Narrative Review on Radiation Exposure in Healthcare Workers: Unveiling the Risks and Safety Measures

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Abstract:

Introduction: The use of ionizing radiation in medical imaging and therapeutic procedures has witnessed a significant rise in recent years. This, however, has led to an increased risk of radiation exposure for both patients and healthcare providers. The cumulative exposure received by healthcare workers in clinical settings has been a major cause of concern. While limited studies have provided a narrative review of the health effects of radiation on radiation workers, this study aims to provide a comprehensive narrative review of the effects of radiation exposure specifically on healthcare workers. It includes potential short and long-term risks and measures for minimizing exposure. **Methods:** An unstructured literature review in which the original articles were screened during the period from January to April 2023, using the following sources: PubMed, Springer Link, TheBMJ, Oxford Journal, Scopus, Science Direct, Google Scholar. The screening process was limited to articles written in English and aimed to identify studies that examine the health effects of radiation among healthcare workers in clinical settings. **Results:** In total, 30 articles were identified, and 15 were selected. Various factors in relation to the health effects of radiation have been discussed. Mitigating measures are presented at the end of this article. **Conclusion:** Understanding the potential health effects of exposure, especially among radiation workers, is crucial. Therefore, it is recommended to tailor targeted preventive interventions to reduce harmful exposure to ionizing radiation and potential health issues due to ionizing radiation.

Keywords: Ionizing radiation, clinical setting, health effects, healthcare workers

Introduction:

The discovery of X-rays in the year 1895 provided the much-desired non-invasive technique of unmasking the internal structures of human anatomy. Theoretically, radiation is divided into two forms: ionizing radiation (IR) and non-ionizing radiation (NIR). IR refers to radiation with high energy that can remove electrons from atoms and cause disruptions in chemical bonds, which may possibly lead to deoxyribonucleic acid (DNA) strand breaks, mutations, and, importantly, raise concerns about its genotoxic and carcinogenic effects. (Jerome Nriagu, 2019). IR, which includes alpha and beta particles and some electromagnetic radiation (gamma and x-rays), can directly or indirectly alter the normal structure of a living cell. Meanwhile, NIR is low-frequency radiation that disperses energy through heat and increases molecular movement, such as ultraviolet rays, visible light, infrared rays, and radio waves (Bahrami Asl et al., 2023).

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has named X-rays as the most widely used radiation in medicine (Charles, 2001). According to the World Health Organization (WHO), in 2022, the most found artificial sources of radiation in clinical settings are diagnostic and radiotherapy. In 2008, more than 3,600 million X-ray examinations, 37 million nuclear medicine procedures and 7.5 million radiotherapy treatments were reported worldwide (Buls, 2016).

The use of IR in medical applications, such as imaging techniques, is crucial for early disease diagnosis, treatment planning, and patient monitoring. Medical professionals widely use IR to create images through various techniques, including computed tomography, fluoroscopy, dual-energy X-ray absorptiometry, mammography, and linear accelerator (Faraj, 2021). Due to the increasing number of IR sources being installed in clinical settings, this technology is expanding to other departments, such as the emergency department, operating theatres, orthopaedics, dental, and cardiac laboratories. Consequently, people who work directly with medical equipment are exposed to IR more frequently.

According to the Department of Statistics Malaysia (DOSM) report in 2022, there were 21,534 cases of occupational injuries in 2021 with 7 cases reported due to radiation. However, in 2022, 30% of cases that included lung disease, skin conditions, and hearing loss were reported due to occupational injuries. Of these cases, 0.04% were related to cancer, indicating an increase from 0.01% in 2021 (Jabatan Keselamatan Dan Kesihatan Pekerjaan, 2022).

This warrants for a comprehensive understanding of radiation in clinical settings. The objective of this paper is to provide a comprehensive narrative review of the effects of radiation exposure on healthcare workers. In addition, the mitigation measures for minimizing exposure will be discussed in this paper.

Materials and Methods:

The narrative literature review was conducted from January to April 2023 where the original articles were screened using the following sources: PubMed, Springer Link, TheBMJ, Oxford Journal, Scopus, Science Direct, Google Scholar. Several combination keywords were used, including “radiation”, “health workers”, “occupational health”, “occupational exposure”, “clinical settings”, and “medical staff”. Search results were enhanced by combining terms with the Boolean operators; AND, OR and NOT.

This study used specific inclusion and exclusion criteria to identify the most relevant articles that met the specific requirements as listed in Table 1. The most specific criteria was to match the objective of this paper, written in English and published between 2013 till present. This is to ensure that this paper captures the recent advancements, changes in regulation or guidelines and current trends in research related to radiation safety and healthcare worker exposure. Exclusion criteria were used to filter out unrelated or irrelevant articles to ensure that only related articles will be addressed and to limit the number of articles to review.

Table 1. Inclusion and exclusion criteria for article selection

Inclusion criteria	**Exclusion criteria**
Articles published between 2013-2023	Articles published before 2013
Articles related to the staff health	Articles discussing on the patient health
Full articles and free access	Abstract and limited access
Articles written in English	Articles written in languages other than English

Figure 1 describes literature selection process for the articles. In total, 30 articles were identified and 15 were selected for reviewing. The information obtained from the articles was structured and combined to create a summary that outlines the present status of scientific knowledge. The findings of this review were then utilized to identify effect of radiation and suggestions to address the issue.

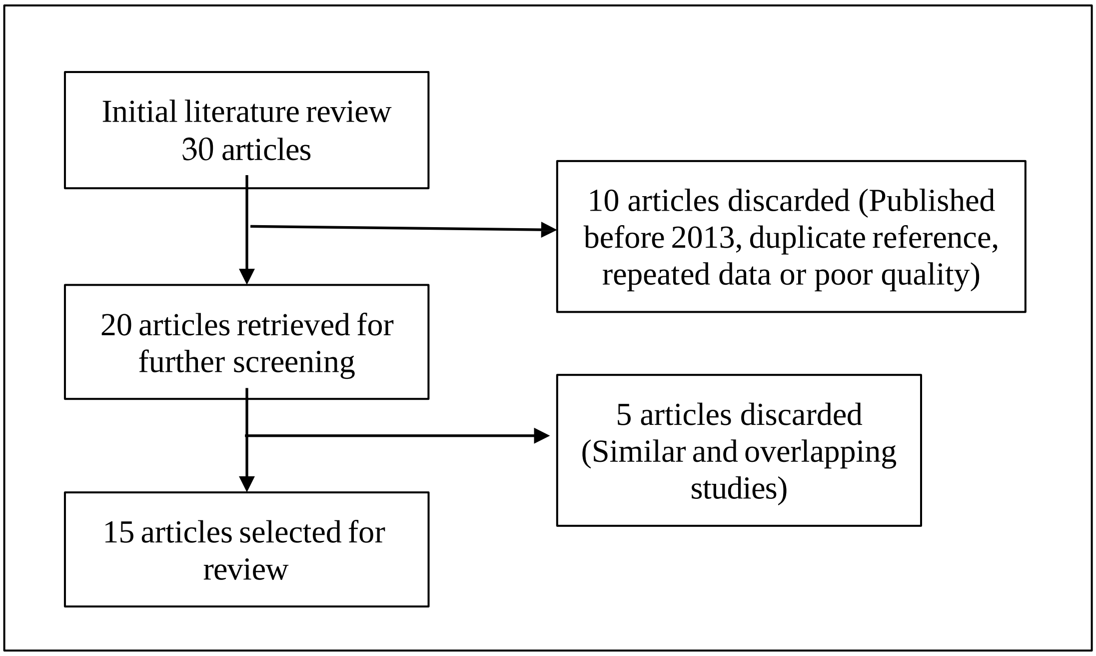

Figure 1. Flowchart of article selection process.

Results:

Biological effects caused by radiation

The consequence of the interaction of radiation with the atom of a living cell is the basis of biological effects. The interaction of radiation with biological cells could take place directly and indirectly. The direct interaction occurs when radiation interacts with the atoms of the DNA molecules or the cellular components that are critical to the survival of the cell.

When a biological cell is exposed to radiation, the probability that the radiation would have a direct interaction with the DNA molecules is very small because the DNA molecules occupy only a small portion of the cell. The component of each biological cell is mostly water. For this reason, the probability of radiation interacting with the water that makes up the cell's volume is higher. Thus, the indirect interaction of radiation occurs when radiation interacts with water molecules of a cell and other events follow.

When radiation interacts with water molecules, it could break the bond that holds the water molecules together, producing fragments such as hydrogen and hydroxyls. These fragments may combine with other ions to form compounds which would not harm the cell. They could also combine to form toxic substances, such as hydrogen peroxide, which could destroy the cell. About two-thirds of the biological damage caused by low-energy radiations, such as X-rays, is due to these indirect interactions while one-third is due to direct interaction. The biological effect of ionizing radiation is classified into two main classes, namely stochastic and deterministic effects.

Short-term Effects Towards Healthcare Worker

Occupational Safety & Health Administration (OSHA) explains in its article on Safety and Health Topics; that deterministic health effects occur when some part of the body is exposed to a radiation dose which exceeds the threshold for the respective health effect. Some of these health effects may develop after a short delay of one to four weeks of irradiation. In most controlled occupational settings, such as clinical settings, the radiation dose exposure that may result in such effects on healthcare workers is less likely. However, according to a fact sheet on IR health effects and protective measures by the World Health Organization (WHO), in scenarios like radiological emergencies, individuals who are at greater risk of being exposed to radiation doses are high enough to cause acute effects, especially first responders and the workers of the affected facility in comparison to the general population.

Acute Radiation Sickness

Acute Radiation Syndrome (ARS) is also known as radiation toxicity or radiation sickness. Centers for Disease Control and Prevention (CDC) defines ARS in its Radiation Emergencies fact sheet as "an acute illness caused by irradiation of the entire or most of the body by a high dose of penetrating radiation in a very short period of time, usually in a matter of minutes". This syndrome is hugely due to the depletion of immature parenchymal stem cells in specific tissues. There are a few required conditions to establish ARS, which are a large dose of radiation greater than 0.7 Gy or 70 rads, an external source of radiation and high penetrating radiation that is capable of penetrating up to internal organs, involving the entire body and, finally, delivered in a short time. According to (Mario López & Margarita Martín, 2011), the progression of ARS is through three phases in which the onset, duration of the phases and dominant syndrome manifestation are proportionate to the radiation dose. It includes post-exposure from 0 to 2 days, post-exposure from 21 to 60 days and the recovery phase.

Long-term Effects Towards Healthcare Worker

Stochastic effects have a certain probability that is directly proportional to the dose. There are various late effects, occurring 90 days or more after irradiation. Therefore, it can be very difficult to determine whether stochastic effects contribute to the development of diseases such as tumours and hereditary disorders, especially on healthcare workers.

Chronic Radiation Syndrome

In stochastics, the body's water management is disrupted. As the immunity of the body decreases, secondary infections invade the organism. Doses above 10 Gy contribute to the formation of intestinal syndromes, which are characterized by reduced appetite, diarrhoea, dehydration, drowsiness, and fever. A significantly reduced number of white blood cells is also observed. All these symptoms can cause death within a few days. Doses above 50 Gy contribute to the development of cerebrovascular syndrome that manifests in a series of disorders including coordination of movements and balance, apathy and agitation, tetanic spasm, diarrhoea, seizures, and coma after a few hours.

Studies have emphasized the importance of complete blood count (CBC) in the evaluation of radiation effects on the body, especially among radiographers, which can play an important role in the prognosis and diagnosis of complications such as chronic radiation injury. Studies have proven the effect of radiation in decreasing the number of white blood cells; lymphocytes, and monocytes in radiology technologies (DavudianTalab et al., 2018). In another study, chronic exposure to low X-ray doses in healthcare workers who are exposed to radiation may significantly change the values of ALT, AST, MDA, total protein, albumin, globulin and GSH in comparison to the control group (Faraj, 2021). Thus, in Malaysia, a routine full medical check-up, including CBC, is compulsory for each radiation healthcare worker to prevent any possible events in future.

In another study, evidence shows that the frequency of chromosomal damage in radiation healthcare workers was higher than in normal individuals (Buls, 2016). At the same time elevated levels of reactive oxygen species (ROS), oxidative DNA damage and immunosuppression may be triggered by irradiation. Exposure to IR can change the numbers and functions of immune system cells and cause an inflammatory response, which activates various pro-survival pathways and factors such as nuclear factor kappa B and members of signal transducers and activators of transcription (STATs) (Bolbol et al., 2021).

Cancer risk

Healthcare professionals' cumulative lifetime occupational radiation dosage and any potential negative effects have been a source of concern for decades. There has been a clear link between radiation exposure and cancer incidence among healthcare workers. Historically, radiology was known as the cause of the first incidence of skin cancer (Rajaraman et al., 2016). Lee WJ et al. (2018) conducted a study in South Korea to calculate the lifetime risk of malignancies brought on by occupational radiation exposure among radiologists and medical radiographers (Lee et al., 2018).

Consequently, the higher lifetime attributable risks (LAR) among women was significant mainly to breast and thyroid cancer risks. Meanwhile, men's LAR were higher in other cancer sites with colon cancer being the highest. In addition, a 14-years cohort study was done among 90,957 radiologic technologists in regards to involvement in fluoroscopically guided interventional procedures (FGIP) in which the analysis showed an approximately two fold increased risk of brain cancer mortality and significant risk in incidence of breast cancer and melanoma (Rajaraman et al., 2016). This high risk may possibly be due to lack of shielding applied during the intervention procedure.

Stochastic effects are also responsible for changes in reproductive cells that may contribute to generating mutations in offspring. However, acknowledgement of the presence of unmeasured confounding by non-radiation risk factors may possibly affect the results as well. In contrast, Kitahara et al (2017) revealed that death from malignant intracranial tumours was not related to cumulative occupational radiation exposure to the brain . The cancer risk due to IR exposure to healthcare workers has to be explored in more detail.

Mitigation Measures

Healthcare workers encounter different health risks in clinical settings due to their exposure to diagnostic ionizing radiation. While the level of exposure is within acceptable limits, being exposed to ionizing radiation still poses potential hazards that can lead to many diseases and unfavourable outcomes as stated in the previous discussion. Due to this, many preventive measures have been taken by the authorities and the systems of each working place, including applying basic radiation protection principles, including distance, time and shielding actions (Bolbol et al., 2021).

Even though authorities have taken many safeguards, the knowledge and practice of the healthcare workers themselves have to be taken into consideration to minimize these risks. In 2020, a cross-sectional study was carried out at the Diagnostic Radiology Department of Zagazig University Hospital, revealing that a plurality of healthcare workers demonstrated a strong awareness of occupational health and safety measures, exhibiting excellent knowledge and adherence to radiation hazard protocols. These include wearing a Thermoluminescent Dosimeter (TLD), lead apron, lead goggles, thyroid collar, and gonad shield on daily work, as well as checking if there are any cracks before wearing. Additionally, it emphasizes strictly prohibited consumption of food and beverages in work areas, and a significant proportion of healthcare workers possess sufficient knowledge regarding exposure doses and utilize various periodic examinations to monitor their exposure levels (Fathy Zaitoun et al., 2021).

By virtue of this matter, all healthcare workers, including those who regularly spend significant amounts of time in radiation environments, necessitate comprehensive monitoring protocols, including job-specific education, training, and the provision of appropriate protective tools and equipment (Miller et al., 2010). On top of that, regular medical examinations of healthcare workers exposed to ionizing radiation are crucial to ensure compliance with safety regulations. These examinations help mitigate the risks associated with developing hazards caused by ionizing radiation. Furthermore, conducting long-term epidemiological surveillance of these workers enables authorities to estimate the potential long-term effects of low-dose radiation exposure (Baudin et al., 2023).

It is recommended to utilize radiation protection tools, hold training courses and follow up the technicians to reduce the effect of radiation on these individuals (Faraj, 2021). Although the accumulation dose in radiation workers was lower than the dose limits, it should be noted that long term exposure to ionizing radiation under defined dose limits can have adverse health effects. This highlights the crucial role of monitoring radiation workers as an at risk population.

Discussion:

In general, this comprehensive overview of the biological effect of radiation on healthcare workers focuses on both short and long-term consequences. It addresses the direct and indirect interactions of radiation with living cells, leading to deterministic effects like ARS and stochastic effects such as cancer and hereditary disorders. It also revealed that chronic exposure to low X-rays in healthcare workers who are exposed to radiation might significantly change the value of ALT, AST, MDA, total protein, albumin, globulin and SGH. Thus, the reviews emphasizes significant risks faced by healthcare workers, especially in scenarios like radiological emergencies.

This paper covers a wide range of topics and is not limited to the effect of radiation but also provides insights into mitigation measures employed. However, while this paper covers the two focus areas, it could benefit other papers in the future by covering a broad spectrum of information, including exact radiation exposure levels associated with different effects. In addition, the review focuses primarily on healthcare workers, which is relevant but may not fully encompass all aspects of radiation exposure and its effects.

In addition, one notable gap that the authors encountered is the lack of discussion on the psychological and emotional impact of radiation exposure on healthcare workers. This includes stress, anxiety and burnout which are increasingly recognized as important factors in occupational health. It is recommended that future studies focus on long-term follow-ups with healthcare workers to better understand the cumulative effects of radiation exposure over time. Comparative studies between different types of healthcare settings, such as hospitals, clinics, and research facilities, could provide insights into varying levels of exposure and risk. Plus, there seems to be a lack of clarity in the standard operating procedure for healthcare staff who have been diagnosed with occupational hazards related to radiation exposure. As a result, it is recommended to establish a proper protocol that can effectively safeguard the health and well-being of the healthcare workers both directly and indirectly.

Conclusion:

It is widely recognized that healthcare workers in clinical settings are at a heightened risk of exposure to radiation, which can have severe impacts on their health and well-being, especially after long-term exposure. From direct interactions with DNA molecules to indirect effects through water molecules in cells, the review outlines the various ways radiation can damage living tissues. As it is proven that exposure to radiation can significantly affect the health status of healthcare workers, an improvement can be made by the local authorities in terms of guidelines and protocols, training programs and occupational safety. In addition, healthcare workers should play an important role in ensuring a safe and healthy environment at their workplace by applying the principle of radiation protection endorsed by the local and international authority.

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