REVIEW: RADIATION PROTECTION IN MEDICINE

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ABSTRACT

Ionizing radiation was used in medicine broadly after the X-ray detection by Roentgen in 1895 and now has the main rule in diagnosis and treatment. Using radiation in diagnostic and therapy is beneficial for many people every day in the world; on the other hand, the radiation can penetrate the human body then make biological effects, minimize its deleterious effects, and balance between the benefit of the radiation and the risk should exist.

During the practices, patients and medical staff may expose to radiation. Many national and international organizations have been worked to avoid overdose exposure to the patients and the staff through the important three keys, justification, optimization, and limitations. However, in some countries, mostly in developing countries, the medical staffs have little or no training in radiation protection. It was estimated that more than 90% using of ionizing radiation in medicine done by radiographers and radiological technologists. Their expertise, skill, care, and information can help them determine the allowable amount of radiation to the patients and protect themselves.

Despite all the rules established by all organizations, insistence and confirmation for applying the rules in all diagnostic and radiotherapy departments at hospitals are necessary, especially in developing countries, to avoid unnecessary exposure to the patients and the staff. In addition, education, knowledge on the effects of the radiation, and traineeship of the medical staff involved in the diagnostic and treatment procedures are essential for the patient and medical staffs' protection.

Keywords: *Ionizing radiation, Radiation protection, Biological effects, Diagnostic, Radiotherapy.*

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INTRODUCTION

The application of ionizing radiation in medicine is one of the primary sources of artificial radiation. After the X-ray detection by Roentgen in 1895, ionizing radiation was used in medicine broadly and now has the main rule in diagnosis and treatment. Radioactive sources have been in use for medical purposes since 1898. The medical use of radiation spread to most parts of the world during the twentieth century and became more frequent [1], Artificial radiation sources are considered the largest source of exposure, accounting for more than 95% [2, 3].

Using radiation in diagnostic and therapy is beneficial for many people every day in the world; on the other hand, the radiation can penetrate the human body then make biological effects, minimize its deleterious effects, and balance between the benefit of the radiation and the risk should exist. The biological effects of ionizing radiation were investigated after discovering radiation in 1895. However, radiation protection was initiated after the atomic bomb program in 1945. Health risks from both artificial and natural sources of ionizing radiation have been ongoing since World War II to investigate the radiation effects on human health [4].

Ionizing radiations divide into directly ionizing and indirectly ionizing depending on the mechanisms of their interaction. Directly ionizing radiation includes charge particles such as electrons, alpha particles, protons. Indirectly ionizing radiation includes X and gamma rays and neutrons [5],Effects of ionizing radiation rely on different factors such as types, energy, and doses of the radiation, age, individual health, the volume of the body exposed. Different types of effects may be produced after exposure to the radiation, such as deterministic and stochastic effects. Deterministic effects arise from acute exposure, while stochastic effects arise from chronic exposure.

Deterministic effects occur due to cell death or delay in cell division if large numbers of cells die to affect the function of the tissues or organ. In stochastic effects, the cells are not dying but alter somehow, causing delay effects such as carcinogenesis and hereditary effect [6, 7].

Ionizing radiation interacts with the human body either by direct or indirect action. In direct action, the interaction takes place directly with a critical target such as DNA; as a result, the atoms of the target will be ionized by Coulomb force interaction then produces biological effects; the interaction dominates for high linear energy transfer (LET) radiations. In indirect action, the interaction between the radiation and water inside the cells since 70-80% of a cell contains water. The radiation can radiolysis the water then produce very reactive free radicals; they can break chemical bonds and cause damage inside the cell. Mostly low LET radiations do this type of interaction [7-9].

The objectives of radiation protection as a state by the National Council on Radiation Protection and Measurement (NCRP) are to prevent clinically significant radiation-induced deterministic effects by keeping dose limits that are below the observable dose or applicable threshold and to limit the serious of stochastic effects to permissible dose level[10],The organization International Society of Radiographers and Radiological Technologists (ISRRT) was formed in 1962 and has been worked to promote radiation protection for both patients and workers. The organization's main objectives are to improve the education of radiographers, support the progress of medical radiation technology worldwide, and promote a better understanding and enforcement of radiation protection standards [1].

During my survey in some hospitals and published some papers about receiving excessed doses of radiation by patients and medical staff encouraged me to write this review. The review aimed to insist, confirm and remember the laws of radiation protection for those who work at the radiology department at hospitals and those who are responsible for the administration of the state, mostly in developing countries, to put the laws in prioritizing their tasks to minimize radiation exposure to the patients and medical staffs to protect them.

Radiation Protection Quantities

When the human body is exposed to radiation, to quantify the effect of absorbed energy, the quantity absorbed dose is used with a unit Gray (Gy) (1 Gy = 1 Joul/ kg). Absorbed dose is not favorable for radiation protection goals because the biological effects vary for different types of ionizing radiation and different tissues; some quantities are introduced, such as organ dose, equivalent dose, effective dose, committed dose, and collective dose. The organ dose is defined as the mean dose D.T. in a tissue or an organ T in the human body given by the following relation:

$$DT = \varepsilon T / mT,$$

where εT is the total energy transferred by radiation to the tissue or the organ, mT is the mass of the tissue or the organ.

The quantity equivalent dose (H.T.) used to compare the effects of different types of ionizing radiation can be determined by multiplying the absorbed dose by to weight factor of the radiation. The S.I. unit of equivalent dose is J/kg which is called Sievert (Sv), the old unit is rem (radiation equivalent man), the relation between the two units 1Sv = 100 rem.

Table (1) contains weight factors for some types of ionizing radiation, which are recommended by the International Commission on Radiological Protection (ICRP) [7, 10-12]. The equivalent dose can be expressed as follow: H.T. = D.R. W.R., where D.R. is the absorbed dose and wR is the weight factor of the radiation.

If the tissue or an organ is irradiated by more than one type of ionizing radiation, the equivalent dose is given by the following; H.T. = Σ D.R. wR.

The amount of the biological effects does not depend only on the type of the radiation; also, the type of organs or tissues has a rule on the effectiveness of the radiations. So, another factor described which refers to tissue or organ called tissue or organ weight factor. Table2 contains weight factors of different tissues recommended by ICRP. Depending on sex and age, these weight factors are constant and applicable for the average of populations. Tissue weighting factors reflect the role of the tissues type to the total detriment to health when the total body is irradiated. The sum of the products of equivalent dose (H.T.) of a tissue or an organ to the weight factor of that tissue or organ (W.T.) is called effective dose (E). It can be expressed as the following: E =∑ W.T. H.T.

Effective dose can be used to assess potential risk from ionizing radiation and as one parameter in evaluating the suitability of examinations involving ionizing radiation [13],Another quantity in radiation protection is a committed dose, equal to the total dose received during a period when a radionuclide is taken into the body. Sometimes it is helpful to measure the total radiation dose to groups of people or a whole population. The total dose, called collective dose, is the product of the mean dose of an exposure group and the number of persons in the group. This quantity is most useful when the received dose by the person has the same magnitude and is delivered within periods that do not significantly exceed a few years [11, 12].

Diagnostic procedures:

Risks associated with diagnostic procedures using ionizing radiation are typically low (except in some cases depending on some factors), but it is necessary and essential to managing patients' exposure so that it is no higher than is needed to obtain the required diagnostic information [7],The potential risk associates with diagnostic procedures are carcinogenesis and heritable effect which they belong to stochastic effects; the effect has no threshold dose below this point there are no observable effects. However, it is increased with increasing the dose [10].

There are many modalities for diagnostic procedures. Each of them uses different techniques, and all use ionizing radiation to make images of the body. Conventional radiography is the most common technique for capturing a static image by transmitting X-ray through a patient's body, a photographic film as a detector placed behind the body [9],All parts of the body cannot absorb X-rays with the same amount. So, various doses are used to view different parts of the human body. Low doses (effective doses of about 0.05–0.2 mSv) are used for most plain film diagnoses of the chest and extremities but the abdomen and lower back use higher doses (effective doses of about 1–3 mSv) to penetrate more [12].

When the X-ray beam is employed with a video screen, the technique is termed fluoroscopy. Fluoroscopy may be a method that enables physicians to visualize the movement of a part of an instrument or dye (contrast agent) through the body in real-time[1],The effective dose of a chest X-ray is hundreds of times lower than straightforward fluoroscopic and is thousands of times lower than a fancy fluoroscopic [14],In some cases, the rate to the skin directly from the fluoroscopy system may range between (0.02-0.05) Gy, betting on the mode which the fluoroscopy operated this ranges could also be changed between (0.01 to quite 0.5)Gy[15]. Ronald et al. (2004) concluded that the more prolonged fluoroscopy employed in coronary interventions had caused severe deep X-ray burns in some patients [16].

Computed tomography (C.T.) could be a technique that enables three-dimensional images to be created, part of a body placed between an emitter of X-ray and receiver; several images are formed during rotating the system around one axis of rotation and also the part of the body may be seen from different sides as shown in Fig.(1). The advantage of this method is, the body may be viewed from different sides, and it can eliminate superimposition of the photographs of structures outside the world of the part of the body which under examination [17].

Standard radiographic examinations have effective doses (and potential detriment) that adjust widely over an element 1000 (0.01–10 mSv). C.T. examinations tend to be in an exceedingly more narrow range but have relatively high effective doses (about 2–20 mSv). Interventional procedures usually use doses ranging from 5 to 70 mSv [13],Kritsaneepaiboon et al. (2018) concluded that patients under age 30 years who had multiple and repeated C.T. scans were at the highest risk of cancer [18],In another study, Yoshimasa et al. (2005) showed that multiple diagnostic C.T. examinations might result from hair loss or other radiations effects [19],The continued ascension of CT-scanning may be a major consider the increasing collective dose to the worldwide population from medical exposure [20]. Radiation-induced skin injury in some interventional producers reported in some literature due to high dose of radiation delivered [15, 21, 22].

Diagnostic medicine could be a technique that a radionuclide is given to the patient as a pharmaceutical called radiopharmaceutical, obsessed by tissue or organ preferentially; the administration could also be by injection, ingestion, or inhalation [23],The process with radiopharmaceutical has different clinical applications in medicine like in oncology, cardiology, neurology, etc. Using of radiopharmaceuticals is a smaller amount widespread compared with the opposite techniques; in practice, there's an oversized variation between countries, in some countries, medical specialty diagnostic isn't used in any respect.

It has been investigated that the annual numbers of medical procedures and their collective dose are only 2% and 6%, respectively, of the corresponding values for medical X-rays. The mean dose per procedure is larger for medicine (4.6 mSv) than for medical X-ray (1.2 mSv) [24].

The most popular radionuclides utilized in the diagnostic medical specialty are Auger electron emitters like 67Ga, 81mKr, 99mTc, 111In, 123I, 125I, and 201Tl. They emit photons for imaging and Auger electrons with low energy. Besides emitting Auger electrons in planer imaging and single-photon emission computed tomography (SPECT), positron emission is also employed in the positron emission tomography (PET) technique. The biological effects of Auger electron emitters in diagnostic imaging have been studied before [25],It has been shown that Auger electrons emitters are highly radiotoxic when decay occurs inside the DNA of the organelle [26-28],Several reviews have been published on the biological effects of Auger electron emitters [28-30],Risks resulting from diagnostic medical examinations are associated with potential late induction of tumours [1].

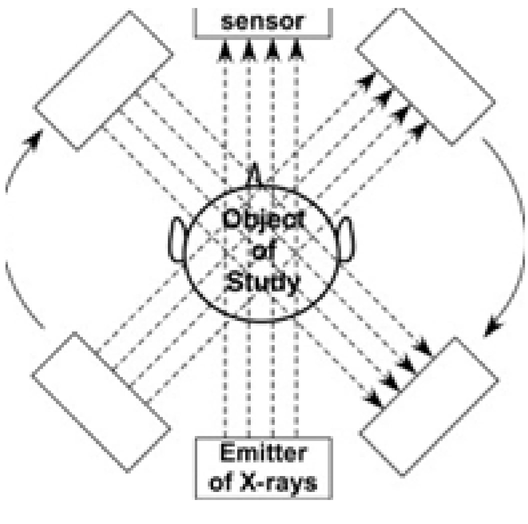

Figure .1. Structure of computed tomography [15].

Table 1. Radiation weighting factors for some types of ionizing radiation9[12]

Type and energy range	weighting factors
All photon energies	1
All-electron energy	1
Neutrons, energy:	
< 10 keV	5
10–100 keV	10
0.1–2 MeV	20
2–20 MeV	10
> 20 MeV	5
Protons, other than recoil protons, energy	
> 2 MeV	5
α-particles, fission fragments, heavy nuclei	20

Table 2. Weight factors for different tissues [12]

Tissue or organ	Tissue Weighting Factor, W.T.
Gonads	0.20
Bone marrow (active)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainders	0.05
Total	**1.00**

Radiotherapy

Radiotherapy aims to kill cancer cells with as minor damage as possible to normal cells. Applying radiotherapy in medicine has different goals: to cure early-stage cancer (curative treatment), to prevent cancer from recurring, and to treat symptoms caused by advanced cancer (palliative treatment). Sometimes chemotherapy or surgery is used with radiotherapy. Radiation may be used before surgery (neoadjuvant therapy) to shrink the tumour or after surgery to help prevent cancer from coming back (adjuvant therapy). For some types of cancer, radiation is used along with chemotherapy because some of the chemo drugs act as radio-sensitizers which enhance the sensitivity of the cancer cells against the radiation. In general, radiotherapy is divided into three types: teletherapy (external radiotherapy), brachytherapy (internal radiotherapy), and nuclear medicine radiotherapy. In external radiotherapy, the radiation is delivered from outside of a body. The medical linear accelerator (linac) is the most widely used radiation source in modern radiotherapy, which can provide either electron or megavoltage X-ray therapy with a wide range of energies. Electron and X-ray radiotherapy is additionally applied with other styles of the accelerator, like betatrons and microtrons. Most contemporary radiotherapy is disbursed with linacs or teletherapy cobalt units. In a few specialized centers, in external radiotherapy, they use heavy particles such as neutrons generated by neutron generators and cyclotrons, protons generated by cyclotrons, and synchrotrons and heavy ions (helium, carbon, nitrogen, argon, neon) generated by synchrocyclotrons and synchrotrons (1,7,12,31).

Brachytherapy or internal radiotherapy means short-distance therapy by a small source of radionuclides. Most brachytherapy sources emit photons example, ^{60}Co, ^{137}Cs, ^{192}Ir, ^{125}I; however, for a few exceptional cases, beta ^{90}Sr/ ^{90}Y and neutron ^{252}Cf sources are used. Brachytherapy sources are usually encapsulated and have different forms like needles, tubes, seeds, wires, pellets. They are used as sealed sources. The capsule is helpful because, contains radioactivity, provides source rigidity, and absorbs alpha and beta radiation produced through sources decay (7,24,31),There are two main types of internal radiotherapy treatment: Interstitial, the radiation source placed directly on or near the tumour. This treatment may be temporary or permanent. For example, in head and neck cancer, interstitial therapy played a massive part in improving cure rates in early tumours and Intracavitary: the radiation source placed in a cavity of the body. This treatment is always temporary (7).

Nuclear medicine therapy involves the oral or intravenous administration of radionuclides in solutions that then travel to an organ, where decay may occur. Since the early days of radionuclide therapy, the number of available radiopharmaceuticals for radiotherapy has increased greatly. For example, the liquid radioactive substance can be taken by mouth for therapeutic purposes. Iodin-131 has been used for treating some cancers of the thyroid. Radioactive iodine takes up by thyroid cells naturally. For other types of cancers, the antibody joined the radioactive substance travels through the blood to the correct location. Nuclear radiotherapy can be used to relieve pain for some types of cancers. Some types of radiopharmaceuticals are used to treat the pain of bone metastases, such as samarium-153-lexidrona and strontium-89 chloride (12, 24).

In radiotherapy, the patients are exposed to high doses of radiation, so the probability of occurring accidents is high. In general, the accident infrequent because radiation protection. However, several unfortunate accidents in radiotherapy happened before and may continue to occur due to scientific, technical, and managerial failures. In particular, the international atomic energy agency (IAEA) has reviewed 90 accidents in radiotherapy (including teletherapy, brachytherapy, and some therapy with unsealed radionuclides) reported to regulatory authorities and professional associations or published in scientific journals. Analysis of the starting events and contributing factors for these accidents will allow the event of lessons to be learned and measures for prevention (24).

Principles of radiation protection

The principles of radiation protection and safety upon which the IAEA safety standards are based are developed by the ICRP. The detailed formulations of those principles are often found in ICRP publications, and it was challenging to rewrite without losing their fundamentals (7) . The principles are:

Justification

In applying ionizing radiation for any practice purposes, a justification basis should be considered, which means that benefit of the radiations exposure must be more than the harm. In radiation protection, justification must be considered for all human effects such as somatic and genetic effects from the radiation exposures. During using ionizing radiation in the different fields, several options can be considered; one must choose which can do more good than harm.

Optimization

The goal of optimization is to confirm that the magnitude of individual doses, the number of individuals exposed, and the probability that potential exposures will happen should all be kept as low as reasonably achievable (ALARA) economic and social factors being taken under consideration. In keeping with the revised recommendations of ICRP, this process of optimization below restriction should be applied regardless of the exposure situation, i.e. planned, emergency, and existing.

Limitation

Both justification and optimization apply to all exposure situations like plan exposure, existing and emergency. However, limitations are used to planned exposure situations only. Limitation dose in radiation protection means the total dose to any individual from all planned exposure situations other than medical exposure should not exceed the proper limits described by ICRP. It is assumed that the chance of producing a stochastic effect increases with a dose with no threshold dose [32, 33].

Radiation protection of patients and medical staff

Accidents may occur during diagnostic and radiotherapy due to patients being exposed to different doses of the radiation from that in standard practices. The accident may be an operating mistake, equipment failure, or other mishaps [24].

Medical staff also may expose to radiation during diagnostic and radiotherapy due to the above reasons, or they do not have sufficient knowledge on radiation protection. The probability of medical staff to expose to radiation in all techniques may occur. However, it is more in nuclear medicine during transport, labelling, and being close to the patients. A previous study showed that to reduce exposure of the hands and fingers of the staff, training and education of the staff in radiation protection is very important for patient's safety and the staff themselves [34-36].

Different studies have been done on radiation protection of patients and medical staff for various techniques. One of these studies showed that in PET/CT technique, analytical approaches to dose evaluation were practical to apply radiation protection for patients and the staff [34].

Three main factors can protect the staff to a high degree: minimizing time of exposure, increasing distance from the source, and using shielding [36].

In radiotherapy, quality assurance for medical exposure is an essential criterion for improving radiation safety in the medical application of ionizing radiation. The primary safety standards (BSS) require that registrants and licensees establish a comprehensive program of quality assurance which includes, inter alia:

Evaluation of patients during and after treatment; Traineeship and education of radiological medical practitioners, technologists, medical physicists, radio-chemists, radio-pharmacists and also non-radiology professionals; Commissioning, calibration, and maintenance of equipment; Independent audits for dosimetry and treatment planning; Maintaining records of relevant procedures and results; Protocols for treatment procedures;

Supervision of delivery

Applying the principles of radiation protection mentioned above can help protect the patients from unnecessary doses during diagnostic and radiotherapy.

Once a worker has been notified of pregnancy, additional protection of the embryo/fetus should be considered for pregnant workers. For pregnant patients, the feasibility and performance of medical exposures during pregnancy require specific consideration attributable to the radiation sensitivity of the developing embryo/fetus. The pregnant patient encompasses a right to understand the magnitude and sort of potential radiation effects which may result from in-utero exposure [32].

The utilization of the techniques for diagnosis and radiotherapy varies significantly between countries. The procedures should be according to the scientific and professional standards, which national and international organizations establish.

The main concern of the medical staff within the fields of radiology and radiotherapy is to guard the patients against unnecessary radiation and themselves. Although this will be done by qualified staff altogether radiation facilities, such policies should be adopted by all regulators and government agencies [37].

CONCLUSIONS

The education of medical professionals in radiation protection issues and radiation safety may be a continuing problem, mostly in developing countries. Despite radiation protection rules, there are unexpected errors and accidents which weren't envisioned. Radiation protection procedures and policies are developed around an existing base of kit and assuming a particular technology. With an increasing number of procedures in diagnostic and radiotherapy with higher quality, measures of radiation protection for both patients and staff members should evolve to sustain the applying of this modality in medical practices. There is an unbroken have to review and update all radiation protection policies and procedures as new equipment is taken into clinical use. Insistence and confirmation for applying the principles all told diagnostic, and radiotherapy departments at hospitals are necessary, especially in developing countries, to avoid unnecessary exposures to the patients and also the staff. Education, information on the results of the radiation, and traineeship of the medical staff involved within the diagnostic and treatment procedures are essential for patients' and medical staffs' protection.

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