MAGIC-\(f\) Gel in Nuclear Medicine Dosimetry: study in an external beam of Iodine-131

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Abstract. MAGIC-\(f\) gel applicability in Nuclear Medicine dosimetry was investigated by exposure to a \(^{131}\)I source. Calibration was made to provide known absorbed doses in different positions around the source. The absorbed dose in gel was compared with a Monte Carlo Simulation using PENELOPE code and a thermoluminescent dosimetry (TLD). Using MRI analysis for the gel a R2-dose sensitivity of 0.23 s\(^{-1}\)Gy\(^{-1}\) was obtained. The agreement between dose-distance curves obtained with Monte Carlo simulation and TLD was better than 97% and for MAGIC-\(f\) and TLD was better than 98%. The results show the potential of polymer gel for application in nuclear medicine where three dimensional dose distribution is demanded.

1. Introduction
The use of radionuclides for cancer treatment led to new area of radiotherapy that is known as: targeted radionuclide therapy (TRT). This area requires specific dosimetric studies; from the theoretical point of view one possibility is to use Monte Carlo Simulation and experimentally this task can be accomplished by dosimeters, among these, polymer gel dosimetry is a relatively new method for 3D dosimetry with potential for TRT that has only a few applications in nuclear medicine [1].

On the other hand Monte Carlo (MC) Simulation is one of the most used tools assisting TRT dosimetry. The use of MC simulation codes in nuclear medicine could be more accurate through the combination with data from the Medical Internal Radiation Dosimetry (MIRD) [2]. The combination of the radiation transport in matter made by the PENELOPE code [3] and the biological information given by MIRD would make this kind of tool widely used in TRT.

Specific calibration procedures are required in nuclear medicine dosimetry considering that life times are short leading to source activity decay in a time compared with the exposition time, a situation completely different when compared with other sources used in radiotherapy consequently the dose rate also changes drastically over time. In this way, polymer gel dosimeters could be a feasible option because they are able to integrate dose in time without fluency dependency [5].

An experimental dosimetric study using \(^{131}\)I was reported where the radionuclide was added during the gel manufacturing, getting a transversal relaxation rate (R2) value as function of the dose [4]. Our study sought to determine a relationship between R2 value and dose for an external beam, investigating the dose-response of MAGIC-\(f\) dosimetry for a radiotherapy treatment using \(^{133}\)I source.
2. Materials and Methods
Irradiation procedures were performed in the Nuclear Medicine Service (NMS) of the Hospital and Clinics of the School of Medicine of Ribeirão Preto (FMRP).

2.1. Irradiation process
In this work an iodine-131 solution with 1110 MBq of initial activity was used, the initial volume as delivered by the radionuclide supplier was diluted in final volume of 5 mL of 0.9% saline solution. Thermoluminescent dosimeters (LiF-100) were positioned radially in front and behind the gel tubes to provide dose comparisons.

Irradiation geometry was made aiming the study of gel response in an external iodine-131 irradiation. The gel tubes and TLD were positioned in the experimental arrangement shown in Figure 1. A and B regions are symmetrical to each other and this geometry was used to study the gel dose-response with the distance and to have two measurements and estimate the uncertainty, their standard deviation. C region was used to calculate the attenuation coefficient for the MAGIC-f to $^{131}$I. With this set up an efficient use the exposure time could be attained.

Figure 1: Experimental arrangement for gel and TLD irradiation in $^{131}$I source. (A) and (B) study regions were designed to obtain the dose-response with the distance and uncertainties and (C) study region to obtain the attenuation coefficient.

2.2. Gel Manufacturing
The following composition was used for preparation of 50 ml of gel: 4.1 g of Bovine Skin Gelatin (300 Bloom), 17.6 mg of Ascorbic Acid; 2.95 g of Methacrylic Acid; 1 mg of Cooper Sulphate; 1.5 ml of Formaldehyde solution with 30% concentration stabilized in 10% of Methanol and 40.50 ml of Water Deionized [6]. The gel was stored in rubber capped glass tubes previously conditioned with a soft vacuum, commonly used for blood collection, and kept in a refrigerator at 10º during 24 hours before irradiation.

2.3. Magnetic Resonance Measurements
The gel imaging was performed in a Philips Achieva 3.0T Magnetic Resonance Imaging (MRI) Scanner, using the head coil and a multi spin echo sequence with 16 equidistant echoes, TE (echo-time) of 15-240 ms and TR (repetition-time) of 6000 ms, pixel size of 0.5 mm and a slice thickness of 2 mm. The slice position was select in order to avoid oxygen contamination effect in the image. The
mean signal intensity in a region-of-interest defined in each tube (Figure 1) 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 R2 value for each tube and the standard deviation from the fitting. The relaxometry procedure is used to correlate R2 with absorbed dose [7].

2.4. Monte Carlo Simulation
The virtual source and geometry studied were faithfully represented in PENELOPE code. Photon energies considered for $^{131}$I were 284.3 keV(6.2%), 364.5 keV(81.6%) and 606.0 keV(7.2%). The primary activity was $1.11 \times 10^9$ particles/s, simulating exactly the experimental source activity. Gel material was described in PENELOPE with the following weight fractions: $w_H = 10.62$, $w_C = 7.51$, $w_N = 1.39$, $w_O = 80.21$, $w_S = 2.58 \times 10^{-3}$ and $w_{Cu} = 5.08 \times 10^{-4}$. A previous work have already shown the equivalence of this simulated gel to the experimental one [8].

3. Results and Discussion
Simulated data were first compared to TLDs measurements to validate the geometry, material and source conditions. Figure 2-a presents absorbed dose values in different positions obtained with TLDs and simulated with PENELOPE. Calibration was made using an iodine-131 source with 962.6 MBq of activity with an irradiation time of 2 hours, the TLD where in air during irradiation and backscattering radiation was produced by water present inside the tubes. The concordance between these data ranged from 95.7 to 98.5%, with a maximum difference of 3%, thus a simulation was used to calibration the MAGIC-f gel.

![Figure 2](image)

**Figure 2:** Absorbed dose using the geometry described in the Figure 1-a,b. (a.) relationship among absorbed dose in TLD and MC. (b.) relationship with R2 signal and distance from the source.

Figure 2-b presents the R2 value as a function of the distance from the source; it is possible to observe the agreement with the inverse square law, to a source activity of 1110 MBq. The same relation is represented in Figure 1-a, it is possible to observe a similar behavior between the both figures.

The range of dose predicted by Monte Carlo simulation for 14 hours of irradiation is 1.12 to 5.62 Gy, for 2 hours of irradiation the range of dose was 0.16 to 0.80 Gy. Figure 3 shows the linearity response obtained with gel MAGIC-f, sensitivity was 0.12 s⁻¹Gy⁻¹ for low doses, obtained with 2 hour irradiation and 0.22 s⁻¹Gy⁻¹ in the 14 hours irradiation. The intercept of the fitted line at zero dose shows the R2 of non-irradiated gel samples of 1.11 s⁻¹ with a standard deviation of 0.1 s⁻¹.
The R2 signal for 2 hours of irradiation demonstrated that the experimental geometry and the short time of irradiation do not contribute to a stable polymerization process, probably because of oxygen contamination. Another study [4] demonstrated that for a low dose rate, the polymerization process is stable, but with an internal irradiation of the gel and a long time of irradiation condition what was different from the conditions used in the present work.

![Figure 3](image1.png)

**Figure 3:** MAGIC-f sensitivity to Iodine-131 for 2 hours (Dose $\leq$ 0.60 Gy) and 14 hours of irradiation.

![Figure 4](image2.png)

**FIGURE 4:** Relaxation rate $R_2$ of the gel as function from the distance from the source.

Relaxation rates $R_{2}\text{dose}$ distribution obtained along different distances in the polymer gel tubes at 14 hours exposure can be seen in Figure 4. This data was obtained with the arrangement show in Figure 1-c and into each tube 5 array of 3x5 pixel for each point in the Figure 4 were made. The attenuation coefficient for MAGIC-f was 1.28 cm$^{-1}$ for an iodine-131 source, other studies are being studied at the present to more precisely determine the attenuation coefficient for MAGIC-f.
4. Conclusion

The results obtained agree well with reference values adopted in this work. MAGIC-f gel presents an adequate sensitivity for $^{131}$I dosimetry, demonstrating the great ability of polymer gel in the study of TRT. This ability of gel includes the study of dose distribution in specific region, contributing as an accurate experimental tool to confirm the dose distribution simulated by Monte Carlo.

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