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# Radiation Safety Awareness for Future Healthcare Workers: Educational and Legal Perspectives

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**Abstract:**

Radiation technologies used in the medical field have greatly improved diagnostic and treatment processes. However, these developments pose significant risks to healthcare professionals and patients, especially due to the biological effects of ionizing radiation. This review addresses the subject from educational and legal perspectives in order to increase healthcare professionals' knowledge, awareness and application skills on radiation safety. ALARA principle, personal protective measures, national and international regulations, in-service training and awareness studies are analyzed in detail. In addition, good practice examples from different countries are presented, Turkey's current situation is evaluated and future strategies are included. This review aims to contribute to current and future healthcare professionals working with radiation with a safer, more conscious and responsible approach.

## 1. Introduction

Radiation is a powerful tool widely used for diagnosis and treatment in modern medicine. Healthcare professionals work with radiation-based technologies in many areas such as computerized tomography (CT), magnetic resonance imaging (MRI), nuclear medicine applications and radiotherapy. However, the incorrect, uncontrolled or uninformed use of these technologies can lead to irreversible health problems for both healthcare professionals and patients.
It is known that ionizing radiation in particular directly damages DNA, causing mutations, cell death and, in the long term, serious diseases such as cancer [1,2]. Therefore, radiation safety is a multidisciplinary issue that should be addressed not only with technical knowledge but also with ethical, legal and educational dimensions.
Various legal regulations and training protocols are implemented worldwide regarding radiation safety. However, the extent to which these regulations are effective in healthcare institutions is directly related to the level of education of the personnel. Raising awareness of healthcare professionals about the biological effects of radiation and receiving training according to national/international standards is indispensable for the provision of safe healthcare services.
This review aims to explain why radiation safety awareness is necessary for future healthcare professionals, to reveal the strengths and weaknesses of the current situation, and to identify areas for improvement in terms of education and law.

## 2. Definition, Types and Use of Radiation in Healthcare

### 2.1 Definition and Classification of Radiation

Radiation refers to the emission of energy in the form of electromagnetic waves or particles. It is generally divided into two main groups: ionizing and non-ionizing radiation. Ionizing radiation can ionize atoms, disrupt chemical bonds and cause serious damage to biological tissues. This group includes X-rays, gamma rays, alpha and beta particles [3]. Non-ionizing radiation is lower energy and does not directly ionize cells; examples include microwave, infrared, radio waves and UV rays [4].

### 2.2 Uses of Radiation in Healthcare

Radiation is used in the health sector for both diagnostic and therapeutic purposes. While imaging techniques such as computerized tomography (CT) and fluoroscopy help make fast and accurate diagnoses; applications such as radiotherapy are indispensable, especially in the treatment of cancer patients [5]. Nuclear medicine applications are another area where radioactive substances are used for both diagnosis and treatment. Advanced imaging techniques such as Positron Emission Tomography (PET) monitor the distribution of radionuclides in the body and evaluate metabolic activities.

### *2.3 Risks of Exposure*

Healthcare workers are at constant risk of exposure to ionizing radiation because they use these devices frequently. Especially those working in the fields of radiology, nuclear medicine, anesthesia and surgery are included in higher risk groups in terms of exposure. In environments where dose monitoring is not carried out, healthcare workers can unknowingly exceed annual limits. This situation, as will be detailed in the following sections, can lead to serious health problems.

## *3. Biological Effects of Radiation and Health Risks*

### *3.1 Cellular Level Effects*

The biological effects of ionizing radiation begin at the atomic level. Radiation can directly or indirectly affect the DNA molecule in the cell nucleus, causing structural damage [6]. These damages; It manifests itself in the form of single-stranded or double-stranded DNA breaks, base changes and chromosomal anomalies. If the cell cannot repair this damage, mutations may occur, which may lead to uncontrolled cell proliferation, i.e. cancer [7].
Indirect effects generally occur through the formation of free radicals as a result of the ionization of water molecules. These radicals expose intracellular structures, especially DNA, to oxidative stress. Genetic changes, especially in germline cells, can be transferred to subsequent generations [8].

### *3.2 Acute and Chronic Effects*

Health problems related to radiation are divided into two according to the characteristics of the dose and duration of exposure: acute and chronic effects. Acute effects occur as a result of short-term exposure to high doses. Nausea, vomiting, hair loss, hematological disorders and radiation syndromes that can result in death in severe cases are observed [9].

Chronic effects occur more insidiously and are usually the result of long-term exposure to low doses. The risk of developing cataracts, infertility, cardiovascular disorders and especially cancers such as leukemia increases [10]. According to the International Atomic Energy Agency (IAEA), exposure to more than 100 mSv per year significantly increases the risk of cancer [3].

### *3.3 Occupational Exposure Risk Areas*

In the health sector, radiology technicians, radiologists, interventional radiology and cardiologists, nuclear medicine personnel, anesthesiologists and operating room workers are particularly at risk. These groups are high-risk occupational groups that are frequently and directly exposed to radiation (11). Studies have shown that the doses to which these personnel are exposed exceed the limit values in some cases (12).

### *3.4 Risk in Fetuses and Pregnant Women*

Radiation exposure for pregnant women can have various consequences depending on the developmental stage of the fetus. Especially in the first trimester, miscarriage, congenital anomalies and developmental delays can be observed due to radiation. The World Health Organization recommends that pregnant women be kept away from radiation if possible and that protective equipment such as lead aprons be used in cases of necessity [13].

## *4. Radiation Safety Principles*

### *4.1 ALARA Principle*

The basic principle in radiation safety applications is ALARA (As Low As Reasonably Achievable). This principle aims to expose to the lowest possible radiation dose within the framework of scientific, economic and technological possibilities [1]. The ALARA approach should be accepted not only as a physical measurement but also as a way of thinking and institutional culture.
ALARA is based on three basic strategies:
• Time: Keeping the duration of radiation exposure as short as possible
• Distance: Reducing exposure by staying away from the source
• Protection: Using personal protective equipment such as lead aprons, thyroid shields, mobile lead barriers [2]

### *4.2 Dose Limits*

Organizations such as ICRP and IAEA have determined annual dose limits for workers and the public. The recommended dose limit for healthcare workers is 20 mSv per year; this dose should not exceed 100 mSv over a lifetime. The annual limit for the lens of the eye is 20 mSv, and for the skin and extremities it is 500 mSv [1]. These limits should be kept under control with regular dosimetry monitoring.

### 4.3 Protective Equipment and Technology

Personal protective equipment is the first line of defense in radiation safety. Lead apron, thyroid shield, lead glasses and gloves are effective in protecting workers. In addition, technology-supported devices also increase safety:

• Dosimeters: Allow personal dose measurement.

• Automatic dose monitoring systems: Allow real-time monitoring of exposure.

• Mobile screens and lead panels: Provide direct protection in interventional procedures.

### 4.4 Management of Radiation Exposure

Personal dose records of personnel working with radiation sources should be kept and evaluated at regular intervals; if necessary, a change of duty or medical intervention should be planned. In addition, it is recommended that institutions establish radiation safety commissions and systematize both clinical and educational supervision [14].

## 5. Current Situation and Needs in Radiation Safety Education

### 5.1 The Importance of Educational Foundation

Radiation safety education for healthcare professionals is as critical a requirement as professional skills. Individuals who use ionizing radiation in clinical practices are expected to have sufficient knowledge and awareness about the effects of radiation, dose control, equipment use and protective measures [5]. This knowledge is of great importance not only for their own safety but also for patient safety and professional ethics.

### 5.2 Curriculum and Education Deficiencies

In many healthcare programs, the subject of radiation safety is either not included in the curriculum at all or is only addressed superficially. Especially in medical schools, radiology courses are taught on a theoretical basis, and practical safety training is often neglected [15]. Similarly, in health vocational schools, only basic physics knowledge is given to students at the technician and technician level, and safe practices are not sufficiently covered.

### 5.3 Types and Methods of Education

Radiation safety education can be addressed under two main headings, both formal and informal. Formal education includes theoretical courses, laboratory practices and internship experiences within the scope of the curriculum. Informal education is provided through in-service training, seminars, simulation studies and online training [16].

Effective radiation education should be supported by the following methods:

• Case-based learning: Teaches how to analyze real events.

• Simulation technologies: Provides practical application with realistic scenarios.

• E-learning modules: Provides learning independent of time and place, especially in in-service training.

• Blended learning: A hybrid method where both face-to-face and online techniques are used together.

### 5.4 Effectiveness of Education and Monitoring Mechanisms

The effectiveness of education should be evaluated with pre-post knowledge level measurements, behavioral changes and long-term application results. It has been shown that theoretical training given once a year does not provide the expected safe behaviors in daily practice [17]. Therefore, trainings should not only convey information but also provide behaviors.

### 5.5 Current Situation in Turkey

Radiation safety training for healthcare professionals in Turkey is limited by legal obligations. Periodic in-service trainings are provided in hospitals; however, the duration, content and implementation method of these trainings vary from institution to institution. In addition, there is no effective follow-up and measurement-evaluation system for those who receive radiation safety training [18]. This situation reduces the efficiency of the training and leads to lack of knowledge in the field.

Radiation safety training for healthcare professionals in Turkey is limited by legal obligations. In addition, a study has shown that health services vocational school students have limited knowledge about radiation protection and lack practical applications such as using dosimeters [19]. These findings show that current trainings are inadequate both theoretically and practically.

## 6. National and International Legal Regulations

### 6.1 Radiation Safety Legislation in Turkey

Regulations on radiation safety in Turkey are framed by the "Ionizing Radiation Safety Regulation", which entered into force in 2009 [20]. This regulation includes the licensing of radiation sources, personal dose monitoring of employees, working hours, health screenings and training obligations. With the transfer of TAEK's duties to TENMAK in 2020, some changes were made to the regulatory framework.

It is mandatory to establish a radiation safety committee in health institutions and for this committee to regularly inspect the dose values and safety practices of employees. However, the field applications of these regulations largely remain on paper and an effective inspection system cannot be developed.

### 6.2 International Standards

The main organizations that provide guidance on radiation safety worldwide are as follows:

• ICRP (International Commission on Radiological Protection): It is the most competent organization that determines the principles of radiological protection on scientific grounds. The guideline numbered 103 published by it forms the basis of radiation safety practices [1].

• IAEA (International Atomic Energy Agency): IAEA, which determines safety standards on a global scale, presents regulations under the title of "International Basic Safety Standards" (GSR Part 3) [3].

• WHO (World Health Organization): It makes recommendations for the protection of healthcare professionals.

• European Commission (EC): Directive 2013/59/Euratom imposes radiation safety training, auditing and reporting obligations on member countries [21].

### 6.3 Comparative Practices

Radiation safety training and auditing are carried out more systematically in many countries in Europe. In Germany, healthcare professionals are required to receive radiation safety training from an accredited program at least once a year. In England, there must be a "Radiation Protection Advisor" (RPA) in every hospital and personnel working with radiation must be registered [22].

In contrast, practices in Turkey have not yet been institutionalized to this level. Training is generally given quickly to cover personnel shortages; follow-up and inspection processes remain weak. In this context, the adaptation of international good practices to Turkey offers an important development opportunity.

### 6.4 Legal Responsibilities

Radiation safety is not only a technical issue, but also a legal issue. Health problems that develop in employees or patients as a result of radiation exposure may lead to administrative and criminal liabilities. A patient exposed to radiation may file a lawsuit against the healthcare institution if appropriate information is not provided and precautions are not taken (23). Similarly, employees may also claim rights within the scope of occupational health and safety.

## 7. Future Strategies and Conclusion

### 7.1 Integration of Technological Developments

Artificial intelligence (AI) and big data analytics have the potential to initiate a new era in radiation safety. Smart imaging systems can automatically calculate the most appropriate radiation dose for the patient and the procedure. Dosimeter data can be monitored instantly on cloud-based platforms, and risk groups can be identified at an early stage thanks to artificial intelligence algorithms [24].

In addition, augmented reality (AR) and virtual reality (VR)-based simulations offer healthcare professionals the opportunity to experience theoretical knowledge in a practical environment. Integrating such applications into training programs will increase the quality of learning.

### 7.2 Policy and Management Recommendations

• National Radiation Safety Training Program: The Ministry of Health should develop an accredited, centralized training system for all healthcare professionals in cooperation with the YÖK and TENMAK.

• Mandatory Certification: All personnel working with radiation should have regularly updated competency certificates.

• Audit and Feedback Mechanisms: Independent radiation safety audits should be conducted in hospitals; personnel performance should also be evaluated and rewarded in terms of safety.

### 7.3 Ethical and Human Dimension

Radiation safety is not only a technical necessity, but also an ethical responsibility. As healthcare professionals, protecting both ourselves and the patient is a requirement of practicing our profession in accordance with medical ethical principles. Preventing conscious exposure is a critical issue for both individual and social health

## 8. Conclusion

Radiation safety is one of the most critical issues in today's health systems, both at individual and institutional levels. The findings presented throughout this study clearly show that the main factor that will shape the quality and safety of health services in the future is the deepening of radiation safety awareness. Healthcare professionals must now have not only technical knowledge but also a holistic understanding of radiation safety that encompasses ethical, legal, psychosocial and digital aspects.

Radiation safety is not just a precaution or procedure; it is a lifestyle, an employee's stance and a professional responsibility. Healthcare professionals of the future must be individuals who can manage the risks they are exposed to, use technology effectively, adopt international standards and constantly improve themselves. At this point, educational institutions, health managers, legislators and professional organizations have a historical duty. The shaping of education programs, the integration of technology and the establishment of legal control mechanisms are no longer an option, but a necessity.

A "radiation safety culture" that encompasses not only individuals but the entire health system must be built. This culture is a dynamic process that transforms knowledge into behavior, behavior into institutional policy and institutional policy into social awareness. If this transformation can be achieved, both the quality of life of healthcare professionals will be protected and a sustainable safety net will be built at the public health level.

As a result, future healthcare services are only possible in safe environments, with conscious individuals and strong systems. Radiation safety is one of the cornerstones of this structure and its neglect should be considered not only as professional but also as human irresponsibility.

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