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Radiation Safety and Patient Education in Diagnostic Imaging

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Abstract **Review Article**

In health care, radiation safety within diagnostic imaging constitutes an important aspect. Any form of imaging involves some level of ionizing radiation exposure of patients. In a way, this is rather hazardous for them. Therefore, the potential radiation effects must be balanced with clinical benefits offered by the imaging procedures. There are some basic principles including justification, optimization and dose limitation which are important for ensuring patient safety. Still, the effectiveness of these measures largely pertains to the awareness and collaboration of healthcare providers as well as patients. Patient education is key to understanding the risks and benefits of radiation, as well as safeguards. When everyone communicates clearly, patients can make informed choices. It helps reduce the anxiety that comes with imaging, and builds trust in medical staff. In addition, the adoption of patient-centered education as a standard practice in diagnostic imaging will improve compliance and facilitate safety and radiation protection culture. In this abstract, the relationship between radiation safety practices and patient education is described. Together, these tools can assist in enhancing patient outcomes, avoiding unnecessary exposure and promoting safe imaging practices.

Keywords: Radiation safety, Patient education, Diagnostic imaging, Radiation protection, Patient-centered care.

1. INTRODUCTION TO RADIATION SAFETY

Radiation safety aims to prevent the harmful effects of radiation by applying the basic safety concepts of justification, optimization, and dose limits [1]. These concepts help reduce patient exposure during exposure and reduce the number of x-ray procedures, limiting unnecessary utilization [2]. Radiation safety affects an estimating six billion people worldwide who are exposed to diagnostic medical imaging procedures annually [2]. Increased utilization of x-rays, CTs, fluoroscopy, radiation therapy, and other radiation-producing medical imaging procedures raises the risk of excess radiation exposure to patients and others surrounding them [3]. Ensuring that the radiation doses remain within safe boundaries requires a keen awareness of the interactions between radiation and matter, an understanding of the biophysical interactions between ionizing and non-ionizing radiation and human tissue, and comprehensive knowledge of various shielding techniques throughout the medical imaging process [4]. In the United States, approximately 3.6 billion diagnostic x-rays are performed annually [5]. Advances in technology have increased the availability and use of CTs, which deliver doses about 100 to 1,000 times greater than traditional chest x-rays [6].

2. Understanding Diagnostic Imaging

Diagnostic imaging is essential for medical procedures and patient management worldwide [7]. Computed tomography (CT) alone accounted for nearly 72 million scans in 2007 in the United States, and ultrasound and magnetic resonance imaging (MRI) remain important alternatives [8]. The number of CT units worldwide increased from about 4,000 in 1988 to nearly 53,000 three decades later, with strong growth expected [9]. Interventional procedures are increasing and often involve long fluoroscopic examinations lasting for hours; exposure can be significant, typically associated with high entrance surface dose rates [7]. Certain plain radiography investigations, such as myelography, can also involve substantial exposure [10].

2.1. Types of Diagnostic Imaging Modalities

The most common options available in diagnostic imaging are X-ray (plain radiography and fluoroscopy), computed tomography, mammography, nuclear medicine with positron emission tomography, ultrasound, and magnetic resonance imaging (natural and artificial radiofrequency emitted) [2]. The physics underlying each relies on the information acquired by the detection of the radiation signal: imaging techniques therefore vary depending on the instrument and the type of radiation used [11]. They can be grouped according to the nature of the radiation: the first group includes techniques based on ionizing radiation; the second, non-ionizing radiation [12]. Plain X-rays use ionizing electromagnetic radiation, which passes through the body and is attenuated according to the characteristics of the structures encountered [13]. In computer tomography, the technique is essentially the same as plain radiography, but the information is acquired from multiple angles to create a three-dimensional dataset for further processing [14]. Fluoroscopy uses a moving X-ray beam (video X-ray) to image a subject, such as in investigations of the digestive system or during angiography procedures [15]. Mammography uses plain X-rays at low energy to reduce the radiation dose and provide good contrast to breast tissues [15]. Nuclear Medicine provides information on organ function, rather than anatomy as in the X-ray modalities, by introducing radioisotopes in the body that are engineered to accumulate in the organ of interest [16]. The tracer emits gamma photons that are detected by a gamma camera in different configurations to portray, for example, the function of the heart, brain, or bone [17]. Positron Emission Tomography (PET) is essentially a more sophisticated gamma camera where the tracer emits pairs of photons in opposite directions [17]. The camera then detects the pairs and reconstructs a three-dimensional distribution of the tracer [18]. The tracers often have much shorter half-lives than in conventional nuclear medicine procedures [18]. Finally, Magnetic Resonance Imaging and ultrasound belong to the non-ionizing group. Ultrasound employs first a piezoelectric crystal and then the received echoes of reflected pressure waves to construct an image [19]. Magnetic Resonance Imaging uses the radiofrequency emission originating from the spin of hydrogen atoms in tissues excited by an external magnetic field [19].

2.2. Principles of Imaging Techniques

The principles of different imaging modalities rely on interactions between electromagnetic radiation and matter [20]. Radiography and computed tomography (CT) use X-rays (ionizing radiation); nuclear medicine imaging uses radioactive isotopes; magnetic resonance imaging (MRI) uses magnetic fields and radiofrequency pulses; while ultrasound uses high-frequency sound waves [20]. X-rays are parts of the electromagnetic spectrum with photon energies of 100 electron volts (0.1 keV) and greater [21]. The radiation dose and risk of diagnostic X-rays depend on the energy-dependent X-ray cross-sections and the body size/shape of the patient [22]. For example, at a given photon energy, the radiation dose to a child is higher than to an adult with a similar X-ray entrance dose because the cross-section in children is greater and the mass for normalizing the energy absorption is smaller [23]. These relationships vary in going from soft tissue to bone and from low photon energies to high photon energies [23].

3. Radiation Exposure in Diagnostic Imaging

The contribution of diagnostic radiation to the world population's radiation dose has significantly increased, posing new challenges for a sound knowledge of radiation doses recently [14]. Ionizing radiation, radiation safety, and radioprotection are critical in diagnostic radiology, and these concepts have great importance in protection from radiation and safety in the use of ionizing radiation in medicine [24]. Diagnostic radiology involves electromagnetic radiation (X-rays and gamma rays) and particles (alpha, beta and neutrons) to produce images of anatomical cross-sections at reasonable doses for patients [25]. Important hazards are minimizing radiation exposure of individuals, such as patients, staff, and owners [25]. Although radiation safety practices are employed, significant radiation exposure can occur in veterinary practice (26). To improve radiation safety compliance, education and training of veterinary professionals are needed [1]. Diagnostic imaging in medicine involves X-rays, gamma rays, and a combination of radiopharmaceuticals generating gamma rays, which irradiate the patient [27]. The attenuated radiation reaching the detectors gives information about patients present and functionality, unlike sound or magnetic applications [27].

3.1. Sources of Radiation

Radiation safety in medicine is a patient-centred concept aimed at protecting patients from unnecessary exposure during diagnostic imaging [28]. Diagnostic imaging utilizes different parts of the electromagnetic spectrum to non-invasively visualise anatomical or functional processes, offering benefits to the patient that outweigh any potential risks [1]. The various types of commonly used diagnostic imaging modalities include X-ray, fluoroscopy, mammography, computed tomography, ultrasound and magnetic resonance imaging [29]. As X-ray, fluoroscopy, mammography and computed tomography are all forms of ionising electromagnetic radiation, this paper will focus on the concept of radiation safety during these techniques [30]. Ionising radiation can arise from natural background sources or as a result of human technological activity [31]. Despite the ubiquity of natural sources of ionising radiation, man-made, artificial radiation has almost doubled the collective dosage received by United States residents in recent decades [31]. The majority of human-generated ionising radiation dosage arises from the process of medical diagnosis, since this form of radiation can be controlled and a dose applied in the clinical setting [32]. The development of an effective radiation safety practice within the diagnostic setting is imperative to ensure the safety of the patient [33]. Through educated knowledge of the diagnostic procedure characteristics, healthcare workers are able to implement a practice to provide high-quality images with as little dose to the patient as reasonably possible, the ALARA (as low as reasonably achievable) principle [34]. To provide a comprehensive understanding of dose optimisation and radiation safety principles, the concept of radiation and beam characteristics must be reviewed [35]. Ionising radiation follows the electromagnetic radiation theory as outlined in diagnostic imaging [35]. Computed tomography imaging involves the utilisation of combined x-ray beam projections and is described in greater detail as an extension of the general radiation characteristics [30].

3.2. Measuring Radiation Dose

The increasing use of ionising radiation in diagnostic imaging results in growing patient exposure and potential hazards [36]. To make informed decisions about the justification and optimisation of individual radiological procedures, radiologists and radiographers should be familiar with the various dosimetric quantities [37]. These quantities enable the evaluation of compliance with Diagnostic Reference Levels (DRLs), a mandatory component of radiation protection strategies [38]. Effective dose serves as a practical metric for comparing different imaging modalities and procedures, as well as communicating radiation risk to patients. In cases involving recurrent imaging and cumulative effective doses, special consideration should be given to subsequent justifications and optimisations of future imaging practices [36].

4. Health Risks Associated with Radiation

Radiation poses health risks associated with medical diagnostics and treatment. Specific risks include increased lifetime cancer risk from imaging procedures such as CT scans and cardiac imaging [12]. Fetal exposure to radiation during pregnancy can lead to childhood cancer [38]. Avoidable risks arise from the inadequate tradition of translating knowledge of the associated risks of exposure into clinical practice when ordering an investigation [39]. Hence it is essential to have increased awareness and education to protect high-risk groups and promote adherence to the radiation safety principle of justification [40].

High doses of radiation cause short-term effects on the skin, such as erythema or necrosis, and in the months following exposed individuals to a higher risk of developing cataracts or skin cancer [29]. Children are more sensitive to the effects of ionizing radiation, and due to their longer expected lifetime, they are also more vulnerable to the development of long-term, stochastic-related effects [41]. Expanding the use of imaging tests, such as computerized tomography, disclosure of risks, justification of requests, justification of alternative options without exposure, and optimization when exposure is unavoidable, is crucial [42]. Worldwide initiatives support international actions to address this urge for awareness [42].

4.1. Short-term Effects

Patients exposed to high doses of ionizing radiation during a short period may display deterministic effects, also known as tissue reactions [43]. The intensity of tissue reactions depends on the absorbed dose, and the effect appears only above a specific threshold of exposure [44]. Such effects usually become apparent within minutes to days following exposure, or even months or years later [45]. Tissue reactions can affect various organs and/or tissues and may be reversible or permanent, including examples such as skin erythema, epilation, blood changes, and cataracts [46]. Some tissue responses are pathologically reversible if the absorbed dose is low, whereas others, such as cataracts, are irreversible [1].

4.2. Long-term Effects

Long-term effects of radiation exposure to cellular structures occur through indirect damage following the initial interaction between photons and the molecule [47]. Such damage results from the production of free radicals and the alteration of the cell cycle [48]. Postirradiation cellular changes arise from secondary interaction of photons with molecules, differing from patients exposed to diagnostic radiation, where the main mechanism is direct damage produced by X-ray photons during the primary interaction [1]. Most of these long-term effects require months or years to manifest and are far more complicated than the short-term effects [49]. Repair or reparation processes and dissemination of damage into the extracellular matrix take place [29]. The most important and largely studied long-term effect from radiation exposure is the induction of cancer; however, other less frequent manifestations include genetic mutations, immune and haematological disturbances, as well as hormonal dysfunctions and cellular ageing [50]. The risk of inducing such effects depends on the radiation dose received and on the proliferative activity and radiosensitivity of the exposed tissue [51].

5. Best Practices for Radiation Safety

Radiation safety is the patient-centred practice of limiting the dose of diagnostic or therapeutic radiation to a level that balances the risks with the benefits [29]. The principle of ALARA, meaning "as low as reasonably achievable," remains the socioeconomic framework for judging the adequacy of a radiation dose [33]. The increase in use of diagnostic radiology for patient management has accompanied growing concerns about radiation risks [30]. Radiation-safety best practices in diagnostic imaging emphasize the use of the lowest doses possible and consider the justification for imaging carefully [52].

5.1. ALARA Principle

The International Commission on Radiological Protection (ICRP) recommends that radiation doses in diagnostic imaging be maintained at levels as low as reasonably achievable (ALARA), taking into account economic and societal factors [33]. This principal guides pathways for minimising radiation exposure to patients and communities [53]. Protective equipment may be used to shield radiosensitive organs when it does not interfere with image quality or the diagnostic efficacy of the study [54]. Good collimation that restricts the beam to the target tissue is also an effective method to reduce the volume of irradiated tissue and, it follows, radiation dose [55]. Radiation safety principles assist in reducing both deterministic and stochastic effects and are therefore of paramount importance because of their patient-centered approach [56].

Advances in instrumentation, shielding and collimation, as well as the application of the ALARA principle, have minimised x-radiation hazards in medicine [1]. Nevertheless, the ICRP defines three fundamental principles of radiation protection: justification, optimization and dose limits [57]. Justification means that no practice involving radiation should be adopted unless it produces a net benefit to the exposed individuals or to society [58]. Optimisation (equivalent to the ALARA principle) requires that the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposure should all be kept as low as reasonably achievable [56]. Lastly, limits are only appropriate for exposures that are not related to the direct medical care of a patient and relate to the total dose from all regulated sources in planned exposure situations [59].

5.2. Protective Measures for Patients

Applying the principles of radiation protection can prevent the deterministic effects of ionising radiation and decrease related stochastic effects [60]. Proper observance of protective measures by radiographers eliminates most unnecessary radiation hazards [61]. Localization of the radiation field is essential to reduce patient doses; limiting the exposed area to the target reduces unnecessary exposure [62]. Beam collimation significantly decreases doses to the skin and internal tissues [63]. The use of lead aprons and protective equipment for patients and their companions during radiographic examinations is crucial [64]. One effective method to reduce dose is complete beam filtration, which eliminates low-energy photons incapable of reaching the image receptor but still contributing to skin dose [65]. Other protective measures target radiosensitive organs: thyroid shields, breast shields, gonadal shielding, and ocular shields are frequently used to lower exposure [66].

Guarding against overexposure also involves increasing the image receptor sensitivity; digital receptors often permit lower doses than conventional film-screen systems [67]. These dose-reduction initiatives can drastically limit individual cancer risk without compromising image quality [68]. Compliance with Medication Guides that inform patients about radiation risks and precautions is more common in mammography than in other procedures [29]. Successive waves of information from health professionals can improve patient knowledge and assist decision making, but the general population typically receives insufficient information about radiation exposure and associated risks [69]. Consequently, educational strategies should be developed to enhance patient awareness when ordering diagnostic imaging tests [70].

Patient education revolves around the principle of professional communication: the physician must provide the patient with relevant information about their health status, test options, and a clear rationale for choosing a test—should the patient express interest in understanding these matters [71]. This approach respects knowledge asymmetry, refraining from forcibly instructing patients who do not wish to learn more, yet remaining open to more thorough explanations [72]. Such an approach reduces anxiety and fear of radiation exposure by promoting collective responsibility and shared decision making [73].

6. Patient Education Strategies

Patients generally lack adequate information about the radiation exposure and associated risks of diagnostic examinations [73]. Designing initiatives to enhance patient awareness prior to ordering imaging tests is advisable [29]. Surveys indicate limited patient knowledge about medical radiation during imaging procedures; interventions to improve awareness of radiation risks may therefore be beneficial [2].

Educating patients about ionizing radiation is the guiding principle of European regulations [74]. Professionals should inform patients, including through sensitive explanations emphasizing that the clinical benefit outweighs the potential cancer risk, and provide appropriate answers to their concerns [75]. As the ALARA approach dictates that doses be sufficient to ensure a diagnostic interpretation of adequate quality, simple, clear, and adapted information—rather than technical details or raw dose figures—may reassure patients and establish a basis for constructive dialogue [76].

6.1. Importance of Patient Education

Providing education to patients remains a primary component of diagnostic imaging and radiation safety and should take priority before acquiring informed consent [49]. When educating patients, it is important to communicate clearly in a way that is understandable and direct [77]. The general population, nevertheless, does not receive adequate information regarding radiation exposure or the associated risks related to imaging procedures [29]. Initiatives therefore should be designed to reinforce patient awareness when ordering a diagnostic test [78].

Educating patients on risks and benefits remains an essential consideration of safety in diagnostic imaging that should extend throughout all levels of professional health care [79]. Patient education, in addition to ensuring safe radiological practices, reflects the way radiation safety awareness is instilled among many healthcare professionals [79]. Several authors therefore emphasize inadequate training in radiation management at various stages of medical education, including residents and physicians alike [80]. Much variation exists in the level of awareness about methods of protection, radiation doses, and the principles of radiation safety—and is further confounded by differences across countries, regions, and subspecialities [12]. Similar concerns apply to efforts focused on patient education—where understanding of the radiation doses associated with various common imaging procedures, along with knowledge of potential risks (including cancer), are crucial to these efforts of safety [81].

6.2. Effective Communication Techniques

Effective communication is essential for fostering a quality doctor-patient relationship and improving clinical outcomes [82]. Properly educating patients about radiation exposure and its associated risks further strengthens trust and supports shared decision-making [29]. Radiologists performing image-guided interventions, in particular, must be capable of interacting with patients on short notice, conveying either encouragement or confronting potential complications [72]. Moreover, image-guided intervention permits patients and healthcare professionals to communicate throughout a procedure rather than only at its beginning or conclusion [83]. The implementation of injection procedures such as myelography or hysterosalpingography compounds the importance of establishing a clear line of communication, as patient well-being remains largely unobservable during the examination [84].

7. Informed Consent in Imaging Procedures

Informed consent involves providing patients with information about the anticipated benefits and potential risks of imaging examinations before the procedure begins [85]. Effective communication with patients about radiation safety is essential throughout the diagnostic imaging procedure [86]. Campaigns such as Image Wisely and Image Gently have empowered clinicians to communicate radiation risks to patients [85]. Expanding these programs to address the risks of intravenously administered contrast agents and gadolinium-based paramagnetic substances would further improve patient understanding [87]. Adopting a consistent, patient-centred approach to radiation safety will reassure patients about the quality of their care and encourage open dialogue between clinicians and patients [29]. Healthcare policymakers should review regulations to clarify the legal position on consent in diagnostic imaging [88]. Statutory bodies must ensure that any relevant policies are publicized [89]. Investigating consent practices among healthcare professionals such as radiographers and nurses, as well as actual versus reported practices, represents a future research opportunity [90].

7.1. Legal and Ethical Considerations

Legal and ethical considerations for diagnostic imaging underscore the critical need to protect patients from harm during procedures while ensuring their access to beneficial services [31]. Throughout the professional environment of a radiology department, emphasis on legal and ethical radiation safety is essential [34]. Many ethical issues are associated with radiation protection in diagnostic radiology, including justification of examinations, obtaining informed consent, and managing patient risks [91]. Discussions highlight the importance of ethical frameworks, informed consent, and justification for radiation exposure to ensure patient safety and address current concerns about unjustified examinations, especially in young patients [92]. The ethical considerations involve balancing diagnostic benefits against radiation risks and establishing clear communication of risks to patients [93].

According to a 2020 study that evaluated the principles of protection in diagnostic radiologic examinations, technical competence and protective performance directly influence radiation safety [20]. Best practices in digital radiography and adherence to radiation safety standards in radiotherapy have been assessed, and a review of protection levels in radiology departments indicates areas that require improvement [94]. Proper equipment operation and beam collimation are fundamental for reducing patient dose, especially in pediatric radiology [95]. Regular training and compliance with international guidelines remain crucial for safeguarding both workers and patients in radiological procedures [96].

A 2017 overview of risks and safety highlights limited physician awareness of radiation knowledge in the context of high reimbursement rates for imaging procedures [1]. Non-radiologists increasingly add imaging services, often practicing defensive medicine for malpractice reasons [72]. Community members express limited understanding of radiation risks, and some feel more comfortable only after receiving informational materials [97]. Efforts to improve knowledge result in modest gains in comfort and understanding of radiation exposure [97].

8. Role of Healthcare Professionals

Radiologists and radiographers play pivotal roles in ensuring radiation safety and managing patient exposure [98]. As the primary interpreters of radiographic images, radiologists make informed decisions on the appropriateness of examinations and manage the application of ionising radiation in diagnostic information acquisition [27]. Radiographers are charged with the technical aspects of radiography, including the operation of equipment and application of appropriate exposure parameters [94]. Both groups bear responsibility for communication with patients and other healthcare professionals [99]. Facilitating a comprehensive understanding among patients about the benefits and hazards of radiological examinations constitutes a critical part of their practice [100]. Consequently, it is incumbent upon all healthcare professionals involved in medical imaging to maintain a solid grasp of radiation safety concepts, dose quantities, and protective principles [101].

Ensuring rigorous safety standards for radiation-emitting devices constitutes a primary aim of health and safety legislation [102]. The proper operation and maintenance of equipment, in accordance with national regulatory systems, supports the safe use of ionising radiation for diagnostic procedures [103]. Verification of technical competency through examination and adherence to recognised procedures should serve as the fundamental minimum requirement for healthcare professionals engaged in the use of ionising radiation within the medical environment [104]. Comprehensive education and training—focusing on the fundamentals of diagnostic medical imaging, associated risks, regulatory standards, and protective strategies—remains essential for safeguarding patients and professionals alike [12].

8.1. Radiologists' Responsibilities

Radiologists have a pivotal role in the clinical management of patients undergoing diagnostic imaging procedures and in communicating with patients about radiation safety [2]. They are responsible for understanding and explaining the basic principles of radiation safety and the doses associated with common procedures [12]. Recommended guidelines and national rules are available to assist radiologists in fulfilling this obligation [30]. Radiologists should discuss radiation safety in greater detail when the procedure is known to result in substantial exposure—that is, where the estimated dose is likely to be significantly above background radiation [105]. The principle of Justification underpins these interactions. Increasing awareness among referring clinicians and patients of the risks associated with ionising radiation is essential to ensure the best management plan is proposed, patient anxiety is minimised, and information is delivered clearly and simply [1]. A stronger knowledge of radiation protection may allow medical doctors to gain closer control of the situation, protect their patients properly, and remain within the radiation protection principles and regulations [106].

8.2. Technologists' Role in Patient Education

Medical imaging technologists play an important role in radiation protection and patient dose reduction [53]. These individuals are oftentimes the only employees within the medical imaging department that have direct contact with the patient [47]. It is the technologist’s duty to apply all measures available to them to reduce patient dose while maintaining image quality [107]. Since technologists have direct contact with patients and their families, and operate the radiographic equipment, they can positively impact patient radiation safety awareness [108]. Information and education should be provided by technologists to help alleviate any concerns and anxiety a patient has regarding ionizing radiation exposure [109]. It is essential that technologists communicate radiation safety information to ensure patients are adequately informed and that the risk–benefit equation is clearly understood by both the patient and the provider caring for the patient [110].

9.1. Addressing Patient Concerns

Addressing common patient concerns about radiation exposure represents an important aspect of radiation safety [79]. A large segment of the population believes that radiation exposure from medical imaging procedures can be fatal [12]. Although this belief is false and understandable, these patients are often the individuals who demand answers [102]. Patients also ask a wide range of theoretical questions [70]. It is impossible, even for the most well read and thoughtful responders, to have an immediate answer to every radiation-associated question [44]. Answering those questions is an extensive, time-consuming process that requires a high level of education and enthusiasm for the topic [111]. Specialties and individuals that routinely use and employ radiation safety principles are often baffled by many of the inquiries as to why and with what effect radiation appears in the universe on a random basis [112].

Physicians performing and reading imaging examinations bear an important responsibility for educating the population [113]. These individuals should extensively understand why an individual procedure is required and consider how an increased risk of cancer or noncancer illness might be produced by the use of ionizing radiation [114]. Understanding how radiation systems are used throughout the world is critical for individuals who are interested in radiation protection and patient education [115].

9.2. Answering Patient Questions

In diagnostic imaging, patients ask a range of questions about x-ray examinations and radiation safety [72]. It is important to be prepared to dispel common myths and misconceptions [67]. Patients continue to overestimate doses, to express concerns, and to seek reassurance about the safety of the planned procedure [2]. Many of the queries are based on incomplete or incorrect information obtained from family, newspapers, or social media [116]. Misinformed patients often believe that all radiological exposures cumulate and that body parts that accumulate radioactive elements, such as the thyroid and bones, are at greater risk [117]. Clear, standardized answers are essential in answering patient questions [1].

10. CONCLUSION

Patient-centred approaches to radiation safety, including rigorous patient education and consent practices, aim to provide adequate information for effective decision-making and to mitigate concerns regarding potential risks; in parallel, emerging technological innovations strive to reduce radiation doses and enhance overall safety in medical imaging [12]. 39139239358

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