Recommendations for reducing exposure to medical X-ray irradiation (Review)

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Abstract. With the increasing frequency of X-ray examinations in clinical medicine, public concern regarding the harm caused by exposure to X-ray radiation is also increasing. However, some physicians are not completely aware of the dangers of exposure to X-ray irradiation. Individuals specialized in this field, including physicians, have a better understanding of these dangers, which limits the use of X-rays in medicine. The present study aimed to address strategies for reducing the harm caused by exposure to medical X-rays and increase public awareness regarding X-ray radiation. Through a literature search and review, combined with the current status of clinical X-ray examination and the authors' professional experience, the present study highlights the importance of reducing X-ray exposure, and proposes several specific recommendations and measures for reducing the frequency or dose of X-ray irradiation. On the whole, the finding discussed in the present review suggest the minimal use of medical X-ray examinations and that alternative tests should be selected whenever possible. When medical X-ray screening and treatments are necessary, the risk-benefit ratio should be assessed, possibly aiming to achieve avoidable exposure. Further attention should be paid to protect sensitive glands and reduce the risks in children.

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Abbreviations: CT, computed tomography; ALARA, as low as reasonably achievable

Key words: radiology, cancer, CT, radiation, medical X-rays

Contents

1. Introduction

On a daily basis, humans are subjected to natural background radiation (1-8), which is the largest source of human radiation exposure, with a global average dose of 2.4 mSv (9).

Medical diagnostic techniques, such as routine conventional radiography or computed tomography (CT) scans, which are also based on X-ray irradiation, are vital for the diagnosis of certain diseases. Simultaneously, the possible damage caused by radiation has attracted increasing attention and has become a subject of public concern and a potential healthcare issue (10).

X-rays are one of the most widely used forms of radiation in medical diagnosis and treatment. In the United States, 13 million patients underwent CT examinations in 1990 (11). This number increased to ~62 million in 2006 (12) and to >84 million after accounting for multiple scans in 2016 (13). Following the discovery of X-rays, it was found that frequent exposure experienced by physicians increased their risk of developing cancer (13-18). Studies on atomic bomb survivors (19-24) and patients with cancer receiving radiation therapy (25-35) have found that the risk of tumorigenesis is associated with acute or fractionated high-dose radiation exposure. Although opinions differ as regards the harm of low-dose radiation to the human body, the impact of low-dose radiation on cancer risk has gained scientific attention. For example, a study reported that in the United States, 1.5-2.0% of all cancers are considered to be attributable to radiation from CT scans (12). Radiation can damage DNA by direct and indirect mechanisms that may lead to cancer development (36).

Direct damage is caused by breaks in the DNA molecule caused by radiation energy, while reactive species, which may be produced from the ionization of water, can induce indirect damage to the DNA molecule.

Despite the differing opinions on the exposure threshold required to induce carcinogenesis, including the risk of both single-acute dose and recurrent small-dose exposure, the most popular accepted model of cancer risk associated with radiation is a linear no-threshold dose-response curve (37). This risk model is the reason that the current guiding principle of radiation safety is 'as low as reasonably achievable' (ALARA), which indicates that radiation should be avoid as much as possible, even if the dose is minimal, if it has no direct benefit (38).

As numerous individuals undergo radiographic examinations each year (12,39-43), raising awareness concerning the risk of X-ray irradiation is particularly important (39). However, to date, at least to the best of our knowledge, no specific literature has addressed methods with which to reduce X-ray exposure in China. To fill this gap in knowledge, a literature review was conducted to discuss some practical strategies that may be applicable in China to reduce the bodily harm caused by medical X-ray exposure and to increase awareness regarding X-ray radiation.

2. Literature selection and search criteria

The present narrative review focused on reducing X-ray radiation exposure. First, based on the current status of X-ray use in clinical practice, the authors' medical knowledge and experience regarding X-ray radiation was combined with existing literature resources to outline measures and suggestions for reducing X-ray exposure. According to this outline, relevant topics in the literature were identified for the search. Various literature databases were searched, including PubMed, Web of Science, Wanfang Data and China National Knowledge Infrastructure. The Baidu search engine was also used. The present study was a review and did not require informed patient consent or ethics committee approval.

Inclusion and exclusion criteria. The selected literature was required to be published in the English or Chinese language, or translated into English, for inclusion in the study. The literature included professional medical textbooks, professional medical journals, and medical reports with content on radiographic or CT radiation. The following literature studies were excluded: Non-English and non-Chinese studies.

Literature selection. Two authors selected the literature independently, first reviewing the title and abstract, followed by selecting references for complete review, and finally including the literature deemed most suitable.

Data extraction. The authors read the titles preliminarily and selected the literature after extracting the entire text. The authors then compared and discussed the selected items. For the literature screened, those items for which an agreement could not be reached, were discussed and excluded.

3. The importance of reducing X-ray exposure

The harmful effects of X-ray radiation exposure, such as cancer induction, have been well established (12). As aforementioned, in the United States, 1.5-2.0% of all cancers are considered to be attributable to radiation from CT scans (12). According to the Chinese National Central Cancer Registry, the average incidence of cancer in the Chinese population is 285.91/100,000 (317.97/100,000 for males and 253.09/100,000 for females), with an average mortality rate of 80.54/100,000 (224.20/100,000 for males and 135.85/100,000 for females). These values suggest that the Chinese population may be one of the highest risk groups for cancer worldwide (44). Hence, further focus on the rational use of X-rays and the prevention of harm caused by medical X-ray radiation is warranted.

Medical X-ray use needs to be economized to reduce risks associated with radiation exposure. The aim of the present study was to propose methods with which to reduce unnecessary radiation exposure based on the authors' professional experience and to promote the dissemination of scientific knowledge throughout medical staff and the general public.

4. Specific recommendations and measures for reducing X-ray radiation exposure

Specific recommendations and measures for reducing unnecessary exposure to medical X-ray radiation are presented in Table I.

Enhancing medical knowledge and education regarding radiation within the general population (including physicians)

Radiologists and technicians require comprehensive knowledge of radiation hazards. Radiologists and technicians perform radiographic examinations of patients. Their understanding of radiation hazards involves the following: The radiation doses that patients receive; radiation protection for patients, themselves, and those in the vicinity while a scan is ongoing; scientific recommendations for clinicians; and the education of clinicians and patients regarding radiology. This also affects their self-preservation. The International Commission on Radiological Protection advises that the occupational dose limit for radiation exposure should be 100 mSv over a period of 5 years, with a maximum of 50 mSv in any single year (45). According to a survey performed in Saudi Arabia, a number of radiologists have limited knowledge regarding the harmfulness and carcinogenicity of X-ray radiation (46). The same study found that only 65±13.5% of radiologists had clearer comprehension of the carcinogenicity of CT scans than the patient (46). Approximately 80% of radiologists presumed that CT scans were associated with an elevated risk of developing cancer; however, only 56.5, 48.5 and 65% of the radiologists were aware of the specific risks from radiation involved in the head, chest and abdominal pediatric examinations, respectively (46). Regular, frequent and specific training courses are suggested to improve the fundamental knowledge of radiologists and other physicians regarding radiation exposure from CT scans (46). It is thus suggested that the further training of radiologists, technicians and other medical professionals may also be required in China.

Table I. Measures suggested for the reduction of medical X-ray radiation.

Measures	Concrete measures or rationale
Enhance medical knowledge and education regarding radiation within the general population (including physicians)	Radiologists and technicians require comprehensive knowledge of radiation hazards General healthcare workers need increased knowledge of radiation hazards. Patients and the public need more information about radiation hazards
Reduce excessive radiation doses in screenings	Use appropriate doses to minimize the radiation exposure from each X-ray examination
Reduce unnecessary radiation exposure	Alternative techniques, such as magnetic resonance imaging or ultrasonography, should be used whenever possible For patients requiring follow-up scans, the follow-up duration should be extended whenever possible
Increase protection when performing radiological studies	Increasing protection for non-inspected body parts Radiology examination and treatment rooms should comply with protective requirements For bedside or other mobile inspections, protective measures should be taken, including the protection of surrounding personnel
Develop helpful information technology	A patient's radiology images in one hospital can be used easily and safely in another hospital, thereby reducing unnecessarily repeated tests
Establish social guidance	Reduce repeated and unnecessary radiological screenings for occupational entry or admission to academic institutions Reduce unnecessary and unreasonable radiological checkups due to health-benefit packages
Build a more trusting relationship between doctors and patients	A trusting doctor-patient relationship helps physicians make more confident, reasonable, and scientifically sound decisions in applying radiation
Strengthen scientific analysis and management of radiation applications	Scientific analysis of the rationality of radiation prescripti on benefits management
Special attention to the radiation-sensitive population	Women, children and patients with previous tumors may be more sensitive to radiation damage and may require special attention
Enhanced establishment and dissemination of radiological protection guidelines, consensuses, and laws	Radiological protection guidelines, consensuses, and laws can guide medical workers and the general population in using radiological examinations and therapy more rationally

The knowledge of general healthcare workers about radiation hazards needs to be enhanced. Medical staff provide care to patients, prescriptions for radiological examinations and protective care during examinations. Hence, they should have extensive knowledge of the harmful effects of radiation. Radiology should be applied only when necessary, and appropriate protection must be provided to the patient. From a radiologist's perspective, unnecessary radiological examinations occur due to insufficient knowledge and training of physicians when referring patients for radiological examinations, according to previous a study conducted in Pakistan (47). Physicians in different countries may have varying degrees of understanding of the radiological hazards; however, all physicians must enhance their training and education in radiological protection.

Patients and the public need to be provided with more information regarding radiation hazards. Individuals may require medical X-ray examinations or may be exposed to radiation from other sources during their lifetimes. Further knowledge in this area will help individuals avoid unnecessary radiation sources, including unnecessary screenings or higher-than-necessary radiation doses during screenings.

Reducing excessive radiation doses in screenings. The use of appropriate doses is required to minimize the radiation exposure from each X-ray examination. It has been demonstrated that the radiation dose is proportional to the risk of developing tumors (40). The radiation doses differ depending on the target body parts, the body part being examined and scan parameters, such as kilovoltage (kVp), tube current (mA), slice thickness (mm), examination type, volume CT dose index, dose-length product and scan model (15). For routine conventional radiography, digital X-ray equipment is used, which has high detective quantum efficiency detectors, uses special image-processing and noise-reduction software, and optimizes the exposure chart with detectors which can reduce the radiation dose (48,49). For CT scans, there are several techniques, including the reduction of tube voltage, the use of dual-source CT for high-pitch helical scanning, modulation of the tube current and optimization of the scan length which have been used to reduce radiation doses (50). For example, a previous study found that by reducing the peak potential from 120 to 80 kVp, multidetector-row computed tomography may reduce the effective radiation dose by 68.58% and can maintain uncompromising image quality in pediatric neck CT examinations (51). Another study demonstrated that automatic current selection setup was more effective than the fix tube current according to the ALARA principle. These findings suggest that the automatic current selection with iterative reconstruction technique can reduce the effective dose to an average of 0.71 mSv (reduction of radiation dose by ~50%), whereas it can maintain an image quality comparable to that obtained with the fixed-tube-current of 35 mAs with iterative reconstruction technique in individuals with a normal body mass index (52). It is noteworthy that different organs have different risks of radiation-induced cancer. For example, the extremities have a low risk of radiation-induced carcinogenesis, whereas solid organs, including the lungs, and particularly glandular organs, such as the thyroid and mammary glands, have a much higher risk (45). The same exposed body part may even receive varying radiation doses depending on the effective dose when undergoing a CT scan (53-55). To reduce the harm of radiation to the human body, the dose in each X-ray examination needs to be minimized. Therefore, X-ray device settings are crucial as they directly relate to the amount of radiation dose.

Reduction of unnecessary radiation exposure

Alternative techniques, such as magnetic resonance imaging or ultrasonography, should be used whenever possible. In 2016, radiographic examinations and CT scans were performed for 42,027,701 (523 per 1,000) and 17,897,944 (223 per 1,000) individuals, respectively, in Jiangsu Province, China (39). In light of the large numbers of radiographic and CT studies being performed, other methods, such as magnetic resonance imaging and ultrasonography, need to be considered whenever possible to reduce X-ray radiation exposure.

For patients requiring follow-up scans, the follow-up duration should be extended whenever possible. Diseases, such as lung cancer or infections, often require re-examination post-treatment; therefore, when conducting radiological re-examinations, the risk-benefit ratio should be weighed, and a radiological review should be conducted as late as possible while still meeting the clinical requirements. Frequent and inappropriate re-examinations may increase radiation-related risks in patients. We should strengthen the training and test of medical professionals with the authority to prescribe radiology, which may maximally change practice among medical professionals.

Increasing protection when performing radiological studies

Increasing protection for non-inspected body parts. During radiological examinations and treatments, it is recommended that only the areas necessary for inspection are exposed. Particular attention should be paid to protect children and sensitive glands, such as the thyroid (54). Children are the most radiosensitive subgroup, with a lifetime risk of developing cancer induced by radiation exposure two or three times higher than that in the general population (45).

Radiology examination and treatment rooms should comply with protective requirements. Radiological examination and treatment rooms receive numerous patients daily. The radiation hazards to outside personnel should be monitored. There is a significant risk of occupational exposure if protection requirements are not met.

For bedside or other mobile inspections, protective measures should be taken, including the protection of surrounding personnel. Radiological studies may be performed in an operating room or ward. However, these areas often lack adequate protection systems. Therefore, radiation damage is likely to affect medical personnel or other people in such environments (56). The protection of these individuals should be prioritized.

Development of helpful information technology. A patient's radiology images in one hospital can be used easily and safely in another hospital, thereby reducing unnecessarily repeated tests. Due to high mobility rates in the Chinese population, patients have the option to pursue quality medical care and tend to move from one hospital to another or from one city to another. During this process, if radiology data are lost or if the data obtained in a previous radiology examination are not adequately clear, the patient may require additional scans. Therefore, it is crucial to develop robust information technology networks whereby patients can retain high-quality imaging data available in different hospitals and avoid unnecessary, repeated radiological tests.

Establishing social guidance

Reducing repeated and unnecessary radiological screenings for occupational entry purposes or admission to academic institutions. As is known in China, for certain entry-level reasons, radiological examinations are often performed to assess the fitness of a candidate in China. However, in some cases, if a candidate has undergone a recent scan, an additional scan is not required for the entry examination. Certain entry level requirements include the irrational request of asking healthy, young job seekers to obtain a CT scan, which could easily be replaced by a conventional, routine radiological examination. A CT scan has effective radiation doses that may be 5-20-fold higher than those of routine conventional radiology (57). There are several radiological assessments for occupational entry purposes or for entry into academic institutions each year, and unreasonable or unnecessary examinations should be minimized.

Reducing unnecessary and unreasonable radiological check-ups due to health-benefit packages. As is known in China, a number of employers offer annual health check-ups, which often include a routine chest radiography or chest CT scan. However, it is not necessary for all individuals to undergo such an annual radiological examination, particularly if they are young and healthy. However, owing to the lack of knowledge regarding radiation, a number of individuals choose free radiological screenings without considering the actual risk-benefit ratio.

Building a more trusting relationship between doctors and patients. A trusting doctor-patient relationship helps physicians make more confident, reasonable, and scientifically sound decisions as regards the use of radiation. The physician-patient relationship in China is an important topic (58). A healthy physician-patient relationship, based on trust, will facilitate physicians in making proper scientific decisions. Theoretically, if the physician-patient relationship is unhealthy or not trustworthy, the physician may then inappropriately apply radiology due to excessive concern for misdiagnosis.

Strengthening of scientific analysis and management of radiation applications. The scientific analysis of the rationality of radiation prescription benefits management. It is beneficial to analyze the rationality of radiation applications in medical management, including justification of examination types, doses, intervals between examinations, and whether an alternative examination can be selected, which is conducive to further scientific radiation application in the future. The over-prescription of X-rays causes the misuse of medical resources and increases the risk of radiation-induced cancers (12), thereby exerting serious economic burden on patients and society.

Special attention should be paid to the radiation-sensitive population. Women, children and patients with previous tumors may be more sensitive to radiation damage and may require special attention. Females have a higher risk of developing cancer induced by radiation than males. This may be attributed to the increased risk of thyroid and breast cancers in women. In addition, the effects of estrogen and cytochrome P450 enzymes may promote radiocarcinogenesis in women (59,60). Children are more sensitive to radiation damage than the general population. Patients with tumors are more sensitive to X-ray radiation injury than the general population and require special consideration (61). Older adults have reduced organ function and less actively dividing cells compared with children, and they have a shorter lifespan, which is the reason why older adults have a lower risk of most of the radiation-induced cancers (45).

With the increase in the average life expectancy and with the improvement of medical conditions in China (62), as well as the increasing number of health check-ups, individuals have increased opportunities to undergo medical X-ray examinations throughout their lives. Therefore, the cumulative effects of radiation on individuals should also be considered.

Enhanced establishment and dissemination of radiological protection guidelines, consensuses and laws. Radiological protection guidelines, consensuses and laws can guide medical workers and the general population in using radiological examinations and therapy more rationally. Currently, in China, laws and regulations, such as 'Law of the People's Republic of China on Prevention and Control of Radioactive Pollution' (www.gov.cn/bumenfuwu/2012-11/13/content_2601283.htm), 'Regulations of the People's Republic of China on Health Protection of Medical Treatment X-ray' (http://www.law-lib.com/law/law_view.asp?id=2158), 'Basic Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources' (http://www.nirp.cn/userfiles/file/GB18871-2002.pdf), and others, which are critical for medical X-ray radiation exposure protection, are in place. The aforementioned laws and regulations put forward basic requirements and principles for the use and protection of radioactive radiation, including medical X-radiation. Therefore, these laws and regulations need to be followed. The establishment and dissemination of radiological protection guidelines, consensuses and laws needs to be strengthened. Relevant guidelines should establish dose standards for various radiological examinations or therapy techniques, with updates as techniques develop. There should also be a consensus regarding the dose standards. Professional personnel involved in radiological protection can further strengthen their pre-job training. This is crucial in order to improve general awareness of radiation protection. Medical physicists and radiobiologists should strengthen the training of medical staff and the dissemination of scientific knowledge among the general population. At the same time, the importance of departmental record keeping needs to be emphasized, as it is beneficial for scientific research and helps physicians better understand the dangers of radiation.

5. Conclusions and future perspectives

The authors acknowledge that the present review has several limitations. The present review was based on the authors' professional experience and primary understanding of radiation, and some suggestions are put forward in combination with ideas from the literature, which may not be well-rounded.

In the present study, it is emphasized that the intention was not to prescribe dose limits and constraints for individual patients, as these may cause more harm than good by reducing the effectiveness for a particular diagnosis or treatment (45). Instead, the present study aims to emphasize the legitimacy and optimization of medical procedures, and the application of diagnostic reference levels to diagnostic procedures (45).

In conclusion, the use of medical X-ray examinations needs to be minimized, and alternative tests should be used whenever possible. If medical X-ray screening and treatment are necessary, the risk-benefit ratio should be weighed to determine the most effective dose, while protecting other areas from avoidable exposure. Particular attention should be paid to the increased radiation risk in children and the protection of sensitive glands (45,54).

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Authors' contributions

HMS and FHJ performed the analysis, including the literature selection and search. HMS and ZCS were involved in the writing of the original draft. FHJ was involved in the writing, reviewing and editing of the manuscript. All authors have read and approved the final manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

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Competing interests

The authors declare that they have no competing interests.

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