Integration of Health Law and Radiation Safety Aspects in the Medical Physics Curriculum for Radiotherapy Treatment

Ratna Widyaningrum[1], Khoirun Nofik[2], Ainul Masruroh[3], Sari Hernawati[4]
[1]Faculty of Medicine, Medical Study Programme, Wahid Hasyim University, Semarang, Indonesia
[2,4]Faculty of Islamic Studies, Wahid Hasyim University, Semarang, Indonesia
[3]Faculty of Law, Wahid Hasyim University, Semarang, Indonesia

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ABSTRACT

Purpose of the study: This study aims to analyze the legal regulations related to radiation safety in radiotherapy and develop a systematic approach to integrating health law and radiation safety aspects into the medical physics curriculum.

Methodology: A qualitative library research approach was used, analyzing journals, regulatory documents (WHO, IAEA, BAPETEN), and academic books through content analysis.

Main Findings: International and national regulations, including IAEA, ICRP, and BAPETEN, strictly govern radiation safety in radiotherapy, covering dose limits, exposure monitoring, and waste management. However, medical physics curricula lack structured integration of legal and safety aspects. A systematic curriculum model is proposed, incorporating progressive learning, practical simulations, clinical internships, and competency-based assessments to enhance student preparedness in radiation protection and regulatory compliance.

Novelty/Originality of this study: This study proposes a structured curriculum model linking technical and regulatory aspects through progressive learning, practical training, and industry collaboration, ensuring better radiation safety implementation in clinical practice.

Corresponding Author:
Ratna Widyaningrum,
Faculty of Medicine, Medical Study Programme, Wahid Hasyim University,
Jl. Raya Gunungpati No.KM.15, Nongkosawit, Kec. Gn. Pati, Kota Semarang, Jawa Tengah, 50224, Indonesia
Email: ratnawidyaningrum@unwahas.ac.id

1. INTRODUCTION

The use of radiotherapy technology in cancer treatment continues to rise, supported by advancements such as Stereotactic Body Radiotherapy (SBRT), Intensity-Modulated Radiation Therapy (IMRT), and Image-Guided Radiation Therapy (IGRT). These technologies enable the precise delivery of radiation doses with minimal risk to healthy tissues [1]. The combination of advanced technology and an improved understanding of tumour biology has significantly enhanced treatment effectiveness, increasing survival rates for certain cancer patients from 30% to 80% over the past two decades [2]. Despite these advancements, the use of radiation in medical therapy requires strict management and monitoring [3]. Errors in procedural implementation or inadequate radiation exposure control can lead to significant adverse effects [4]. Thus, in addition to technological improvements, strict safety protocols must be implemented to minimise risks for both patients and medical personnel involved in radiotherapy procedures.

Uncontrolled radiation exposure poses severe risks to both patients and healthcare professionals [5]. These risks include DNA damage, which may trigger cellular mutations and increase the likelihood of long-term cancer development [6]. Moreover, repeated radiation exposure can weaken the immune system and elevate the risk of degenerative diseases [7]. For medical professionals exposed to radiation over extended periods, cumulative radiation effects can lead to tissue damage, organ dysfunction, and, in some cases, skin injuries due to high-dose exposure [8].

To mitigate these risks, international regulations have been established to ensure radiation safety. The International Atomic Energy Agency (IAEA) has introduced the Fundamental Safety Principles (SF-1), which serve as the foundation for protecting human health and the environment from radiation hazards [9]. These principles are further reinforced through the International Basic Safety Standards (BSS), which regulate radiation dose limits, protection procedures, and monitoring mechanisms across multiple sectors, including healthcare [10]. Additionally, the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP) provide guidelines on radiation safety in medical practice [11]. These regulations emphasise the necessity of radiation dose monitoring systems, safe imaging technology, and specialised training for medical personnel to mitigate excessive exposure risks.

Although international regulations have been widely implemented to ensure radiation safety, their effectiveness heavily depends on the understanding and preparedness of medical professionals and physicists in applying these regulations [12]. One of the major challenges in achieving optimal safety standards is ensuring that health care and medical physics professionals comprehend and adhere to existing regulations. However, this goal cannot be achieved without a well-structured educational system, particularly within the medical physics curriculum [13]. Unfortunately, current curricula lack adequate integration of health law and radiation safety, leaving graduates inadequately prepared to address regulatory challenges in clinical practice.

Many medical physics programmes still prioritise technical and physics-based aspects while providing insufficient training on radiation safety standards, exposure dose limits, and the legal responsibilities of medical personnel [14]. Yet, regulations such as IAEA's International Basic Safety Standards (BSS) and safety guidelines from Indonesia's Nuclear Energy Regulatory Agency (BAPETEN) are crucial to ensuring the safe and compliant use of radiation [15]. The lack of legal and safety integration may result in low awareness among students regarding the importance of protecting both patients and medical professionals from excessive radiation exposure. Consequently, a comprehensive and regulation-based curriculum revision is necessary to produce competent medical physics graduates with a holistic understanding of radiation safety regulations [16].

Considering the issues outlined above, this study aims to provide a deeper understanding of radiation safety regulations in radiotherapy and propose a systematic approach to integrating health law and radiation safety into medical physics education. The findings of this study are expected to serve as an academic and practical foundation for educational institutions to enhance medical physics students' competencies in both technical aspects and regulatory compliance. The novelty of this study lies in its approach to combining legal frameworks with medical physics education, an area that has received limited attention in previous research.

2. RESEARCH METHOD

This study employs a qualitative approach using library research methodology. Library research is a method that relies on literature sources as the primary data [17]. The study analyses various references, including books, peer-reviewed journals, reports, and regulatory documents related to radiation safety regulations at both international and national levels, as well as their application in medical physics education.

The data sources in this study consist of scientific journals on medical physics, radiation safety, and health law regulations. Additionally, regulatory documents from organisations such as the WHO, IAEA, and BAPETEN serve as key references. Furthermore, academic books and radiation safety standards used in medical practice are examined to reinforce the study’s findings.

This study employs content analysis, which involves examining, interpreting, and drawing conclusions from various written and printed sources. The collected data is systematically analysed to gain a deeper understanding of radiation safety regulations within the context of medical physics. Through this approach, the study aims to provide meaningful academic contributions by exploring how health law and radiation safety aspects can be effectively integrated into the medical physics curriculum.

3. RESULTS AND DISCUSSION

3.1 International and National Regulations on Radiation Safety

International regulations on radiation safety are established by global organisations, primarily the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP). The IAEA is responsible for formulating the Fundamental Safety Principles (SF-1), which emphasise the protection of human health and the environment from the hazardous effects of ionising radiation [18]. These principles form the basis for further regulatory developments, including the International Basic Safety Standards (BSS), which set radiation exposure limits and protective measures for workers and the general public [19].

The ICRP, an independent body providing recommendations on radiation protection, publishes various guidelines on radiation safety, including risk mitigation strategies, dose monitoring, and optimised protection measures [20]. Key ICRP publications, such as Publication 103 and Publication 60, introduce the As Low As Reasonably Achievable (ALARA) principle, which states that radiation exposure should be minimised to the lowest possible level without compromising its intended benefits [21] [22].

Additionally, radiation safety regulations cover monitoring and radioactive waste management. The IAEA’s WS-G-2.7 document underscores the importance of proper waste management systems for radioactive materials used in medical, industrial, and research applications. These regulations aim to ensure that radioactive waste is safely handled to prevent adverse health and environmental effects [23].

In the healthcare sector, radiation safety regulations include guidelines for medical professionals using radiation-based technologies, particularly in radiotherapy and medical imaging. The IAEA and WHO establish maximum allowable radiation doses for both patients and medical personnel to mitigate harmful side effects. The ICRP Publication 73 provides safety guidance for medical applications, including dose monitoring and strategies for reducing radiation exposure [24].

Radiation safety is also a critical concern in nuclear emergency preparedness and response. The IAEA’s General Safety Requirements Part 7 (GSR Part 7) outlines emergency response protocols for radiation incidents, including evacuation, decontamination, and environmental monitoring following a radiation-related event. These regulations are designed to protect populations from potential hazards resulting from nuclear accidents or radiation exposure emergencies [25] [26].

National regulations on radiation safety in Indonesia are governed by the Badan Pengawas Tenaga Nuklir (BAPETEN) through various legal frameworks and policies aimed at protecting workers, the public, and the environment from ionising radiation risks. Law No. 10 of 1997 on Nuclear Energy serves as the primary legal foundation regulating all aspects of nuclear energy utilisation, including radiation protection and safety measures. Further legal instruments include Government Regulation (PP) No. 33 of 2007, which outlines safety provisions for ionising radiation protection and radioactive source security [27].

As the primary regulatory body overseeing nuclear energy in Indonesia, BAPETEN has also issued several technical regulations, including Regulation No. 4 of 2013 on Radiation Protection and Safety in the Utilisation of Nuclear Energy. This regulation provides safety guidelines for various nuclear energy applications, covering medical, industrial, and research sectors. The framework mandates radiation protection systems, dose monitoring, safety protocols, and mandatory training for personnel working with radiation sources [27].

In the health sector, radiation safety is crucial, particularly in radiotherapy and diagnostic imaging. Government Regulation (PP) No. 58 of 2015 on Radiation Safety and Security in the Transport of Radioactive Materials establishes requirements for safe transportation of radioactive substances, preventing risks to the public and the environment. Moreover, radioactive waste management is regulated under Government Regulation (PP) No. 61 of 2013, which mandates that institutions utilising radioactive materials must implement proper waste disposal mechanisms in compliance with international safety standards [28].

To ensure compliance with safety regulations, BAPETEN conducts licensing, inspections, and periodic radiation safety audits for facilities using ionising radiation sources. The BAPETEN Head Regulation also mandates that radiation workers must obtain a Radiation Worker License (SIB), certifying that they have undergone training and competency assessments in radiation protection and safety. Furthermore, radiation exposure limits are strictly regulated, ensuring that workers do not exceed annual dose thresholds set by national and international standards [29].

In emergency scenarios, national radiation safety regulations also include response procedures for radiation incidents or nuclear accidents. BAPETEN Head Regulation No. 6 of 2015 on Radioactive Source Security outlines mitigation strategies, including evacuation plans, decontamination measures, and coordination with relevant agencies to minimise the impact of uncontrolled radiation exposure. This regulation also highlights the importance of simulation drills and emergency preparedness exercises to enhance institutional readiness in managing radiation-related incidents [28].

With strict regulations and oversight from BAPETEN, Indonesia continues to improve radiation safety standards to align with international guidelines. However, challenges remain in implementation, including a lack of qualified human resources in radiation protection and the need for increased awareness of radiation safety across various sectors. Therefore, regulatory improvements, enhanced training programmes, and personnel certification are essential steps in strengthening Indonesia's radiation safety framework [27], [28].

3.2 Implementation of Regulations in the Medical Physics Curriculum

The integration of health law and radiation safety into the medical physics curriculum requires a systematic approach, ensuring that students gradually comprehend regulations, from fundamental principles to practical application in professional practice. According to Vygotsky’s Constructivist Learning Theory (1978), learning should begin with conceptual foundations before progressing to more complex understanding through hands-on experience [30]. Therefore, the curriculum structure must be designed progressively, incorporating teaching methods that align with students' evolving comprehension levels.

At the initial stage, students are introduced to fundamental radiation safety concepts and health law regulations applicable both nationally and internationally. Introductory courses include Radiation Physics and Biological Interactions, which explores how radiation interacts with the human body and its health effects. Additionally, students are familiarised with radiation safety regulations from the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), and Indonesia's Nuclear Energy Regulatory Agency (BAPETEN). Learning at this stage employs interactive lectures, group discussions, and literature reviews, aligning with Bloom's Taxonomy (1956), which highlights the importance of cognitive understanding before practical application [31].

As students advance, they explore the application of regulations in various medical physics domains. Key subjects include Radiation Protection in Medical Practice, which discusses dose limits for medical personnel and patients based on IAEA and WHO standards, and Risk Analysis and Radiation Safety Management, which delves into radiation exposure risk mitigation strategies in clinical environments. To provide a more in-depth learning experience, the case-based learning (CBL) approach is applied, where students analyse real-world radiation safety violations and propose solutions based on existing regulations. This approach aligns with Kolb's Experiential Learning Theory (1984), which emphasises learning through direct experience to enhance conceptual understanding [32].

At the next stage, students begin to apply theoretical knowledge through laboratory practical sessions and technology-based simulations. The Radiation Protection Laboratory provides students with opportunities to operate radiation monitoring instruments, such as dosimeters and survey meters, and conduct simulated radiation safety inspections using artificial intelligence-based software. Additionally, students must analyse regulatory compliance documentation, such as radiation exposure monitoring reports in accordance with BAPETEN and IAEA standards. Sweller's Cognitive Load Theory (1988) supports simulation-based learning, as it reduces cognitive overload and enhances students' ability to apply theoretical knowledge in practical scenarios [33].

To prepare students for real-world challenges, participation in mandatory internships at hospitals or medical physics laboratories is required. During these placements, students:

1. Observe radiation safety protocol implementation in radiotherapy and diagnostic imaging departments.
2. Participate in radiation dose measurements and safety monitoring for medical staff.
3. Engage with regulatory authorities and safety officers to understand how radiation safety policies are implemented in clinical settings.

This approach follows the Work-Based Learning (WBL) model [34], which Raelin (2008) asserts is highly effective in enhancing professional competencies through industry-based experiences [34].

After completing the learning and internship stages, students undergo competency-based assessments to ensure their mastery of health law and radiation safety regulations. Evaluations include written examinations on radiation safety standards, practical assessments on radiation protection equipment usage, and case study analyses on radiation-related incidents. These assessments are developed in alignment with the Outcome-Based Education (OBE) framework, ensuring that graduates possess applicable skills for professional practice [35].

To enhance the curriculum's effectiveness, continuous evaluation and improvements must be implemented through various mechanisms, such as:

1. Graduate and professional feedback surveys to assess learning outcomes and workplace readiness.
2. Ongoing discussions with regulatory bodies, such as BAPETEN, to ensure that the curriculum remains aligned with the latest regulatory developments.
3. Academic workshops and seminars to discuss innovations in radiation safety education and facilitate knowledge-sharing among educational institutions.

This evaluation process follows the Continuous Quality Improvement (CQI) model, which emphasises the need for ongoing assessment and refinement to maintain a high standard of education [36]. By adopting a systematic and theory-based curriculum design, integrating health law and radiation safety into medical physics education can be implemented more effectively. This approach ensures that graduates not only possess technical expertise in radiotherapy and medical imaging but also have a comprehensive understanding of radiation safety regulations and professional responsibilities. Such integration is crucial in producing professionals who excel not only in technical competence but also in legal and ethical awareness regarding radiation-based technologies, ultimately contributing to higher safety standards in medical facilities.

4. CONCLUSION

Based on this study, legal regulations concerning radiation safety in radiotherapy procedures have been strictly enforced by both international and national organisations. Institutions such as the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP) have established radiation safety standards that encompass dose limitations, exposure monitoring, and guidelines for radioactive waste management. In Indonesia, national regulations issued by the Nuclear Energy Regulatory Agency (BAPETEN) through various government regulations and agency decrees provide a comprehensive framework for the protection of medical personnel, patients, and the environment from the hazards of ionising radiation. The integration of health law and radiation safety into the medical physics curriculum is systematically structured and implemented in progressive stages. The process begins with the introduction of fundamental concepts related to radiation physics and radiation safety regulations, followed by a deeper understanding of regulatory applications. This is further reinforced through practical training and technology-based simulations, enhancing students' competencies in radiation protection. Subsequently, students undertake internships at medical facilities to gain first-hand experience in regulatory implementation within real-world clinical settings. In the final stage, a competency-based evaluation is conducted, encompassing theoretical assessments, practical proficiency in radiation protection equipment, and case-based analyses on radiation safety compliance.

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