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Challenges And Solutions In Radiation Protection For X-Ray Procedures

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Abstract

Chapter 1 introduces the basic concepts and quantities used in radiation protection. Depending on the type of imaging procedure, the radiation dose given to the patient has the potential to cause harmful biological effects. Understanding these effects requires knowledge of radiation physics, the interaction of X-rays with human tissue, and the biological changes at the cellular and molecular levels. This chapter provides radiologists and other clinicians with the information needed to make informed decisions about how much radiation is acceptable for a given imaging task and the potential benefit to the patient. This information is also important for researchers developing and testing new imaging methods who must weigh the benefits of improved diagnostics or therapy with any potential risks to the patient. An understanding of radiation physics and biology is also essential for epidemiologic studies aiming to assess health risks from medical radiation at the population level.

Radiation exposure from X-ray procedures has been identified as a public health problem. Increased utilization of X-ray examinations and the high radiation doses associated with computed tomography (CT) scans have raised concerns about the long-term effects of ionizing radiation on the population. In response to these concerns, the U.S. National Institutes of Health formed the Biomedical Imaging Program in 2004 to investigate and develop novel imaging methods that reduce the radiation dose to patients. This dissertation supports the objectives of the NIH program and presents original research addressing radiation protection for X-ray and CT procedures. The specific aims of this work are: (1) to investigate the radiation dose and potential biological effects from current and novel X-ray imaging procedures; (2) to develop and validate methods for estimating, monitoring, and reducing patient radiation dose; and (3) to investigate the effectiveness and implications of reducing radiation dose in terms of image quality and patient outcomes. These aims are addressed using specific research projects involving exposure assessment and epidemiology, physics and engineering, clinical image interpretation, and image-guided intervention.

Keywords: *The effectiveness and implications of reducing radiation dose in terms of image quality and patient outcomes*

Introduction

In terms of scattering over a few cells, alpha and beta particles cause negligible damage to the surrounding cells when they travel to their target site. However, when compared to the effects of low LET radiation, the target site receives a far greater radiation dose. High-LET radiation is more damaging to the more radiosensitive tissues and causes irreparable damage to the cell DNA, given that it scatters its energy over a small, specific area. Changes to cell DNA can lead to mutations and cancer, although it should be remembered that there is a cell repair mechanism that is quite efficient in repairing DNA damage due to ionizing radiation.

An understanding of the characteristics of radiation and tissues is crucial to being able to confront and potentially solve the problems encountered in X-ray and interventional procedures. A sound understanding of physics is required in order to appreciate the side effects of different forms of ionizing radiation. High-LET radiations, such as alpha and beta particles, cause ionization along their paths and scatter their energy over a few cells. This is in contrast to low LET radiations, which scatter their energy over a broad area and cause ionization over a large number of atoms in a cell or within a few cells. 90% of diagnostic radiology involves low-LET radiation.

Radiation protection involves a scientific strategy to prevent, withstand, and reduce the risks brought about by exposure to ionizing radiation. Protection in this sense involves a combination of control measures involving procedural techniques, the use of shielding, and the monitoring of personnel and the workplace to determine the extent of control, which have become the major constituents of radiation protection in the workplace. In the later part of this paper, the control measures will be discussed with respect to the specific problems encountered in X-radiation and interventional procedures.

1.1 Importance of Radiation Protection

Ionizing radiation is an essential tool in modern medical practice. However, it has been estimated that up to 3% of solid cancers in developed countries in the 1990s were caused by medical radiation, and the cancer risk may be two to three times higher for radiologic procedures in the developing world, where a high proportion of equipment is old and/or not properly maintained. It is anticipated that if current trends continue, the annual frequency of radiologic procedures will have increased by up to 2.5 fold in 2010 compared with that in 1985. Similarly, in the United Kingdom, there is a projected 75% increase in CT procedures over a 7-year period, leading to increased radiation exposure to the population, and practicing and trainee physicians must be adequately trained in radiation protection. Such increases in radiation exposure may potentially lead to detrimental effects on both the patients and the various groups of medical staff involved in performing these procedures. It is essential that these adverse effects be identified and countered by the appropriate means. Thus, it is necessary to consider current issues in radiation protection for medical x-ray procedures in order to safeguard the health of both patients and radiation workers. This book addresses these issues, which are in many respects different from those of diagnostic radiology or interventional fluoroscopy. (Pati et al., 2022)

1.2 Overview of X-Ray Procedures

Diagnostic radiography is the term used for plain film x-rays, the routine examination that is familiar to most people. Usually, two views of the chest are taken, one from the back and the other from the side, to assist in the detection of abnormalities in the lungs or heart. Mammography is a specific x-ray examination of the breast that is used to detect and evaluate breast changes. Currently, there are two types of mammography: film-screen and full-field digital. Although film-screen mammography is still widely practiced, full-field digital mammography is slowly replacing it as the image-receptor technology of choice. Both mammographic techniques use low-energy x-rays and involve the patient having to hold uncomfortable x-ray views for only a short amount of time. Fluoroscopy is an imaging technique commonly used by physicians to obtain real-time, moving images of the internal structures of a patient through the use of an x-ray. This is accomplished by using an x-ray image intensifier and a fluorescent screen to view the internal body part and capturing the images with a video camera for further review. This particular x-ray procedure has an enormous range, from relatively simple examinations such as an upper GI series at the low end to highly complex cardiac catheterization and interventional radiology procedures at the high end. More complex fluoroscopic procedures and the associated high radiation doses have been a recent area of concern within the medical community. Interventional radiography is a subspecialty of radiology that uses various minimally-invasive medical techniques to diagnose and treat certain conditions, using the guidance of x-rays, ultrasounds, CTs, or MRIs. These procedures are usually carried out by interventional radiologists or other specialists and may involve several types of image guidance in order to locate the abnormality and confirm the correct treatment. Due to the relatively high radiation dose associated with some of these procedures, it is not uncommon for patients to receive a radiation skin injury. High-level evidence has shown that skin injuries and certain other deterministic effects are avoidable with increased awareness, education, patient dose monitoring, and more stringent dose reduction methods. (Osmanu, 2022)

Most medical X-ray procedures are performed on an outpatient basis; that is, the patient is briefly exposed to ionizing radiation in order to obtain a radiographic or fluoroscopic image of a particular body part or function. Each year, the average American can expect to receive an effective dose of ionizing radiation from all medical sources of about 3.0 mSv (milliSieverts), compared to the average natural background dose of about 3.1 mSv. This represents a substantial increase in medical radiation exposure in the last two decades, mainly due to higher utilization of more complex imaging studies and greater population screening. Highlights of some of the more common and/or higher-dose x-ray procedures include the following:.

1.3 Purpose of the Work

The purpose of this work is to address the challenges in radiation protection specific to X-ray-guided interventional procedures. These procedures are increasing in number and complexity as technology and clinical expertise advance. X-ray-guided interventions are now being performed in many medical specialties. The benefit of these procedures is that they are minimally invasive, have decreased morbidity, and are often performed using local anesthesia. An essential element in ensuring the long-term success of this form of therapy is to minimize the risk of radiation-induced injury to patients and staff. This will be achieved by identifying the potential hazards in X-ray-guided procedures, examining the different ways radiation can cause injury, and then outlining strategies for effective radiation protection. A significant variable influencing the radiation dose delivered to a patient is the type of procedure and its clinical goal. To address the radiation protection challenges, it is necessary to have a basic understanding of the equipment used and the details of the procedure. This information is not widely known among practitioners who are not radiologists. Thus, this work is also aimed at medical specialists and other healthcare professionals who perform X-ray-guided procedures. The intent is to provide them with sufficient knowledge to enable effective communication with radiologists and understanding of the advice given. (Rehani et al., 2021)

Challenges in Radiation Protection

Exposure to ionizing radiation from X-rays represents a major potential public health hazard, particularly as a source of iatrogenic illness. In recent years, the growth in the use of ionizing radiation in medical practice has resulted in a great increase in population exposure, a matter of concern to radiation protection professionals. This growth has been due to an increase in the number of medical procedures involving radiation and an increase in the radiation dose per procedure. One of the great challenges in radiation protection is the large number of diagnostic X-ray examinations and interventional procedures for which the anticipated medical benefit is small. In such cases, the principle of ALARA (as low as reasonably achievable) is often given inadequate attention, with the result that the radiation detriment outweighs the expected benefit. A recent review of radiological practice in a leading UK teaching hospital revealed that the clinical justification for a high proportion of the radiological procedures was questionable or absent. This represents a failure in radiation protection and a clear case where patients are being exposed to medical radiation with little benefit to their health.

2.1 Exposure Risks for Patients

Radiation exposure to patients has been increasing due to the dramatic rise in the use of x-rays in medical procedures. The average dose received per person has nearly doubled in the past two decades. It has been estimated that x-ray exposure comprises 10% of the total radiation dose in the U.S., which means that the public is more frequently exposed to radiation from medical imaging. While the benefits of x-rays are often immense, this practical and essential medical tool can result in unnecessary radiation doses for patients. With the development of new procedures and technology within medical imaging, it is becoming more difficult to balance the benefits of x-rays as a medical tool with the associated risks. Radiation protection for the patient is a complex issue due to the varied methods of medical imaging and the large differences in dose received from different procedures. This complexity has resulted in inconsistent application of radiation protection by medical staff, which is sometimes inadequate. It is a common misconception that the technicians operating x-ray machines and medical doctors are the only ones exposed to ionizing radiation in the medical sector. In fact, a huge percentage of the 10% of ionizing radiation used in the U.S. for medical imaging is directly ionizing the public, who are patients in a medical facility. This is because scatter radiation is often overlooked as an indirect form of patients' radiation. For example, a study determined that a patient undergoing a pelvic x-ray received 175 mR of scatter radiation during the procedure from 1 meter away from the tube. 175 mR is more than the amount of radiation (100–150 mR) used in a typical general x-ray procedure. This is a significant dose relative to the initial dose, and it is an unnecessary dose. Patients often assume that the prescribed medical imaging procedure is a guaranteed way of improving their health or determining the cause of a symptom. Unfortunately, some patients are receiving excess radiation as a result of repeat examinations. In a study of a sample of 241 patients undergoing CT colonography, it was found that six percent of the patients underwent a repeat examination. Reasons for the repeated exams were inadequate stool tagging, colonic distension, and an incomplete examination. A repeat examination will usually result in a higher radiation dose than the initial examination. Thus, methods to ensure the radiation dose to the patient is as low as reasonably achievable (ALARA) are required to be implemented for every procedure. (Benn and Vig2021)

2.2 Exposure Risks for Medical Staff

Control measures to reduce radiation exposure to the urology team include avoiding exposure where possible, increasing distance from the radiation source, and using protective radiation aprons and gloves.

Staff that are most at risk are those who are in close proximity to the patient to manipulate the fluoroscopy unit. This includes urologists, radiologists, operating department practitioners, and sometimes nursing staff. Staff exposure is dependent on the length of time spent near the radiation source as well as the radiation intensity.

Fluoroscopic procedures are of particular concern as radiation intensity can be up to 100 times greater than that of a standard x-ray and can be employed for anywhere up to several hours. The use of x-rays in the detection and treatment of urinary stones has increased significantly over the past few decades, and in many practices, this is now the standard of care. This represents a substantial number of both diagnostic and interventional procedures carrying a high risk of staff radiation exposure.

Medical staff are at risk of exposure in the urological suite given the universal use of C-arm fluoroscopy. Exposure results from scattered radiation and direct exposure to the primary x-ray beam. The detrimental effects of radiation exposure are well documented in the literature and include cataract formation, an increased risk of developing cancer, and adverse genetic effects. While it is difficult to correlate radiation exposure directly with these effects, it is widely regarded that there is no safe threshold for radiation exposure, and all measures to reduce exposure are justified.

2.3 Radiation Dose Monitoring

The most recent and advanced technique for monitoring radiation dose in diagnostic radiology is the use of a radio-photoluminescent glass dosimeter (RPLGD). These dosimeters have a very high sensitivity (+–5%) and wide measuring range (1 mGy–30 mGy), which makes them suitable for any diagnostic radiology procedures. The RPLGD is considered the best method for assessing radiation doses for patients because it is able to provide a three-dimensional dose measurement and is available in a variety of shapes and sizes. Despite the availability of these dosimeters, radiation dose monitoring is still not a routine practice in diagnostic radiology, and they are often underutilized. This can be attributed to cost, a lack of awareness of radiation dose levels, and some physicians' belief that the benefits of diagnostic radiology procedures outweigh the potential radiation risks.

The radiation dose to the patient can be monitored with radiation detection-type instruments called dosimeters. These primarily include thermoluminescent dosimeters (TLD), optically stimulated luminescence dosimeters (OSL), and pocket dosimeters. In diagnostic radiology procedures, the dose to different body parts is varied and relatively low for each exposure. Pocket dosimeters are therefore not very useful as they provide a measure in terms of the total accumulated dose over a specific period of time. The TLD and OSL dosimeters are more suitable as the doses can be assessed for different body parts by placing these dosimeters at specific locations and then reading them at a later time. The TLD and OSL dosimeters are also available in the form of a badge, which can contain several dosimeters and can be worn by the patients for an extended period of time to assess the overall radiation dose.

Radiation dose monitoring is an essential part of any radiation safety program. There are two aspects to radiation dose monitoring. First, to assess the radiation doses received by the patients undergoing diagnostic or therapeutic radiology procedures. Second, to measure the radiation doses received by the radiation workers and compare these doses with the recommended dose limits. This article will discuss radiation monitoring for patients undergoing diagnostic radiology procedures. It is relatively easier to monitor the radiation dose for therapeutic radiology and nuclear medicine procedures where the dose is delivered over a specific period of time. Monitoring becomes difficult for diagnostic radiology procedures, especially those done on outpatients.

Solutions for Patient Protection

The use of proper exposure and processing techniques is essential and can reduce patient doses by a factor of 10 in some cases. Factors relevant to exposure technique include the use of the appropriate film/screen combination, the use of the correct kilovoltage, proper film processing, and the use of filtration. There is evidence to suggest that increasing kV above the recommended level can have a significant impact on increasing patient-absorbed dose, with a 15% increase in kV potentially doubling the entrance skin dose. This is of particular concern in the UK, where a recent multi-center study discovered overexposure in over a third of lumbar spine examinations. Compliance with European Union regulations and an increased awareness of the importance of regularly auditing X-ray equipment are essential. The use of modern equipment and implementing the latest techniques is important, with the use of computed radiography providing a dose reduction of up to 50% compared with screen/film radiography. Yahav-Dovrat et al. (2022)

Optimization of X-ray techniques means the provision of an X-ray examination using a suitable technique that provides the best image quality with the lowest possible radiation dose. It is widely accepted that there is a large scope for dose reduction in most types of X-ray procedures. In some cases, using up-to-date equipment and applying the 'as low as reasonably achievable' (ALARA) principle can reduce patient doses by up to 50%. In order to implement ALARA, it is important to have knowledge of the radiation dose rate of different examinations and the relative contributions to effective dose from different procedures. The guidance of a medical physicist is invaluable in this process.

3.1 Optimization of X-Ray Techniques

An area of ionizing radiation from medical procedures that has grown substantially in recent years is interventional procedures. This is due to the benefits they offer in treating various conditions that may previously have required surgery. Interventional procedures

are at higher risk in terms of potential radiation damage as the conditions being treated often require high radiation doses to achieve satisfactory results, and in most cases, there is no threshold dose of radiation for deterministic effects. Effects will occur with an increase in radiation dose, and the severity of these effects increases with increasing radiation dose. For interventional procedures, it is suggested that a radiation protection specialist be involved to provide expert advice on the protection of those in the room during x-rays, suitable protective clothing, and an assessment of radiation risks and doses relating to the patient. This area is currently under review by the European Commission, which has produced a document, Radiation Protection 136: European Guidelines on Dose Management in Interventional Procedures. This document includes guidance on dose reference levels for various procedures, quality assurance, and retrospective and prospective dose assessment. Measures such as these are a positive step in reducing the radiation dose to patients during interventional procedures. (Frane & Bitterman, 2020)

Radiation is harmful to the human body; it damages living tissue, so we should aim to reduce the amount of radiation a patient is exposed to during an x-ray to the smallest amount possible while still achieving a satisfactory image. This can be achieved through the optimization of x-ray techniques. This involves both adjustments to the equipment, such as changing x-ray tube voltage and current, and changes to the examination, such as using the most suitable projections for the condition. By doing this, it is often possible to reduce the radiation dose received by the patient by 50% without any loss of image quality. The greatest radiation dose received by a patient during an x-ray comes from computed tomography. Avoidance of CT where possible is a simple way to reduce the radiation dose to the patient. MRI and ultrasound are radiation-free, and patients should be encouraged to consider these alternatives.

3.2 Use of Shielding Devices

A general consideration for widespread use of shielding devices is an assessment of the relative increase in protection, balanced with the cost and possible increased time spent preparing for procedures. Staff compliance in using these devices also requires considered effort in education and culture change. An example that points to a positive shift in radiation protection culture is a recent study showing the increasing use of lead aprons for the protection of staff during X-ray imaging in pediatric emergency departments and the subsequent decrease in use of the aprons as parents realized that the aprons were originally designed for the protection of radiation workers and not patients. This led to the development of specific lightweight, lead-free aprons for use on children.

An area of concern for some workers is that the use of protective equipment could potentially hinder the correct execution of a procedure or result in added procedure time. This is a perceived drawback that must be overcome by accepting that the protection of the patient is of paramount importance. This raises the point that staff using shielding devices need optimized X-ray imaging to keep a clear view of the area being examined and reduce the need for retakes. Further links to the next section on optimization of X-ray techniques.

Practice in interventional procedures has identified the need for dedicated disposable radiation protection for specific tasks, such as covering the patient with a sterile drape that has a lead-impregnated coating on one side to offer protection without hindering aseptic technique, or a simple lead thyroid collar that is now being manufactured as a disposable product. These items are specific for tasks that can be quite varied; for example, a radiologist may need to kneel by the patient during a fluoroscopic procedure, or a surgeon may require an X-ray image during a sterile intervention. Adherence to the ALARA principle should see the ongoing development of task-specific shielding devices.

The use of shielding devices, although straightforward in theory, presents challenges in specific implementation for individual X-ray procedures. A fundamental principle is that the closer the shield is to the patient, the more effective it is in reducing the dose to the patient's body. This can be achieved with simple devices such as lead rubber pads, which can be moulded to the required shape, or clear Perspex immobilisation devices; these are effective, yet the ease of use varies with procedures.

3.3 Patient Education

Health education is a consensual process of sharing, promoting, and reinforcing individual habits to promote health. It is mainly to increase public understanding of how to improve health status. Patient education specifically involves a thorough explanation of medical and dental status and treatment to attain informed consent and usually involves manipulation of patient behavior to encourage compliance with prescribed therapeutic regimens. The goal of patient education is to influence patient behavior and create awareness about their health status. The most crucial element in a strategy to protect patients from any detrimental effects of radiation is minimizing unnecessary exposure to radiation. This can be achieved by helping patients understand the condition and proposed treatment, weigh the benefits and risks of x-rays and radiation therapy, and encourage compliance with all medical and dental health instructions. Failed to explain condition and treatment to the patient to obtain informed consent, whereby consent is legally effective authorization from a from a voluntary and competent patient regarding diagnostic and therapeutic procedure consent and permission explicitly given by the patient or guardian to have the procedure done. Often, patients give consent without understanding the procedure, suggesting that this is implied consent since the patient has not enough information to make an intelligent decision. Obtaining informed consent today has become a defensive mechanism in cases of medical litigation and malpractice, and it should be viewed as part of an effort to uphold patient safety and the right to correct and accurate information on their health. But health care providers must understand that in certain situations, especially in medical emergencies, implied consent is the legal way to proceed despite having no proper informed consent. (Almohiy et al., 2020)

Solutions for Medical Staff Protection

Personal protective equipment (PPE) includes a range of medical clothing and accessories designed to act as a barrier between the employee and infectious materials. While it's most often used in the care of patients with infections, PPE is also used during procedures such as x-rays. It includes such items as gloves, gowns, masks, and protective eyewear. Utilization of PPE is a significant step to minimize occupational radiation exposure to medical staff. Toward that goal, the FDA has established special regulations for PPE intended to provide protection against ionizing radiation. PPE for radiation protection is designed to protect the individual wearing it as well as others who may be exposed to radiation scattered from the patient. This personal protective equipment is usually lead aprons, which are designed to attenuate the majority of scatter radiation. A high level of PPE compliance should result in a noticeable reduction in staff exposure to scatter radiation during many x-ray procedures. Similar to the effect training and education have on increasing patient understanding, staff education is a powerful tool for influencing behavior. Understanding the potential harmful effects of radiation, as well as the various ways to reduce dose, helps staff successfully implement changes in procedure or technique. Such understanding can come from various educational resources offered in a convenient manner, such as online webinars. This may include Joint Commission requirements for education; these are the requirements that staff take steps to minimize the risks associated with ionizing radiation. This educational mandate might be the result of a sentinel event or new evidence that has surfaced regarding the risks of x-rays. It's important that such requirements are met with effective educational tools and not the typical in-service lecture given by someone with minimal understanding of the subject at hand. (Sherer et al., 2021)

4.1 Personal Protective Equipment

Personal protective equipment (PPE) represents the front line of defence against exposure to ionising radiation. PPE includes items such as lead aprons, thyroid shields, leaded glasses, and radiation monitoring devices. It is widely accepted that lead aprons represent a useful device for reducing radiation dose to the torso and represent a simple and effective means of reducing radiation dose. However, other devices have generally been less readily accepted by medical staff. This is largely because devices such as thyroid shields and led eyeglasses inherently cause a certain level of discomfort through user interference and incompatibility with other headwear. Lead-free PPE represents an alternative with the potential to provide better protection with greater comfort and user compliance. This is particularly true with the recent development of lead-equivalent composite materials; however, such devices require further quantitative testing to validate their protective efficacy. The efficacy of PPE is highly dependent on user compliance with safety regulations. Staff who do not wear protective devices or do so in an incorrect manner may receive higher doses than those not wearing PPE due to the radiation backscatter from the protective device. (Martin & Barnard, 2022)

4.2 Training and Education

Relevancy to the particular roles and radiation practices of medical staff is an important factor in effective education, with studies showing that contextual learning and learner-centered strategies are most effective. Training in radiation protection for non-radiologist physicians, other non-radiology medical staff, and physician trainees is generally haphazard and inadequate. Many physicians are not aware of the radiation doses associated with various diagnostic and interventional procedures and often grossly underestimate radiation risks. A European survey of radiation protection training in medical imaging found large discrepancies in both the quantity and quality of training between member states and overall deficits in training for physicians and allied health professionals outside the radiologic specialties. National and international bodies have begun advocating for increased and standardized radiation protection training for medical practitioners and have produced various guidelines and resources to this end.

Effective training and education in radiation safety is a fundamental aspect of protecting medical staff and requires an initial and ongoing component. Recency of information is important since guidelines and protocols for radiation use in medicine are under constant revision. Initial training for all medical staff should provide radiation safety training specific to their workplace, whether it be a dedicated radiation department, operating theatre, emergency department, or medical imaging facility. There is a large body of information considering radiation and radiation safety, and often a one-size-fits-all approach to radiation safety training is unproductive.

4.3 Workstation Design

The hypothetical increase in radiation-associated cancer and genetic abnormalities in the population has prompted the NCRP to recommend that the collective annual dose equivalent to the lens of the eye be limited to 15 mSv, as opposed to the previous limit of 150 mSv (NCRP, 1993). Doses of ionizing radiation to the skin should be limited to 500 mGy in a week, with no more than 50 mGy in any one hour. A significant amount of exposure is attributable to X-ray procedures and interventional radiology. By adhering to ALARA principles and remaining mindful of the latest dose limits, the risks associated with radiation exposure can be minimized. As previously mentioned in this paper, medical staff have previously been known to ignore patient dose considerations when they conflict with what is personally convenient or beneficial. An example of this is a radiologist not wearing protective clothing so that he may quickly perform fluoroscopy and take an X-ray without impediment. In order to not only discourage this behavior but render it impossible, modifications to radiation procedures must simultaneously consider patient dose and prevent/limit practice that is not in the best interest of the patient. This is a broad, deep, and complex task and is beyond the scope of this paper. However, Xu has suggested some useful and practical methods by which unwanted practices can be prevented or deterred. These include periodic review and questioning of the necessity of certain procedures involving high doses, the inclusion of 'unnecessary' procedures in dose monitoring with automatic reporting to higher authorities, and a reduction in the availability of ionizing radiation to some specialists. All these propositions entail changing the way things are done now, and as with any change, there will be resistance. The success of these methods depends on the degree of awareness of radiation protection issues and the understanding of the reasons for these changes by medical practitioners. This brings us back to the global issue of education and training, the effects of which can take some time to be fully realized, and also ensuring that when these changes are occurring and in all future radiation procedures, the new technologies and equipment used do not reintroduce the same old problems in new forms. (Linet et al., 2021)

Quality Assurance in Radiation Protection

One of the approaches embodied in the optimization principle is quality assurance (QA). This is defined as all those planned and systematic actions necessary to provide adequate confidence that a given item will satisfy established quality requirements. Quality assurance comprises two elements: quality control and quality management. The former are the operational techniques and activities used to fulfill quality requirements. According to the Commissariat l'Energie Atomique, this means "all the actions derived from requirements for quality." According to the Commissariat a l'Energie Atomique, this means actions taken in planning, implementation, and documentation to provide confidence that an item will fulfill given requirements for quality. Quality assurance is a diverse subject in its own right, and it is straightforward to find generic texts. Loosely speaking, the aforementioned concepts of quality control management in the context of a radiation protection scenario, particularly in the optimization of protection, can be viewed as clinical audits. In a clinical audit, specific medical practitioners' performance is reviewed against agreed standards, and changes are implemented where needed to ensure that the standards are being met. The process involves problem identification, data collection, analysis, and changes made to improve the outcome. This compares with the concepts detailed in the requirements for optimizing protection. Head of state or government commitment should correspond to the need for resources, including the explicit radiation protection infrastructure. This enabling factor will lead to implementation, with the ultimate goal of improving health and safety standards. What a healthcare provider must do is akin to the process of identifying and addressing factors that deviate from an ideal state towards effective control of risks in their working practices. This will ensure that the implemented protection will achieve the best possible standards in health and safety for patients and staff. (Farzanegan et al., 2020; Okonkwo et al., 2022)

5.1 Regular Equipment Calibration

Quality assurance (QA) in radiation protection plays an important role in ensuring that patients and staff are appropriately protected from the harmful effects of ionizing radiation during X-ray procedures. QA is defined by the International Atomic Energy Agency (IAEA) as all those planned and systematic actions necessary to provide adequate confidence that a radiological procedure will be conducted in the optimum manner and that the radiation dose will be as low as reasonably achievable (ALARA). There are many components to QA, and it is unrealistic to expect all procedures to be 100% effective all of the time. The objective of QA is to provide a high level of confidence that a procedure is optimised and will result in an ALARA dose. In current health care environments, this is achieved through a process of identifying the optimum procedures and tasks and putting measures in place to ensure that these are carried out systematically to achieve the desired outcome. The QA cycle identifies problems or variations in practice and puts in place actions to prevent these from adversely affecting the desired outcome. This process should be continued until the level of confidence is high that the desired outcome will be achieved. QA programs have been designed specifically for diagnostic radiology, have become a requirement by regulatory bodies, and are an integrated part of the radiography curriculum.

5.2 Compliance with Safety Guidelines

A defining factor in the provision of radiation protection is the maintenance of compliance with safety guidelines. The development in this field has seen the production of numerous general and patient-specific guidelines, and working to implement these in a working clinic is a complex process. Success in implementing the guidelines is influenced by the beliefs and attitudes of practitioners, as well as environmental factors. As a result, there is often a disparity between the knowledge of what should be done to protect a patient and what is actually done in an x-ray procedure. To try and bridge this gap, it may be necessary to redesign certain procedures and simplify others. This method of improving guideline compliance should be geared towards long-term change, with an emphasis on the complete integration of new techniques so that they become routine. Short-term interventions, education, and reminders are unlikely to promote sustained change. It is important to monitor the impact of changes to procedures and guidelines to ensure that they are effective and do not compromise the diagnostic utility of the x-ray. This can be achieved through dose audits, comparing pre- and post-change data. Regular reviews of incidents should also be used as a tool to identify any recurrent breaches of safety guidelines. (Rehani & Nacouzi, 2020)

5.3 Incident Reporting and Investigation

Accidental overexposure of patients and underexposure of medical staff due to X-ray procedures are direct results of the failure to ensure quality radiologic practices. It is true that ionizing radiation is hazardous, and the potential for radiation-induced injury or harm is great. Due to the deterministic nature of radiation injury, the clinical signs and symptoms of harm from a significant radiation dosage will be apparent soon after the incident. It is important that any such adverse event, or near miss, be followed by a thorough investigation. All relevant information regarding the procedure parameters and the individuals concerned will be needed to determine the radiation dose and the potential for harm. This will be compared to diagnostic reference levels (DRLs), and with any overexposure incident, a cost-benefit analysis of the procedure will be performed. DRLs were introduced to optimize the amount of radiation needed to obtain a diagnostic image, providing medical benefit while minimizing risk, and should have been considered when seeking consent for the procedure. With this in mind, it may be that the incident was entirely justified; however, a sufficient rationale for deviation from DRLs should be documented. In order to identify and quantify any radiation-induced injury, it is essential that the affected individual's clinical or biological changes be compared with their pre-procedure status. With this in mind, the incident must be adequately documented, and an incident report form specific to radiation incidents should be completed and submitted to a national reporting and learning system such as the "National Reporting and Learning Service" (NRLS) in the UK. By comparing incidents from different institutions, the NHS can learn from the events of others and identify national trends so that appropriate measures can be taken to prevent further incidents. Ideally, an independent advisory service such as the now-defunct National Radiological Protection Board (United Kingdom) or a Radiation Safety Officer should be consulted for expert advice on the investigation and corrective actions that should be taken. (Najjar, 2023)

Future Developments in Radiation Protection

Advanced imaging technologies refer to the digital radiographic systems that are the likely successors to those in clinical use at present. The goal is to obtain the same information as the current imaging modalities but at a lower patient dose while providing equivalent or better image quality. This is achieved by special image processing techniques and direct detectors that eliminate the need for an intermediate step such as film development. These techniques are based on the same principles as current plain film radiography, fluoroscopy, and computed tomography, so the advantages in dose reduction can apply to all the various x-ray procedures. For example, a recent study compared organ and effective doses from CT colonography to those of standard colonoscopy and found that the effective dose from CT colonography was of the same order as that from barium enema and lower than colonoscopy. However, reducing the radiation dose by a factor of 10 for the same examination is generally not economically feasible with the current technology. Therefore, to reduce the radiation risk of x-ray procedures, it is necessary to promote research and use the various existing technologies to their full potential.

6.1 Advanced Imaging Technologies

Flat-panel detectors (FPDs) are made up of a thin-film transistor (TFT) array, which converts x-rays into electrical signals to produce a digital image. FPDs have several advantages over image intensifiers, including higher DQE and better contrast resolution. In terms of radiation protection, FPDs emit a lower patient entrance dose than image intensifiers. Due to the sensitivity of FPDs, they have the ability to reduce x-ray tube output while still maintaining image quality. While this is, in theory, a means of dose reduction, it is important to ensure that the dose is not reduced to the extent that insufficient diagnostic information is obtained. Specific guidance on dose management for FPDs has been produced by the European Commission.

With rapid developments in computer technology and the miniaturization of computer components, there has been a surge in the development of advanced imaging technologies in recent years. Such technologies have included the development of flat-panel detectors and portable image intensifiers, as well as other technologies borrowed from the computer industry such as computed radiography (CR) and digital radiography (DR). These technologies have increased the efficiency and portability of x-ray equipment, allowing for use in a greater range of medical procedures. In addition, image quality has improved with the ability to post-process digital images as well as the use of digital image enhancement technologies. These technologies have all brought benefits to patient diagnosis; however, it is important to realize that each brings its own challenges in radiation protection and a need for continuing innovation in dosimetry, with the technology itself providing some of the solutions to increased radiation risk.

6.2 Automation and Robotics

The drawbacks and limitations of automation and robotic systems lie in the fact that the technology has predominantly been developed for specific x-ray and imaging procedures in controlled environments. The diversity in x-ray equipment and procedures, especially in medical imaging, can be a limiting factor. The cost of implementation is high, and with relatively limited cost-effectiveness evidence and reduced funding in the current economic climate, research in the development and implementation of such systems is an ongoing process.

Articulated robotic arms have also been developed to position the x-ray tube and image receptor in order to carry out a specific examination. The idea behind this is to implement the ALARP principle with regards to radiation protection by removing the need for health workers to hold a patient in position for an x-ray examination to be carried out. This can be witnessed in the development of an intelligent radiotherapy environment at Imperial College London, where an articulated robotic manipulator (ARM) was developed to position a mobile C-arm and image detector in order to create 3-D images of a patient to facilitate conformal radiotherapy.

Automation and robotic systems have been developed in an attempt to remove the potential for human error in the administration of radiation doses or the operation of x-ray machines while improving the consistency and quality of the procedures. Computer-administered algorithms dictate how x-ray machines are configured and activated in accordance with the type of examination required. This operates under the pretense that removing the need for a radiographer to operate the machine manually will reduce the incidence of faulty x-ray examinations.

Conclusion

In conclusion, significant challenges exist in the context of X-ray procedures. However, each challenge has a potential solution. The challenges can be addressed by altering the philosophy related to producing medical images, by emphasizing the importance of the skill of the practitioner and closely monitoring the appropriateness of high technology procedures. Furthermore, the layout and improved availability of information to the professional and patient alike will be of great benefit. The use of informatics to drive decision making should improve the difficult area of the appropriateness of individual procedures to patients. Development of better mathematical models may allow radiation risk to be quantified more precisely than is currently possible. This will assist clinicians in evaluating the benefit-harm balance of X-ray procedures, enabling smarter decisions to be made which will reduce harms without loss of benefit. Finally, the Commission believes there is a need for a stronger and more unified advocacy of radiation protection within the medical community. Employing these solutions offers a safety benefit which is significant to public health given the great and growing number of people exposed to X-ray procedures worldwide. The situation can be monitored and improvements assessed by repeating the method used to evaluate radiation protection in the ESR iGuide. The availability of safe and effective alternative imaging procedures and technologies can be evaluated, while changes in the rate of fatal and serious harm should be identifiable using the statistical record of causes of death and injury in all developed countries.

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