Monte Carlo Simulation of MAGIC-f gel for Radiotherapy using PENELOPE

M Alva¹, T Pianoschi¹, T Marques¹, M Santanna M², O Baffa¹ and P Nicolucci¹

¹Department of Physics and Mathematics, University of São Paulo, Av. Bandeirantes 3900 CEP:14010-901- Ribeirão Preto – SP – Brazil.

²Hospital of Cancer at Barretos (HCB), Av. Antenor Duarte Villela – 1331, CEP: 14784- 400, Barretos – SP –Brazil.

E-mail: alva_mirko@yahoo.com.br

Abstract. MAGIC-f gel has been shown as a suitable dosimeter for different techniques in radiotherapy due to its characteristics of water equivalence (effective atomic number of 7.41) and a spatial resolution better than 1mm. One way to predict the gel results is the use of simulations through PENELOPE Monte Carlo code. This simulation code was used to simulate the MAGIC-f gel and its use for dosimetry in conventional and conformal radiotherapy. The results obtained from the simulation were compared with experimental values. Comparisons from simulation and experimental values show mean differences of 2.88 % and 3.75% for conventional and conformal, respectively. This study shows that PENELOPE code can be simulate the components of the MAGIC-f gel to study and predict the gel response.

1. Introduction

Dosimetry based on polymeric gel has been widely investigated in radiotherapy since it allows the verification of dose distributions [1-2]. Due to its capability of detecting high dose gradients with high spatial resolution, MAGIC-f gel has been shown as an accurate tool in 3D dosimetry [3-4]. A way to study and predict MAGIC-f gel results is the use of computational simulation as the Monte Carlo method. From the codes more commonly used in radiotherapy PENELOPE Monte Carlo code presents the advantage of using a mixed algorithm for the simulation of photons- electrons cascades [5-7]. This code allows the “construction” of materials trough the use of the compound’s chemical composition (i.e., elements present and stoichiometric index, or weight fraction, of each element), mass density, mean excitation energy and energy and oscillator strength. The aim of this work was to use PENELOPE to simulate MAGIC-f gel dosimetric properties and to provide a valuable enhancement in the pre-constructed list of materials from PENELOPE. For validation the simulated material file (MAGIC-f.mat) the percentage depth doses (PDD) curves and a dose distribution were used, comparing experimental values obtained with MAGIC-f gel dosimeter and simulated results.

2. Materials and methods

The components of MAGIC-f gel (water, gelatin, methacrilic acid, copper sulfate, ascorbic acid and formaldehyde) and its characteristics, like atomic number, density and molar mass, were input into the PENELOPE 2008 code [8] to build the MAGIC-f.mat and water.mat material files and for the
simulation of PDDs and the conformal treatment. The simulations used $2 \times 10^9$ primary particles and 0.01mm$^2$ pixel size.

For the measurements, MAGIC- $f$ gel dosimeter was prepared following the description by Fernandes [3]. Relaxometry, weighted in T2, with a 3.0 T, NMR Philips tomography and head coil were used for the readings of the gel samples, which were perpendicularly positioned to the head coil. The images were acquired with a multi spin-echo sequence with 16 echo times, TE=20ms, TR=4000ms, matrix of 256 x 256 pixels, slices of 3mm thickness and 150 mm of FOV. The MR images were processed and analysed with a software developed in MatLab®, that produces R2 maps.

2.1 Percentage depth doses and dose distribution
Simulated PDDs were used to evaluate the MAGIC-$f$.mat constructed by the code. Simulation conditions were 10 x 10 cm$^2$ field size and 100 cm source-skin distance (SSD) for photon beams of 6 MV and 10 MV and phantoms of 30 x 30 x 20 cm$^3$ “filled” with both simulated materials.

Experimental PDDs were determined using MAGIC-$f$ gel and ionization chamber (IC) of 0.6 cc for 6 MV and 10 MV beams. The measurements with the gel were performed using glass tubes of 16 cm length and 1 cm diameter filled with gel. The irradiations were carried out using PPMA cube filled with water and the glass tubes positioned in the center of the volume. A dose of 10 Gy in conventional irradiation conditions for both beams was used.

For the measurement of a coplanar dose distribution, the gel was poured into a PPMA cylindrical phantom of 10 cm diameter and 15 cm height. The irradiation of the phantom was made with 5 fields of 1 x 1 cm$^2$, with a Varian 2100 linear accelerator gantry angles of 0°, 45°, 90°, 135° and 180°. The target was chosen in the center of the cylinder, at 100 cm SSD. The phantom was irradiated with 10 MV beam with 2 Gy per field. The conformal irradiation was simulated using PENELOPE code in the same irradiation conditions. Both distributions were also compared through the dose profile.

3. Results and Discussions
3.1 PDDs and dose distribution
Figure 1 shows the PDDs through the simulations and from experimental measurements, showing them similar behavior. A maximum difference of 1.93% and 1.88% was found for the 6 MV and 10 MV beams, respectively, when simulated PDDs with MAGIC-$f$.mat and water.mat are compared.

![Figure 1](image)

**Figure 1.** PDDs for water and MAGIC-$f$ simulated with PENELOPE and experimental values for (a) 6 MV beam and (b) 10 MV beam.

For the 6 MV beam, a comparison between experimental gel and water (IC) shows a maximum difference of 3.20% until 10 cm depth. Beyond 10 cm the maximum difference is 5.72% in 12.5 cm. The same comparison was performed for the 10 MV beam and a maximum difference of 1.93% was found until 10 cm depth and of 2.62% at 14 cm depth.
The maximum differences between experimental and simulated values are 1.46% (0.5 cm depth) and 4.3% (17 cm depth) for 6 MV beam. Maximum differences of 2.14% (1 cm depth) and 3.8% (18 cm depth) were found for the 10 MV beam.

The study of conformal dose distributions for 10 MV using 5 fields was performed through simulation using MAGIC-f.mat, shown in the figure 2.a. and experimentally using MAGIC-f gel dosimeter as shown in the figure 2.b.

Figure 3 shows the dose profiles obtained from both distributions.

![Figure 2](image1.png)

**Figure 2.** Dose distribution for 10 MV obtained with: (a) PENELOPE; (b) MAGIC-f dosimeter.

![Figure 3](image2.png)

**Figure 3.** Dose profiles of simulated and experimental distributions.

A maximum difference of 0.5% in a radial distance of 0.55 cm inside the field (approximately half the irradiation field) was found and beyond that distance the differences between the dose distributions are less than 7%.

4. **Conclusions**

The simulations using PENELOPE-Monte Carlo code showed similar behaviors with the experimental values. Although discrepancies were found, specifically in the dose distribution in regions of low doses, this study shows that the code can be used to simulate the components of the MAGIC-f gel for these energies. Moreover, the MAGIC-f.mat file can be useful for studies of response and comparison of the gel.

**Acknowledgments**

This work was partially supported by CAPES. We are thankfully to the personnel from the Cancer Hospital of Barretos and the Hospital of Clinics from Ribeirão Preto. The technical support from J. L. Aziani is also appreciated.
References

[1] De Deene Y, Hurley C, Venning A, Vergote K, Mather M, Healy B J and Baldock C 2002 Phys. Med. and Biol. 47 3441-63

[2] Gustavsson H, Karlsson A, Back S A J, Olsson L E, Haraldsson P, Engstrom P and Nystrom H 2003 Med. Phys. 30 1264-71

[3] Fernandes J, Pastorello B, Araujo D and Baffa O 2008 Phys. Med. Biol. 53 N53-N58

[4] Alva M, Marques T, Schwarche M, Gonçalves L R, Baffa O and Nicolucci P 2009 IFMBE Proceedings. 25 248-251

[5] De Vlamynck K, Palmans H and Verhaegen F 1999 Med. Phys. 26 1874-82

[6] Yamamoto T, Mizowaki T and Miyabe R 2007 Phys. Med. Bio. 52 1991-2008

[7] Sempau J, Acosta E and Baró J 1997 Nucl. Instr. and Meth. B. 132, 377-390

[8] Salvat F, Fernández-Varea J and Sempau J 2008 (Moulineaux, France: Nuclear Energy Agency OECD/NEA)