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PRELIMINARY DOSIMETRIC METHODOLOGY FOR A NEW COBALT-60 IRRADIATOR FOR RADIOINDUCED NECROSIS

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ABSTRACT

The use of ionizing radiation in medical procedures, as radiotherapy, is a well-established clinical process and it has been used for several decades with good clinical results and continuous technology development for treatment optimization. On the contrary, some injuries such as necrosis, may occur with patients, due to wrong administration of the absorbed dose or with expected side effects. To evaluate how these injuries could be investigated and how they can be treated, a new Cobalt-60 irradiator was developed to induce radionecrosis in mice. This irradiator is composed by a cylindrical size and it was set up with eleven Cobalt-60 sources aligned in the surface of a cylindrical lead. This alignment guarantees a small dose focal area in a longitudinal table, with proper frames for positioning mice precisely during the irradiations period. The dosimetric procedure will measure the absorbed dose in the dose focal area, delimited the area of irradiation with penumbra regions (gradients absorbed dose profiles) and others anatomical regions of the mice with high radiosensitivity. Possible dosimetric procedures and related devices will be present in this work. The obtained dosimetric data will be applied to ensure the accurate period of radiation of a given position. This preliminary study assures that the fundamental dosimetric process of this new Cobalt-60 irradiator and it predicates that dosimetric processes are feasible to be conducted.

1. INTRODUCTION

According the Directory of Radiotherapy Centers (DIRAC) database, from International Atomic Energy Agency (IAEA), there are approximately 14680 machines, including linear accelerators, Cobalt-60 irradiators and high dose rate brachytherapy sources (HDR), designed for radiotherapy treatment worldwide [1].

International and national quality assurances and security procedures should be rigorous on these radiotherapic machines, the aims of quality processes that could be highlighted are to guarantee high quality of the treatment, security for the all staff whom it realize the treatments and to minimize the possible or expected side effects on patients who undergo radiotherapy treatment [2-4].

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Radioinduced necrosis may be associated with late toxicities or errors, i.e., overdose, in the absorbed dose delivery on the anatomical local area to be treated. Effects of radioinduced necrosis may affect any irradiated tissue or surroundings. Absorbed dose thresholds for the necrosis to occur vary among patients and modalities of treatment. [5-9].

In order to study the behavior of the radioinduced necrosis, a new Cobalt-60 irradiator was projected to delivery accurate and precise absorbed dose that could be use for gamma irradiation of mice. As necrosis is linked with the total absorbed dose in the tissue, the cell damage caused by ionizing radiation will be helpful in understanding the main mechanisms that govern the necrosis. Afterwards, the research of tissues bank for the treatment the radioinduced necrosis will be enabled.

This work describes the main dosimetric procedures that could be applied to the new Cobalt-60 irradiator. The establishment of an accurate and precise dose profile of this device is important for research the absorbed dose level thresholds for a radioinduced necrosis. Otherwise, dosimetric characteristics of a new device must be investigated extensively, mainly because the lack of data for comparison purposes. The advantages and disadvantages of the dosimetric methods will be evaluated in order to choose proper methods for future measurements.

2. MATERIALS AND METHODS

2.1. New Cobalt-60 Irradiator

Fig. 1 shows a template of this irradiator. Eleven stainless steel Cobalt-60 encapsulated sources with activities ranging from 0.74 to 185 MBq (20 – 5000 μCi). These sources are positioned on the surface of a 4 cm lead layer in right cylinder format with 34 cm outer diameter and 30 cm inner diameter. Cobalt-60 sources are aligned to the center of the inner diameter. Stainless steel source capsules are 1 cm outer diameter cylinder with a 0.1 mm orifice that avoids large divergences of beam. Each source has an independent shield that closes the orifice when the source beam is off, which in turn, enables the control of the amount of absorbed dose in the irradiation region.

An acrylic longitudinal table is used to position the mice during the irradiations. This table was project as a “drawer” to optimize the accuracy of the positioning outside the cylinder. Top acrylic component of this table has a circular orifice with 4 cm diameter that enables the beam focus on directly on the anatomical surface. To achieve stability during the irradiations, acrylic spacers were developed to accommodate the mice body on the table. These spacers are suitable for a large range of mice anatomies.

In order to reduce drastically the radiation dose levels for staffs, the irradiator has two sets of 10 cm lead thickness over the Cobalt-60 capsule sources (Fig. 2). Each set avoids staff exposure and enables the source positioning and correctly alignment. Unidirectional lasers will be used for alignment Cobalt-60 capsules with the irradiation region on the top of acrylic table.

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Dose rates from 0.1 to 20 Gy.s^{-1} and irradiation fields up to 2 cm^2 can be achieved with the irradiator. The large range of dose rates allows a single absorbed dose or fractionated absorbed dose. As each Cobalt-60 capsule can be manually controlled, dose rate values will be chosen without difficulty.

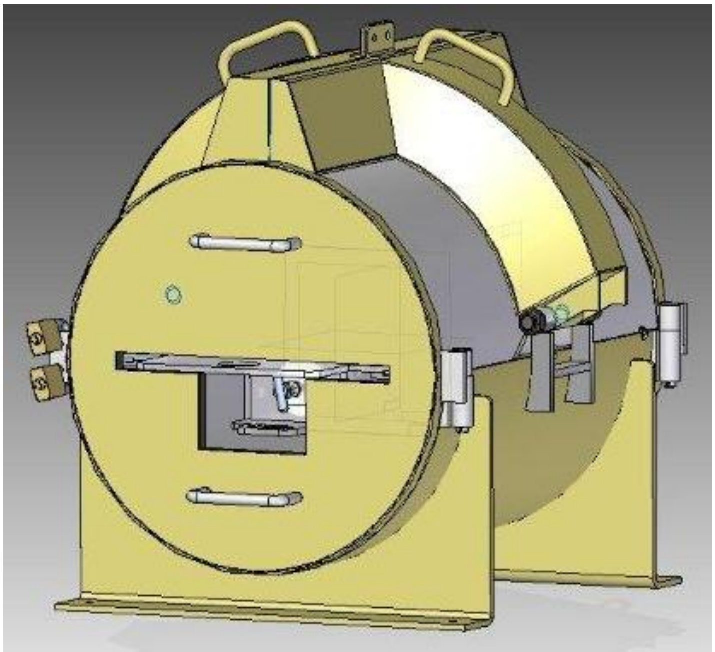

Figure 1. Perspective view of the Cobalt-60 irradiator.

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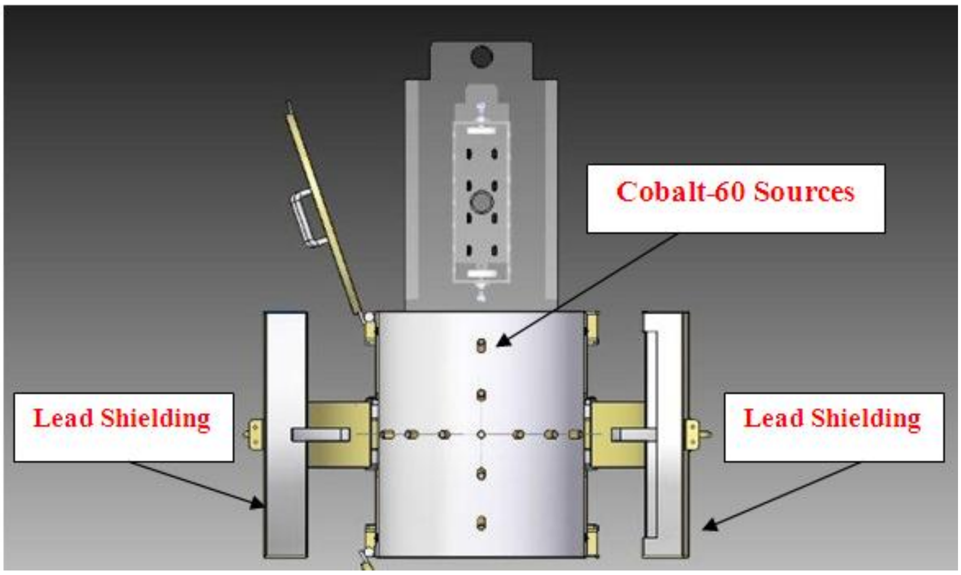

Figure 2. Top view of Cobalt-60 irradiator, in detail the Cobalt-60 sources and the sets of lead for staff radioprotection.

2.2. Absorbed Dose Measurements

To estimate the Cobalt-60 irradiator dose profile, two approaches will be used: experimental protocols and simulations via Monte Carlo algorithm. Comparisons between these two methods will determine better-absorbed dose values. Ionization chamber, radiochromic films and thermoluminescent dosimeters (TLD) will be used in the commissioning process and during the measurements (TLD).

In this work, specific models or designs of the equipments that should be used in the dosimetry of the new Cobalt-60 irradiator will not be defined in details; solely the general characteristic of these equipments will be reported. Monte Carlo algorithm should be used to estimative the absorbed dose profile and the scattering caused by the ionizing interaction within inner wall of the cylinder.

2.2.1. Ionization chamber

A calibrated ionization chamber will be used for the absolute measurements. For this “absoluteness”, the ionization chamber should be proper calibrated for Cobalt-60 beam, major contribution of two gamma rays with 1.17 MeV (99.85 %) and 1.33 MeV (99.98 %) [10]. Ionization chamber calibration will yield the responses in dose to water and dose in appropriate water equivalent materials protocols [11].

Thimble ion chambers and micro ion chambers should be used to measure the absorbed dose profile. Thimble ion chambers have a larger collection volume, yielding higher precision in

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the charge collected, in comparison with the micro ion chambers. However, micro ion chambers are more suitable to use for small fields and gradients on the penumbra region.

Build up cap for charged particle equilibrium conditions should be used for satisfy the basic dosimetric conditions. Acrylic phantoms will be applied to simulated mice volume geometries, as acrylic is water equivalent phantom well established correction factors should be implemented.

Primary and secondary scatterings should affect the ionization chamber responses. Secondary scatterings should be evaluated carefully, mainly to the dose contribution on mice undesired anatomical sites. To the primary and secondary scatterings behavior of the ionization chambers, Monte Carlo simulations will be used.

2.2.2. Radiochromic film

For two dimensional dose distribution of the Cobalt-60 beam in the irradiator, radiochromic films will be used. As radiochromic film is a self-development, nearly tissue-equivalent and little energy dependence. With the proper conditions applied, it is possible to measure the absorbed dose information [12]. High dose gradients and penumbra regions can be evaluated with radiochromic film.

Several previous studies, for radiotherapy applications, involving radiochromic films with small fields and non-reference beams were realized [13-15]. For images studies, scanners and algorithms are available to study the imaging characteristics. Radiochromic films present a certain degree of non-uniformity among different batches, due to marker-dye properties on the active layer of the film. For dose measurement purposes, this inherent characteristic could generate uncertainties on the absorbed dose output.

2.2.3. Thermoluminescent Dosimetry

Thermoluminescent dosimeters (TLD) are widely used for dose ionizing radiation measurements, mainly in radiotherapy and ambient dose measurement [16-18]. As the TLD are relative dosimeters reference calibrations beams are demanded [19]. In order to get lowest possible uncertainties, the absolute dose values will be measured with ionization chamber.

For the Cobalt-60 irradiator, TLD will be applied for *in-vivo* dosimetry and exit dose during the mice irradiations. TLD materials exist in several sizes and geometries, however for our application, the micro-cube TLD (1 mm^3) will be used, due to the size, this dosimeter could put into mice skin or other anatomical area. Lithium Fluoride doped with magnesium and titanium will be the thermoluminescent crystal applied for the measurements, however supralinear corrections should be applied for dose responses [20].

2.3. Monte Carlo Simulations

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Monte Carlo simulations will be used to comparisons with experimental trials and to evaluate situations where the experimental measurements are too complex to measure, as the absorbed dose contribution of the photons (or electrons) that underwent backscatter in the cylinder surface.

Ionization chamber corrections, TLD does responses, radiochromic films non-uniformity and Cobalt-60 beam divergence should be used to simulate using Monte Carlo algorithm. All these trials will take a longer time to perform them; however, with Monte Carlo algorithms only computer hours are demanded. MCNP™ and EGSnrc™ Monte Carlo algorithms will be used for compilation of the Monte Carlo algorithm [21-22].

2.4. Uncertainty analysis

Complete uncertainty analysis will be a complex text for this Cobalt-60 irradiator. The correlations between these uncertainties should be investigated for a complete analysis. Equation 1 shows the overall uncertainty (*k=1*) that will be obtained to the absorbed dose in the measurement area [23].

$$\sigma_{AD} = \left(\sigma_{IC}^2 + \sigma_{pos}^2 + \sum_{i=1}^{n} {}_n\sigma_{CF}^2 \right)^{0.5} \qquad (1)$$

Where: σ_{AD} = Overall uncertainty in the absorbed dose (Type A and Type B);
σ_{IC}^2 = Overall quadratic uncertainty on the ionization chamber measurements (Type A and Type B);
σ_{pos}^2 = Overall quadratic uncertainty on the positioning of the mice on acrylic table (Type A and Type B);
${}_n\sigma_{CF}^2$ = Overall quadratic uncertainties involving the *n* correction factors.

The aim of the uncertainty analysis is to achieve less than 4 % for the value σ_{AD} (*k=1*), assuming a Gaussian distribution. In principle, the correlations between the variables are not assumed, but after successive measurements our device should indicate the reasonable methods to account these correlations.

3. DISCUSSIONS

The new Cobalt-60 irradiator device will afford enough experimental information about radioinduced necrosis. To study dose level thresholds and biological effects, absorbed dose information must be accurate and precise to support the models that should be developed. A previous dosimetric analysis should avoid the waste time with the proper dosimetric methods and a better comprehension of the physical phenomenon.

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This preliminary analysis shows the methodology to develop a dosimetric profile of the Cobalt-60 irradiator. The characteristics of the main dosimetric devices that should be used at the new Cobalt-60 irradiator will provide the necessary information for the accurate absorbed dose measurements. Dosimetric methodologies and protocols with similar devices, such as small animal and gamma knife irradiators, are realized in order to obtain theoretical and experimental comparisons [24-25].

Real time measurements should be done to guarantee the dose prescription during the irradiations. Optically stimulated luminescence (OSL) and MOSFET dosimeters should be evaluated to be applied in the new Cobalt-60 irradiator, the complications arise mainly for the small fields that will be delivered to the target ($< 2\ cm^2$) and attenuation on the irradiation area (shadow effect) caused by the dosimeter size [26-27].

Absorbed dose irradiations should be measured to account the dose from transit dose (table movement before and after irradiations, i.e. mice positioning). The transit dose will be more pronounced for irradiations with highest dose rates. Accurate measurements with the dosimetric methods that will be used for the dosimetry will be done to quantify the transit dose.

4. CONCLUSIONS

The dosimetry procedures for the new irradiator Cobalt-60 for radioinduced necrosis research were presented. Experimental and simulated results will yield accurate and precise absorbed dose measurements to be used for mice irradiation. Dosimetric methods well-established from other radiotherapy techniques will be applied to achieve the lowest uncertainties in the Cobalt-60 irradiator absorbed dose results. Experimental and simulated results obtained from the dosimetric methodology described in this work are being held.

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