USE OF MAGIC GEL FOR DIAGNOSTIC NUCLEAR MEDICINE DOSIMETRY

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Dosimetry using polymer gel is a promising technique used by medical physicists to check the spatial distribution of the dose delivered by radiation techniques. In this study, MAGIC gel was used as a dosimeter in nuclear medicine. Different amounts of Tc-99m solution were mixed with the polymer gel in six glass vials. The normoxic MAGIC gel was used to study its sensitivity to unsealed sources, the range of radioactivity introduced in the polymer gel is between 0 and 666 MBq. MRI was used to evaluate the response of the polymer gels after the radioactive decay of the radionuclide. D dose is calculated using the formalism of MIRD. Preliminary results of this work were used to study the effect of low energies on the polymerization rate, and to establish a relationship between the absorbed dose and the activity of radioactive sources considered based on the calculated values of the polymer gel T2.

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1. Introduction

Radiation therapy plays an important role in the treatment of various cancers. To avoid overexposure or underexposure of patients and treat the tumor at best, a preliminary dosimetric simulation is essential before any irradiation. Dosimeter techniques used in the external radiotherapy (ionization chamber, radiological film, thermo luminescent detectors, diodes, ...) are not adapted to the dosimetry using radionuclides in nuclear medicine.

In nuclear medicine, the therapeutic administration of the radiopharmaceutical to the patient is orally or intravenously. Radiopharmaceuticals are vectors having affinity for a target organ of interest. They consist of a molecule associated with a radionuclide or radionuclide simply only when it has a selective tropism. Unlike external beam radiotherapy, dosimetry in

targeted radionuclide therapy has no standard method easily applied systematically, and because of that, one needs to use dosimetry methods to get to know the dose.

Dosimetry of radionuclides in nuclear medicine requires first quantification of the SPECT images obtained or PET. This quantification is corrected for the accumulated value of the activity of the administered isotope in the target organ. The estimate of the dose depends on the physical and biological half-life of the radionuclide [1], and the size of the patient's target organ. However, the evaluation of the administered dose remains approximate and still in progress research.

The dosimetric gel is based on the radiation-induced polymerization of monomers, which is spatially fixed through the matrix of gelatin [2]. When the gel dosimeter is irradiated, the radiolysis process starts immediately, water molecules are separated into several highly reactive radicals and ions [2]. The number of created reactive free radicals is directly proportional to absorbed dose. A polymerization process is then induced by the free radicals, and the polymer molecule continues to grow through chain propagation reactions [3]. The amount of polymer formed is proportional to the absorbed dose.

The polymer gel is a relative dosimeter that has many potentialities. It can verify the spatial dose distribution using an imaging modality [4–6], it is tissue equivalent, malleable and dose integrator [2]. These features make it sparked an interest in studying its response to unsealed sources.

The formula of the gel MAGIC (Methacrylic and Ascorbic Acid in Gelatin Initiated by Copper) has removed the obstacle of making polymers gel in an anoxic atmosphere by introducing an antioxidant, adding it in the gel solution binds to the oxygen and prevents free radical scavenging consequently [7]. This type of gel is called normoxic for handling ambient air.

Magnetic Resonance Imaging (MRI) can measure 3D dose information in a polymer gel [4]. Indeed, the radiation-induced polymerization increases the viscosity of the solution which results in an increase in the transverse relaxation rates R_2 ($R_2 = 1/T_2, T_2$ is transverse relaxation time). Research work performed in external beam irradiation shows that R_2 varies depending on the absorbed dose in a linear relationship of the type $R_2 = \alpha D + R_{20}$ [8], where R_{20} is the relaxation rate prior to irradiation and α is the sensitivity of the gel. R_2 is considered as the rate of polymerization. Under these conditions, the radical polymerization kinetics is based on an instantaneous production of free radicals, the quantity is a function of the dose. External irradiation is not suitable to describe internal radiation, because it is a prolonged irradiation with a low-dose rate.

Promising research on polymers gels dosimetry using radionuclide sources has shown a relationship between the transverse relaxation rates R_2 and the absorbed dose [9–13].

This work aims to describe the feasibility of using the polymer gel MAGIC [7] as a dosimeter in nuclear medicine imaging. In this study, we used the technetium-99m (Tc-99m) as an internal source uniformly distributed in the volume of MAGIC polymer gel dosimeter. The radiation dose from different activities of the radionuclide was measured by analyzing the radiation-induced change in the gels with MRI.

2. Experimental set-up

2.1. Gel composition and preparation

The gel composition consists of methacrylic acid (Across, Organics), gelatin (300 bloom, Sigma Aldrich), deionized water, ascorbic acid (Sigma Aldrich), hydroquinone and sulfate of copper $Cu_2SO_4 \cdot 5\,H_2O$. The MAGIC polymer gel [7] was manufactured under normal atmospheric conditions. The percentage of the mixtures is summarized in Table I.

TABLE I

Chemical composition of MAGIC polymer gel.

Compound	Concentration
Gelatin	8%
Methacrylic acid	9%
Ascorbic acid	0.0352%
Copper sulphat	0.002%
Hydroquinone	0.2%
Deionized water	82.8%

The MAGIC polymer gel was prepared following the method described by Fong *et al.* [7]. Gelatin was mixed with deionized water and then heated to 50°C using a magnetic stirrer until a clear solution was obtained. At this point, hydroquinone solution was added and the solution was allowed to cool. After further cooling to 38°C, solutions of the ascorbic acid and copper sulphate were added. The whole solution was allowed to mix for a further 2 min before the methacrylic acid was added, and continuously stirred until the monomer was completely dissolved (Fig. 1).

The gel was dispensed into six prepared glass vials. Each vial contained 10% solutions of Tc-99m in deionized water with initial activities ranging from 0 to 666 MBq. Each vial was then gently shaken for 5 min, ensuring an even mix of solution and stored behind a lead shield. To remove any air trapped in the vials, castor oil was later added, filling the vials to the top.

2.2. Dose calculation

We can estimate the mean absorbed dose D for the gel self-irradiation from the technetium by the Medical Internal Radiation Dose (MIRD) scheme [14], using the following equation:

$$D = \frac{\tilde{A} \sum_i n_i E_i \Phi_i}{m}, \tag{1}$$

where $\tilde{A}$ is activity accumulated, E_i is the mean (or individual) energy emitted per nuclear transition, N_i is number of its nuclear transitions per nuclear transformation, and Φ_i is the absorbed fraction.

Cumulated activity $\tilde{A}$ was calculated with the following equation:

$$\tilde{A} = A_0 \int_0^t e^{-\frac{\ln 2}{T} t} dt, \tag{2}$$

where A_0 is the initial activity, t the time post-preparation that scanning took place, and T is the half-life (the half-life of Tc-99m is 6.02 hr [14]).

TABLE II

Decay data for Tc-99m [14].

Emission type	Mean energy [MeV]	Frequency
ce-M e^-	0.0016	0.7460
Auger-L e^-	0.0022	0.1020
Auger-K e^-	0.0155	0.0207
ce-K e^-	0.1195	0.0880
ce-K e^-	0.1216	0.0055
ce-L e^-	0.1375	0.0107
ce-L e^-	0.1396	0.0017
ce-M e^-	0.1400	0.0019
ce-N+e^-	0.1404	0.0004
ce-M e^-	0.1421	0.0003
L X-ray	0.0024	0.0048
K_{α_1} X-ray	0.0183	0.0210
K_{α_2} X-ray	0.0184	0.0402
K_{α_1} X-ray	0.0206	0.0120
γ	0.1405	0.8906
γ	0.1426	0.0002

The delivered doses were calculated for a homogeneous distribution of Tc-99m in 10 ml of gel dosimeter. For this, we have assimilated the gel tubes of the same volume spheres. The absorbed fraction of penetrating

emissions from Tc-99m were taken from Stabin publication [15], absorbed fraction of non-penetration fraction from Tc-99m is ⊘ = 1.Tc-99m decay data (Table II) were taken from the Brookhaven National Laboratory data source [14, 16].

2.3. MRI scanning

The gel vials were left for 5 hours in scanning room to attain uniform thermal equilibrium. MRI images were made 75 hours after irradiation. The gel vials were placed in a head coil of Philips Intera 1.5 T MRI scanner (Fig. 1). The multi slice spin-echo method was used with these parameters: echo time TE = 50–800 MS; repetition time TR = 2000 MS; slice thickness = 5 mm; pixel size = 0.78 mm × 0.78 mm^2 and matrix size = 256 × 256. The transverse relaxation rates ($R_2 = 1/T_2$) value of each vial was determined by circular region of interest (ROI) in images. The ROI was drawn inside the gel in order to avoid inconsistencies in the data from the effects of the glass edges of the vial. The mean signal intensity in a region-of-interest defined in each tube was extracted along the echo times. The transversal relaxation rate was calculated by fitting these mean intensities to a single-exponential decay. We report the R_2 value for each tube and the standard deviation from the fitting. The relaxometry procedure is used to correlate R_2 with absorbed dose [2, 11, 12, 17].

Fig. 1. Gel preparation (left, middle), irradiated vial in MRI scan (right).

3. Results and discussion

The images obtained by MRI (Fig. 2) allowed us to study the variations of signal intensity depending on the activity in the vials. The intensity of the signal for each vial was used to evaluate transverse relaxation rates R_2. R_2 depends on the polymerization rate, the polymerization rate depends on the amount of radioactivity introduced in the vial and absorbed dose. Figure 3 shows the calibration curve of the gel MAGIC R_2 to the absorbed

dose and T_2 to activity. These values also show that the MAGIC gel is sensitive to prolonged irradiation Tc-99m over several hours and this sensitivity is quantifiable. Note that the value of the transverse relaxation rates R_2 increases with the dose absorbed linearly with a sensitivity of 0.31 $\mathrm{Gy}^{-1}\mathrm{s}^{-1}$, and the correlation coefficient of plot was 0.995.

Fig. 2. MRI slices images of irradiated tubes.

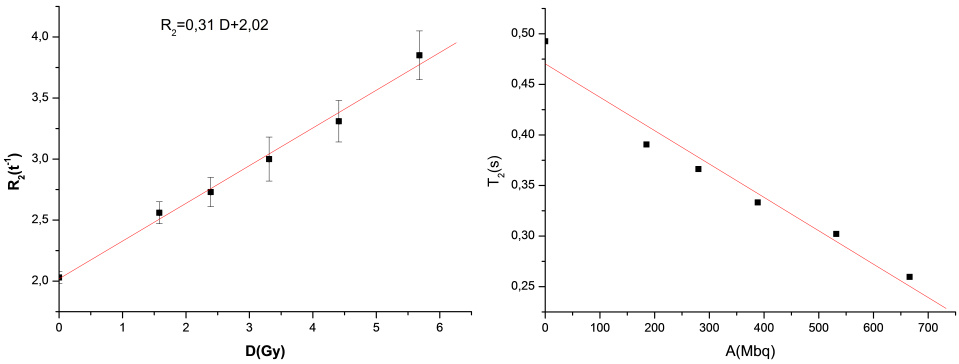

Fig. 3. R_2 as a function of absorbed dose (left) and T_2 as a function of activity (right).

Furthermore, the values of this activity correspond to absorbed doses of between 0 and 5.68 Gy. Analysis of errors in gel dosimetry has been performed, calculation of the dose error is at most 1.5% and the standard deviation of R_2 is less than 6%. As the absorbed dose was quantified using MIRD formalism, this quantification is based on a geometrical approximation and MAGIC gel is assimilated to water (relative density of gel MAGIC is 0.94), the future work will be to determine absorbed dose using Monte Carlo simulation.

4. Conclusion

The results obtained in this work show that the gel MAGIC is sensitive to prolonged irradiation Tc-99m. In addition, the sensitivity is expressed by a polymerization rate which varies proportionally with the activity mixed with the gel. These preliminary results regarding the use of MAGIC gel Diagnostic Nuclear Medicine show that it is quite possible to be used as a dosimeter.

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