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Health education, communication and safety culture in diagnostic imaging: a narrative review of up-to-date guidelines

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Abstract

Introduction. Advances in diagnostic imaging have increased precision and patient access, but also generated new safety challenges regarding ionizing radiation, magnetic field hazards, and procedural complexity. Technological optimization is fundamental, although real-world safety outcomes are heavily influenced by organizational and patient-related factors.

Aim. This narrative review synthesizes up-to-date international guidelines and literature (published between 2015 and 2026), focusing on health education and clinical communication as vital yet underutilized contributors to patient safety.

A brief description of the state of knowledge. Radiation protection remains anchored in the ALARA principle. However, the importance of automated dose tracking systems and AI-assisted image reconstruction is growing. Technology alone cannot completely eliminate all risks; motion artefacts, repeat scans, and workflow delays often result from scan-related anxiety and limited health literacy. Evidence points to the effectiveness of structured patient preparation, particularly Virtual Reality (VR) in pediatrics, to reduce sedation requirements and improve cooperation. Broader safety discussions now include a "Just Culture" approach, burnout prevention, and "Green Radiology" practices.

Summary. Patient safety in diagnostic imaging is a multidimensional issue. Enhancing it requires combining technological optimization with effective health education. Developing communication competencies among radiological personnel via digital technologies, including artificial intelligence, further supports safe practice. To maintain a patient-centered safety culture that evolves as technology changes, embedding health literacy and effective communication strategies into medical curricula is recommended.

Key words: Diagnostic Imaging; Patient Safety; Radiation Protection; Health Education; Artificial Intelligence; Medical Education.

1. Introduction

Diagnostic imaging has become integral to modern clinical practice, supporting decision-making across nearly all medical specialties, from emergency medicine to oncology. While rapidly evolving technologies, such as multidetector computed tomography (MDCT) and high-field magnetic resonance imaging (MRI), now allow for non-invasive visualization of human anatomy with unprecedented precision, these procedures are not without risk. Potential risks range from exposure to ionizing radiation [1], through exposure to strong magnetic fields [2], to adverse reactions to contrast agents [3].

Despite continuous technological advances and ongoing efforts to optimize examination protocols, the widespread availability of imaging and the growing number of procedures performed globally mean that diagnostic imaging remains the main artificial source of collective effective dose [4, 5]. This situation necessitates not only strict adherence to radiation protection principles, but also ongoing education and awareness among both medical staff and patients.

In response to these challenges, the aim of our work is to synthesize the most recent knowledge on patient safety in radiology facilities in light of applicable standards and guidelines. Special attention is given to the role of health education and clinical communication.

These elements are key factors in reducing *scanxiety*, improving cooperation with patients, and, as a result, optimizing the entire diagnostic process [6, 7].

2. Description of the state of knowledge

2.1. Review methodology and data sources.

This study was designed as a narrative review aimed at a qualitative synthesis of the available literature on patient safety and education in radiology. The literature search was conducted across leading medical databases, including PubMed, Scopus, and Google Scholar. Publications from 2015 to 2026 were considered, ensuring the inclusion of the latest technological advancements and updated safety guidelines.

The search strategy employed a combination of English keywords connected by Boolean operators (AND/OR). The primary search terms included: "diagnostic imaging", "patient safety", "radiation protection", "ALARA", "MRI safety", "ultrasound safety", and "patient education". In addition to the database search, the online repositories of key international organizations and medical societies were manually screened. These included the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), the European Society of Radiology (ESR), and the American College of Radiology (ACR), among others.

2.2. Selection criteria.

Strictly defined inclusion criteria were applied during the source qualification process. The following types of publications were qualified for the final analysis:

1) International safety guidelines and standards (e.g., published by the IAEA, ICRP, ESR, ACR, and ESUR).
2) Systematic reviews and meta-analyses evaluating the efficacy of protective procedures.
3) Original articles focusing on technological innovations in radiation protection (e.g., dose reduction techniques, AI algorithms).
4) Clinical reports regarding adverse events and procedural safety.
5) Studies addressing medical communication, health education, and physiological mechanisms of stress responses (including basic research).

Publications issued prior to 2015 (with the exception of key legislative acts) and articles unrelated to the topic of health safety were excluded from the analysis. The review procedure encompassed literature selection, data extraction for specific imaging modalities, and thematic synthesis.

2.3. Characteristics of imaging modalities and associated risks.

Contemporary diagnostic imaging relies on a variety of modalities, each with specific clinical indications and a distinct safety profile. Conventional radiography (X-ray) remains the first-line tool for evaluating the skeletal system and thorax, carrying a relatively low ionizing radiation burden [1]. However, strict screening protocols are mandatory for female patients of childbearing age to prevent inadvertent fetal exposure, in accordance with international guidelines [1, 8]. Conversely, while computed tomography (CT) is the primary contributor to the medical population dose, its speed and high spatial resolution make it indispensable in trauma and oncological imaging, as well as in the diagnosis of complex pathologies [4, 5, 9]. Current trends indicate that optimizing CT protocols remains the most pressing challenge in modern radiation protection.

Non-ionizing techniques provide an important alternative. Magnetic resonance imaging (MRI) offers excellent soft-tissue contrast without X-ray exposure. However, the strong magnetic field introduces unique physical hazards. This necessitates strict adherence to MR safety zones and rigorous screening for ferromagnetic implants [2, 10]. Recent literature also highlights the issue of gadolinium deposition in the brain, which has prompted a revision of guidelines regarding the use of linear contrast agents [11]. An emerging challenge is the risk of thermal burns in patients with extensive tattoos or permanent makeup, mandating thorough pre-scan screening [12].

Finally, ultrasound (US) is the modality of choice in the pediatric population due to the lack of ionizing radiation [13, 14]. Nevertheless, it requires strict hygiene standards and proper probe disinfection to prevent cross-infection [15]. A detailed overview of these risks and associated educational considerations is presented in Table 1.

Table 1. Comparison of imaging modalities: safety profiles and educational aspects.

Modality	Main risk factors	Key diagnostic advantages	Critical patient education aspect
X-ray	Ionizing radiation (low doses) [1]	Speed, widespread availability	Motionless requirement, mandatory pregnancy disclosure [1, 8]
CT	Ionizing radiation (high doses) [5], risk of PC-AKI [3]	Speed, high spatial resolution [16], trauma and oncological imaging [4]	Pre- and post-scan hydration [3], clinical justification, pediatric protection [17], *scanxiety* reduction [6]
MRI	Strong magnetic field, implant safety, thermal effects [2, 10, 12], gadolinium deposition [11]	Excellent soft-tissue contrast [10], absence of ionizing radiation	Screening for implants and tattoos [2, 12], anxiety, pain and claustrophobia management (e.g., via VR in pediatrics) [10, 18, 19]
US	Risk of cross-infection [15]	Absence of ionizing radiation, high safety profile [13, 14], real-time imaging	Procedure explanation, breathing instructions and preparation (e.g., full bladder) [14]

2.4. Radiation protection standards and technological innovations.

Analysis of current guidelines indicates that the ALARA (As Low As Reasonably Achievable) principle remains the basis for radiological safety. According to the International Atomic Energy Agency (IAEA) recommendations, radiation protection is built upon three pillars: justification, optimization, and the application of dose limits for personnel [1]. In clinical practice, Diagnostic Reference Levels (DRLs) serve as a key optimization tool, and their implementation enables the identification of procedures that generate excessive radiation doses, which is a legal requirement in European Union countries in accordance with Council Directive 2013/59/EURATOM [20].

Interventional radiology represents a particular challenge, as personnel are subject to prolonged exposure over the course of complex procedures. New interventional standards developed jointly by the Cardiovascular and Interventional Radiological Society of Europe (CIRSE) and the Society of Interventional Radiology (SIR) emphasize not only the use of lead aprons but also rigorous protection of the eye lenses against radiation-induced cataracts, a critical, yet frequently overlooked aspect of health and safety in hybrid operating rooms [21, 22].

The implementation of the standards is particularly important in pediatric radiology, where the heightened radiosensitivity of the developing tissues necessitates far more rigorous optimization. This is reflected in global initiatives such as the *Image Gently* campaign, which advocates for “child-sizing” radiation parameters, adjusting exposure directly to the age and body size of the child, rather than using default settings for adults [17].

Technological progress significantly supports these efforts. Modern CT scanners are equipped with automatic tube current modulation (ATCM) systems, which adjust the dose to the patient's body habitus in real-time [16]. The integration of artificial intelligence (AI) algorithms can be regarded as one of the most important developments in this field. Deep learning-based image reconstruction techniques allow for diagnostic-quality imaging at significantly reduced exposure parameters [23]. The widespread implementation of the automated Dose Tracking Systems enhances patient safety by providing real-time monitoring and enabling rapid clinical intervention in the event of unexpected dose deviations [24].

2.5. Health education and clinical communication.

The results of the literature review unequivocally indicate that patient education constitutes a pillar of safety that is complementary to the technical parameters of the equipment. Comprehensive preparations, including an explanation of the procedure, the nature of acoustic phenomena in MRI, and the necessity of remaining motionless, significantly reduce levels of "scanxiety" [6]. This reduction in distress directly impacts diagnostic quality, as cooperative patients are less likely to produce motion artifacts, eliminating the need for repeat sequences and additional radiation exposure. In the context of contrast-enhanced examinations, education regarding prophylactic hydration is fundamental for the prevention of Post-Contrast Acute Kidney Injury (PC-AKI), in accordance with the latest ESUR guidelines [3].

In the pediatric population, Virtual Reality (VR) is becoming a promising tool for reducing anxiety and pain perception (e.g., during intravenous cannulation prior to contrast administration) associated with necessary procedures [19]. This allows children to become familiar with the imaging environment. Studies show that simulation of the examination using VR goggles ("virtual preparation") and immersive distraction significantly reduce the requirement for sedation and general anesthesia in children, which directly enhances the safety profile of the procedure [18, 19].

Health education aims to improve patient health literacy through a multi-stage strategy: from the initial referral and the informed consent process to the procedure itself. Informed consent is increasingly viewed not only as a legal formality, but also as a meaningful dialogue regarding the risk-benefit ratio [6]. International campaigns, such as EuroSafe Imaging, promote a culture of safety and transparency in this regard by educating patients, referring physicians, and future medical professionals [25, 26].

Contemporary educational strategies are increasingly moving beyond traditional forms of instruction by leveraging personalized digital tools. Recent findings indicate that the integration of Artificial Intelligence (AI) into the patient communication process enables the development of "AI-driven patient engagement" systems, which tailor the information to an individual's cognitive profile and anxiety levels [27]. These algorithms not only support radiologists in dose optimization, but also contribute to a more individualized, patient-centered model of care. By offering interactive assistants that prepare patients for high-specialty procedures, these innovations may shorten scan times and minimize procedural stress, although further validation in large clinical cohorts is still necessary [27, 28]. Recent studies highlight the growing role of Large Language Models (LLMs) in translating complex radiological reports into patient-friendly language, significantly improving health literacy and reducing post-scan anxiety [29].

2.6. Discussion and broader interpretive context.

The collected data indicate that modern diagnostics are characterized by a certain dualism. We are witnessing the dynamic development of technologies designed to reduce risks for individuals (e.g., advanced artificial intelligence algorithms), but increasing availability and diagnostic pressure mean that challenges related to collective effective dosage continue to arise [5, 16, 23]. As a result, even if individual procedures are becoming safer, the overall cumulative exposure may still be increasing. This broader perspective is sometimes overshadowed in discussions that focus solely on technological innovations.

It should be emphasized that even the most innovative systems cannot completely eliminate the risk of human error. While technology mitigates risk, it does not replace professional responsibility. For this reason, professional clinical communication is an essential complement to technical procedures and remains the foundation of safe practice. Public awareness of the actual risks associated with radiation remains low, which presents a significant challenge. This lack of knowledge often leads either to unjustified radiophobia or, conversely, to disregard for protection principles. Neither of these extremes is conducive to rational, evidence-based decision-making. This situation necessitates an evolution in the role and the approach of medical staff, who are increasingly expected not only to perform procedures, but also to take into account the needs of patients in the form of explanation, contextualization, and education.

Systemic barriers further complicate the implementation of effective patient education. Time constraints faced by medical personnel and a shortage of standardized, layman-friendly educational materials are frequently cited as primary causes for suboptimal health literacy levels. Even well-intentioned staff may find it challenging to provide comprehensive explanations under the pressures of routine clinical workflows. In the context of highly specialized diagnostics, such as Magnetic Resonance Imaging (MRI), safety considerations must extend beyond the patient. Incident analyses underscore the necessity for rigorous screening not only of patients but also of non-medical personnel (e.g., maintenance and cleaning crews), who may require access to controlled magnetic field zones. This highlights that safety is contingent upon both a robust organizational culture and strictly enforced technical protocols [2].

Modern safety frameworks increasingly promote a “Just Culture” within radiological departments, which encourages the transparent reporting of incidents and “near-miss” situations. This approach prioritizes systemic analysis over individual punitiveness as the foundation for improving the quality of care, aiming to identify and rectify latent systemic weaknesses rather than assigning blame. International initiatives, most notably EuroSafe Imaging, advocate for these values by emphasizing transparency and shared responsibility across all levels of radiological practice [25].

The human factor must also be considered through the lens of occupational burnout among radiological staff. Increasing workloads, rising reporting pressures, and mounting administrative requirements significantly contribute to professional exhaustion. Research indicates a direct correlation between staff fatigue and an increased risk of diagnostic errors or patient identification errors [30]. While this relationship is multifaceted, overlooking the mental well-being of personnel would result in an oversimplified understanding of radiological safety.

Parallel to human factors, environmental responsibility is emerging as a new dimension in the safety discourse. The paradigm of “Green Radiology” advocates for the energy-efficient operation of scanners and sustainable equipment life-cycle management. This pursuit of sustainability necessitates the optimization of scanner energy consumption, for instance, through “eco-modes” in MRI, which, paradoxically, may influence established safety protocols and equipment maintenance schedules [31, 32]. However, the shift toward sustainable practice must be carefully balanced with operational reliability. Environmental goals should complement safety standards rather than compete with them.

The findings presented in this review should be interpreted with caution. As a narrative review, this analysis is inherently selective and bounded by the scope of the analyzed literature. The rapid evolution of artificial intelligence tools is likely to shift the current dose optimization paradigm in the near future. Further research and continuous monitoring of emerging safety frameworks will be essential to adapt to these technological and systemic changes.

3. Conclusions

Technological integration of ALARA. Analysis of literature and guidelines published up to 2026 indicates that while the ALARA principle remains the foundational standard of radiation protection, its practical application has gradually evolved toward a more data-driven approach. In routine clinical settings, automated dose tracking systems and deep learning-based artificial intelligence are increasingly embedded in standard workflows. Rather than being viewed as optional technological enhancements, these tools are becoming integral to individualized dose optimization and quality control.

Education as a primary safety measure. Patient education should not be treated as a secondary or purely administrative task. Clear communication before imaging procedures can meaningfully reduce "scanxiety" and improve overall health literacy. As a result, patients are more likely to cooperate during the examination, which limits motion artifacts and minimizes the need for repeated exposures. In procedures involving ionizing radiation, this translates directly into improved safety outcomes.

Comprehensive professional development. Radiological personnel represent the final checkpoint in preventing adverse events. For this reason, professional training requires a broader perspective. Beyond regular updates of technical protocols, attention should also be given to occupational health concerns, such as consistent eye lens protection in the interventional radiology practice, as well as to communication competencies that facilitate effective patient interactions. This multidimensional approach reflects the expanding scope of professional responsibility in modern radiology.

Sustainability and future engagement. The future of diagnostic imaging will likely be shaped by the need to balance technological progress with environmental sustainability. The concept of "Green Radiology" illustrates this shift, encouraging more responsible energy use and equipment management. At the same time, AI-driven patient engagement tools are redefining how information is delivered and personalized. Careful integration of these developments is necessary to ensure that digital and ecological progress reinforces, rather than disrupts, established safety standards.

Systemic educational shift. Current international recommendations suggest that structured health literacy initiatives should play a more prominent role within medical education. Preparing future healthcare professionals to communicate risk effectively may prove as important as technical expertise. Such educational reinforcement is essential for sustaining a patient-centered safety culture capable of adapting to ongoing technological transformation.

Disclosure:

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