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Tools for Optimization of Radiation Protection in Radiology, Radiotherapy, and other Nuclear Medicine Applications

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1. Introduction

In recent times, nuclear technology has progressively played an important role in medical applications. These include the use of ionizing radiation and radioactive material in diagnostic, therapeutic, and interventional or treatment procedures in medical applications. The use of ionizing radiation in the various medical applications needs to consider the potentially hazardous nature of the radiation to ensure appropriate safety precautions.

Nuclear medicine is a relatively new field of expertise with not much widespread understanding of the associated potentially detrimental implications of its use. The use of ionizing radiation in nuclear medicine procedures requires careful monitoring and management. The training of medical personnel mainly focuses on effective use of nuclear technology as part of other medical procedures with not much detail on associated radiation hazards. Similarly, most regulatory personnel that monitor nuclear medicine facilities do not have adequate understanding of the technology or the associated hazards to determine required measures to monitor for ensuring safe use of the technology.

The use of fractionation and establishment of diagnostic reference levels (DRLs) have been the most common approaches implemented by medical practitioners for patient protection and ensuring effectiveness of procedures. The paper aims to analyse the application of these measures to optimize safety for patients and efficiency of procedures. These aspects are essential especially when establishing a new facility with limited experience on application of procedures. The requirements must be implemented by medical practitioners and monitored by regulatory personnel through established inspection programs. This will help prevent harmful radiation exposure and ensure intended benefits of nuclear technology in medicine are achieved.

2. Overview of Nuclear Technology Use in Medicine

2.1 Diagnosis of Ailments

Diagnostic procedures involve the use of radiation in imaging various parts of the body to detect anatomical or physiological disorders. Radiopharmaceuticals can be injected into the bloodstream to act as radiotracers or contrast agents for different body parts in such imaging procedures [5].

2.2 Therapy of Ailments

Therapeutic procedures involve use of radiation therapy treatments for various types of cancers. Radiation therapy can be administered through an intravenous solution of radioactive material, by radioactive sources outside the body such as a ^{60}Co teletherapy machine or a linear accelerator, or through brachytherapy where sealed radioactive sources are placed inside the body next to the tissue to be treated.

2.3 Interventional Radiology

Interventional radiology involves the use of nuclear technology to conduct minimally invasive treatment procedures that are an alternative to full open surgery. Radiation sources help generate images for observing a procedure being conducted inside the body in real-time [6]. Interventional radiology applications therefore involve prolonged exposure to radiation since observation of real-time images is required throughout the whole period of a particular procedure.

3. Safety Requirements

Nuclear technology use in medicine, although beneficial to human health, comes at a cost of exposure to ionizing radiation. There is potential for some procedures to result in harmful radiation doses. Medical facilities must implement appropriate technical requirements as part of quality assurance to ensure safe achievement of the beneficial use of ionizing radiation.

The use of radiation sources in medicine must conform to the general principles of radiation protection. However, this requires an approach that differs from the required protection in other planned radiation exposure situations. This is because the exposure in medicine is intentional and administered for the direct benefit of the patient [2]. Safety considerations must be adopted on a case-by-case basis with optimization of protection in each procedure balanced against the effectiveness of a particular procedure with regard to administered doses.

3.1 Accidents in Nuclear Technology Use in Medicine

Accidents in medical use of the technology are caused by many factors, mainly due to poor understanding of radiation safety requirements by practitioners. Turai and Veress assess some of the most common causes of accidents with radiation sources in medicine [7]. These include administering of the wrong radiation dose due to poor quality control procedures, insufficient training, and inadequate knowledge of radiation safety procedures by medical practitioners.

3.2 Quality Control in Diagnosis of Ailments

The dose utilized in diagnostic imaging procedures requires the application of diagnostic reference levels (DRLs). This helps optimize procedures and patient protection by assigning an appropriate radiation dose based on the individual characters of a patient. Aspects such as patient age, size, and part of the body being examined should help determine the parameters and the dose to use per kilogram of body mass [1].

Table 1: Quantities for Setting Diagnostic Reference Levels

Quantity	Recommended Symbol	Recommended Unit
Entrance surface air kerma	$K_{a,e}$	mGy
Incident air kerma	$K_{a,i}$	mGy
Incident air kerma at the patient entrance reference point	$K_{a,r}$	Gy
Air kerma-area product	P_{KA}	$Gy.cm^2$
Volume computed tomography dose index	$CTDI_{vol}$	mGy
Dose-length product	DLP	mGy.cm
Mean glandular dose	D_G	mGy

The parameters in Table 1 [1] should be used as reference parameters to manage radiation dose to the patient. The assigned DRLs must be those that provide diagnostic usefulness of a procedure for each particular patient. The reference dose must be the most frequently used dose for a particular procedure at similar facilities and not necessarily the lowest. The 75th percentile of the graphical plot of common doses associated with a particular procedure as indicated in Fig.1 should be the one selected [6]. Computer generated treatment plans can be utilized to determine accurate treatment doses and give an indication on safety optimization.

The achievable dose selected in procedures must be the median dose of the graphical plot of the distribution of doses as presented in Fig.2 [6]. This helps reduce variations in treatment in similar procedures that could affect the outcome for different patients. If it is determined that the dose being used in substantially lower or higher than the average dose utilized at similar facilities, a review of the method for performing a particular procedure must be conducted [3]. Typical doses for procedure as in Table 2 [4] can be used for reference to keep used doses within acceptable range.

Table 2: Reference Dose Levels for CT Imaging Procedures in European Countries

Examination	$CTDI_w$ (mGy)	DLP (mGy.cm)	Phantom
Routine head	60	1050	Head
Face and sinuses	35	360	Head
Vertebral trauma	70	460	Body
Routine chest	30	650	Body
HCRT lung	35	280	Body
Routine abdomen	35	780	Body
Liver and spleen	35	900	Body
Routine pelvis	35	570	Body
Osseus pelvis	25	520	Body

Selected DRL values must be comparable to those in Table 2 with the achievable dose selected for a particular procedure being the median dose of the graphical plot of the dose distribution as presented in Fig. 2 [6]. This helps reduce variations in treatment in similar procedures that could affect the effectiveness of the procedure for different patients.

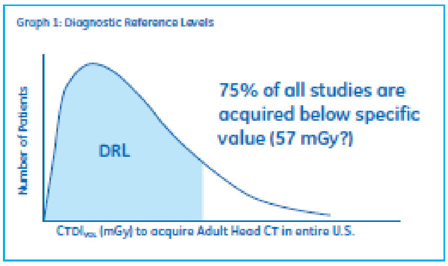

Fig. 1. Diagnostic Reference Levels for Computed Tomography imaging of the head in the United States of America.

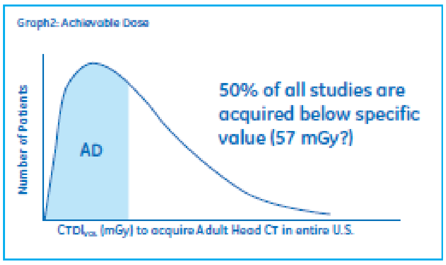

Fig. 2. Achievable Doses for Computed Tomography imaging of the head in the United States of America.

3.2 Quality Control in Radiation Therapy

The use of fractionation technique in radiotherapy can allow the management of the dose given to a patient while also ensuring the effective treatment of a tumour. The fractionation process involves dividing the total radiation dose required for a particular procedure into smaller doses that are administered over a given time period. A typical regime of adjuvant radiation therapy for cancer of the breast, head, or neck can involve a radiation dose in the range of 45 to 60 Gy administered in fractionated doses of 2 to 3 Gy per day within a 5-week period [1]. This not only allows the delivery of smaller radiation doses that are tolerable but also optimizes the procedure for more effective outcomes.

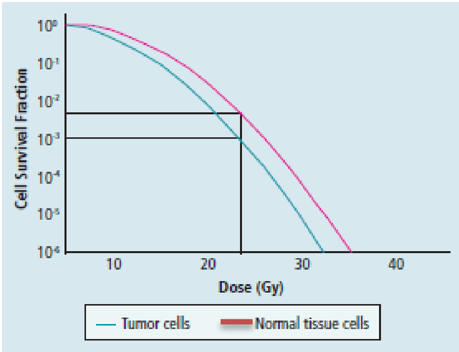

Fig. 3. Differences in recovery rates from fractionated radiation dose to tumour cells and normal tissue cells.

Fractionation allows normal cells enough time to recover from a tolerable radiation dose while a large proportion of tumour cells die as shown in Figure 3 [3]. The gradual increase in radiation dose to reach a maximum required dose allows for optimization of effectiveness of the radiotherapy procedure. Administered radiation dose must be clinically comparable to those at similar facilities and regulatory personnel must conduct necessary reviews of dosimetry records including patient treatment protocols for dose accuracy thereby ensuring safety.

3.3 Quality Control in Interventional Radiology

Interventional radiology procedures are usually performed by practitioners with limited knowledge of radiation protection because such techniques are usually a part of more complex medical procedures. Possible radiation doses to the skin can exceed 1 Gy which can be detrimental to the patient [5].

Table 3: Diagnostic Reference Level data for some interventional procedures in the UK

Procedure	DRL Gy.cm^2
Biliary Drainage	54
Oesophageal dilation	16
Pacemaker insertion	27
Coronary Angiogram	36

Training of medical practitioners on selection of appropriate dose for each particular procedure is necessary to ensure protection from radiological hazards. The DRLs indicated in Table 3 [4] are typical for interventional procedures. These can be used for reference to give guidance on probable effective doses to a patient giving indication for optimization of safety.

3. Discussion and Conclusion

This study addresses safety aspects that also consider quality assurance in use of nuclear technology in medical procedures. The requirements are even more relevant to new facilities that do not have adequate experience in the use of radioactive sources in medicine. The use of ionizing radiation in medical procedures is beneficial to human health, but compliance with appropriate requirements is necessary to ensure safe use and effectiveness of procedures. Medical practitioners must comply with relevant requirements and regulatory personnel must verify these aspects through established inspection and monitoring programs.

The reduction of doses is a key aspect of radiation protection but this is not always the best approach in medical applications. Radiation therapy requires high radiation doses to be effective. Fractionation should therefore be used in a manner that ensures effectiveness of procedures and patient protection. Diagnostic reference levels should be implemented in a way that not only ensures the diagnostic effectiveness of procedures but also considers patient protection. Optimization is therefore an important aspect when administering procedures. Selection of approach must be on a case-by-case basis with adoption of the approach that optimizes the benefit to the patient.

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