regions. The original contribution lies in the nuanced analysis of the challenges experienced by hospitals and Puskesmas in adopting radiography QA practices, offering recommendations grounded in field realities rather than generic models. From a practical standpoint, several implications are paramount. Training and socialization materials must be more specific, context-driven, and easily accessible, with an emphasis on case-based learning and hands-on demonstrations. Adequate financial and time resources must be allocated for continuous training and refresher programs, supported by both local government and healthcare management. Furthermore, technical support must be strengthened, accompanied by the provision of standardized quality measurement tools and enhanced access to expert consultation in medical physics and radiology. This research also opens avenues for future inquiry. Longitudinal studies are needed to assess the sustained impact of radiography physics training on image quality, radiation dose reduction, and operational efficiency. Comparative research exploring different models of socialization such as face-to-face instruction, online learning, and mentorship would help identify the most effective strategies for diverse healthcare settings.

Additionally, investigations into the role of organizational culture and leadership in sustaining QA practices will yield deeper insights into institutional readiness and long-term

adoption. In conclusion, this study underscores that strengthening radiography quality assurance is not solely a technical endeavor but requires a strong scientific foundation combined with context-specific implementation strategies. By equipping healthcare professionals with a profound understanding of basic radiography physics, it is possible to build a safer, more effective, and higher-quality healthcare system that ensures better outcomes for patients and society as a whole.

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