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Evaluation of polymer gels using Monte Carlo simulations

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ABSTRACT

The use of Monte Carlo simulations in dosimetry is a well established area of research, and several correction factors, for ionization chambers, were evaluated with these simulations. Some simulated values were considered even more reliable than the experimental measurements. Besides these uses with ionization chambers, Monte Carlo simulations may also be employed in the development and characterization of new dosimetric materials, as polymer gels. They are largely employed in radiotherapy dosimetry to mimic human tissue. New polymer gels were studied in order to better represent different organs or tissues, to provide more reliable results, or even to use different measurement techniques. The objective of this study was to evaluate the dosimetric properties of polymer gels, in relation to its mass-energy absorption coefficients, energy response and tissue equivalence. For this purpose the MCNPX Monte Carlo code was utilized. Three different materials, employed in radiotherapy dosimetry were evaluated in this work: MAGAS, MAGAT and AMPS. For all simulations carried out, the values were within an acceptable uncertainty and in accordance to the expected results.

1. Introduction

During the last decades gel dosimetry has increased rapidly. The main reason for its use is related to its properties, such as: good accuracy, 3D nature, high resolution and low energy dependence (Ibbott, 2004). These characteristics are very important for medical dosimetry, where the uncertainties must be small. In this scenario, gels are very useful in radiation therapy dosimetry, especially in situations where conventional dosimeters (ion chamber, TLD, OSL) are not suitable.

Another important tool in dosimetry is the Monte Carlo simulation. One of the applications, for example, is to determine the correction factors of ionization chambers (Perini et al., 2013). Some correction factors cannot be determined experimentally, and this characterization is carried out with Monte Carlo simulation. For cases where the experimental evaluation is possible, the simulation presents more precise results. It may also be applied to the determination of the quality dependence factor of different TL materials, in photon and electron beams (Mobit et al., 1998).

Observing the fact that the gel dosimetry is well used in radiation dosimetry, in this work, new polymer gels were studied in order to better represent different organs or tissues, to provide more reliable results, or even to use different measurement techniques. The objective of this study was to evaluate the dosimetric properties of polymer gels, in relation to their mass-energy absorption coefficients (μ_{en}/ρ), energy response and tissue equivalence.

2. Materials and methods

The MCNPX Monte Carlo code was used to evaluate the materials. Three different materials, employed in radiotherapy dosimetry were evaluated in this work: MAGAS (methacrylic acid gelatine gel with ascorbic acid), MAGAT (methacrylic acid gelatine and tetrakis) and AMPS (2-acrylamido-2-methylpropane sulfonic acid). To determine the μ_{en}/ρ of the compounds, in this work, a virtual polymethyl methacrylate (PMMA) phantom with external dimensions of (30×30×30) cm^3 and 1.5 cm thickness in the walls and filled with water was used. Furthermore, to avoid edge effects, dosimeters were placed at the center of the phantom. A plastic tray with 50 holes (1 cm^2 area and 1 mm depth each) was positioned in the phantom. These holes accommodated the dosimetric materials. Fig. 1 shows the virtual PMMA phantom and the direction and distribution of the photons between the source and the phantom.

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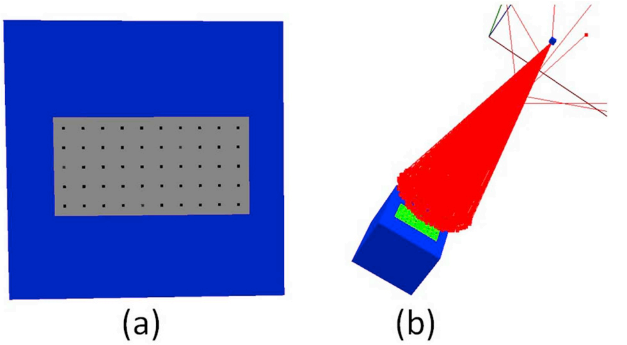

Fig. 1. Virtual PMMA phantom with water and a plastic tray placed on it. In (a) the 50 colored circles represent the holes where the TLD were positioned. In (b) the phantom positioned under the source is presented.

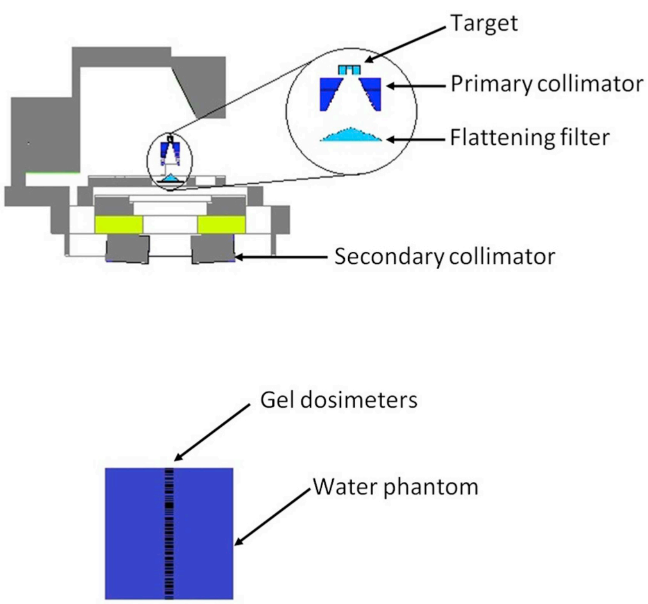

Fig. 2. Main components of the LINAC Varian 2100c and water phantom with the gel dosimeters inserted.

Table 1
Chemical composition and density of the materials used in the present study.

Polymer gel	Chemical elements (%)							Density
	H	C	N	O	S	P	Cl	(g/cm^3)
MAGAS	10.47	8.44	1.15	79.84	–	–	–	1.038
MAGAT	10.45	8.54	1.15	79.28	–	0.15	0.17	1.032
AMPS	10.76	6.8146	2.1456	81.606	0.464	–	–	1.045

All dosimeters present dimensions of (3.3×3.3) mm^2 and 0.9 mm thickness. For the simulations, the dosimeter tray was located at 1 cm below the surface of the phantom, and at 100 cm from the radiation source. In this simulation, a photon point source emitting radiation isotropically at a solid angle specified by the field size was used. The radiation sources used were photons, with energies of 0.02–20 MeV, including a 6 MV LINAC (Varian 2100c), ^{60}Co, ^{131}I, ^{137}Cs and ^{192}Ir, which are normally employed in medicine. A (10×10) cm^2 field size and a Source Surface Distance (SSD) of 100 cm were utilized.

In the MCNPX code, information collected during the radiation transport process is recorded using a variety of records, called "tallies". In this study, *F8 (in MeV/particle) and +F6 (in MeV/g/particle) tallies were used, which represent, respectively, the mean energy deposition

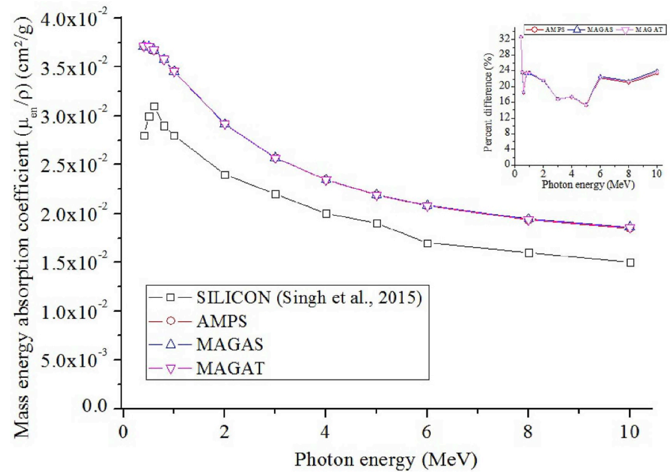

Fig. 3. Comparison of the μ_{en}/ρ (cm^2/g) coefficients, obtained in this work, and the values of silicon (from the work of Singh et al. (2015)) for 0.410 MeV photon energy. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

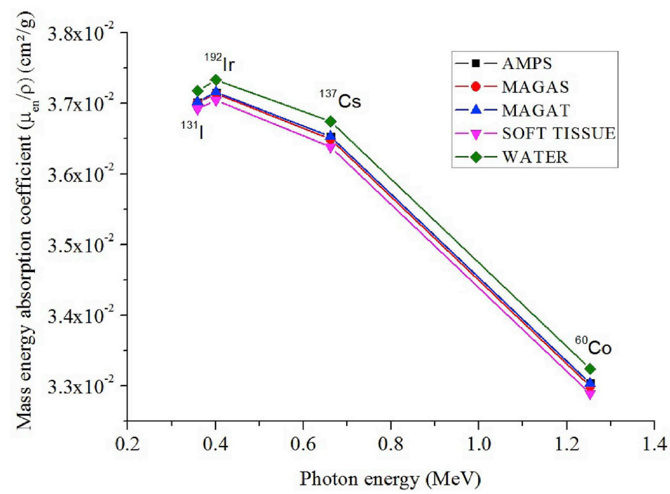

Fig. 4. μ_{en}/ρ for the gel dosimeters simulated in this work. The data were normalized for each radioactive source with mean effective energy ^{137}Cs (0.662 MeV), ^{60}Co (1.25 MeV), ^{131}I (0.359 MeV) and ^{192}Ir (0.401 MeV).

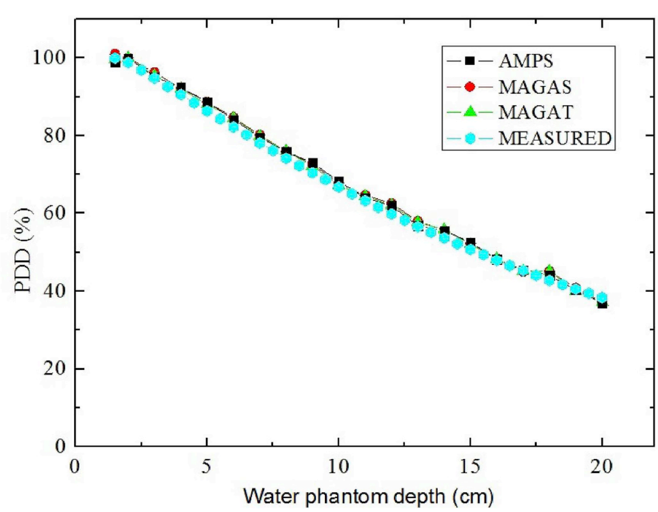

Fig. 5. Comparison among the simulated and measured PDD values. In this comparison a 6 MV beam was employed.

Table 2
Relative difference among the results determined with the MCNPX Monte Carlo code and the experimental measurements.

Depth (cm)	MAGAS (%)	MAGAT (%)	AMPS (%)	Depth (cm)	MAGAS (%)	MAGAT (%)	AMPS (%)
1.5	−1	0	1	11	−2	−2	−1
2	−1	−1	−1	12	−4	−4	−3
3	−1	−1	0	13	−2	−2	0
4	−2	−2	−2	14	−3	−4	−3
5	−3	−2	−3	15	−3	−2	−4
6	−3	−3	−2	16	−1	−1	0
7	−3	−2	−2	17	1	0	0
8	−2	−2	−2	18	−5	−5	−3
9	−3	−2	−4	19	0	1	1
10	−1	−1	−2	20	3	3	4

over a cell and the absorbed dose over a cell (MeV/g/particle) which describe the dosimeter (Pelowitz, 2011).

A water phantom, with dimensions (40×40×40) cm^3, where the dosimeters were inserted, was used to determine the Percentage Depth Dose (PDD). The PDD shows the relation between the absorbed dose deposited by a radiation beam into a medium as it varies with depth along the beam axis. The energy deposition was measured using the **F8* tally (MeV/particle). This deposition was evaluated along the central axis of the beam, and the dosimeters were placed with a separation of 0.5 cm. Various components between the source and the water phantom were used to collimate and shape the beam. Some of the main components of the LINAC 2100c head are the target, primary and secondary collimators and flattening filters. The secondary collimator consists of jaws (upper and lower set) made of tungsten that are used to collimate the beam to a specific square or rectangular field size. In addition to these components, it is possible to observe the distribution of the dosimeters inside the water phantom. A detailed description of the LINAC and the irradiation scenario are presented in Fig. 2.

The simulations were carried out employing the MCNPX (2.7.0) Monte Carlo code (Pelowitz, 2011), with 1E9 particle histories. The precision of the results is satisfactory, considering the complex nature of the problem. In all exposure scenarios, the relative error of all dose calculations was less than 1%, which is acceptable in a teletherapy procedure. The properties of the polymer gels simulated in this work are presented in Table 1.

The obtained results were compared to experimental measurements, carried out with a Farmer type ionization chamber (0.6 cm^3 sensitive volume). This ionization chamber was positioned along the central axis, at depths of 0.5 cm–20 cm in 0.5 cm steps. The PDD were then normalized by the value measured at a depth of 1.5 cm.

The μ_{en}/ρ was also determined, using the tally *+F6* (Mev/g/particle), which represents the fraction of energy deposited in the material. Equation (1) was used to determine the μ_{en}/ρ of the composites:

$$\mu_{en}/\rho = +\text{F6 tally(MeV/g/particle)} \times \frac{A(cm^2)}{E(MeV/particle)} \quad (1)$$

where A is the dosimeter area, tally *+F6* is the energy absorbed normalized to unit mass (MeV/g/particle) and E is the incident photon energy (MeV/particle).

3. Results and discussion

3.1. Mass energy absorption coefficients determination

The μ_{en}/ρ was determined, using MCNPX simulation, for the MAGAS, MAGAT and AMPS polymer gels, and are shown in Fig. 3. The results of the present study were compared with those employing silicon based dosimeters (Singh et al., 2015). Observing Fig. 3, it can be noted that the highest differences are for the lower energies (< 1 MeV). The maximum difference between the results of the present work and those presented by Singh et al. (2015) was somewhat more than 30%. This difference does not compromise the quality of the results of this work, because these differences can be attributed to the different physical and chemical characteristics between the dosimetric materials used in this work, when compared with the those from Singh et al. (2015).

A comparison among the gel dosimeters simulated in this work with water and soft tissue are presented in Fig. 4. As may be noticed, the simulated gel dosimeters are equivalent to water and soft tissue. For all cases, the maximum difference was below 1%.

In addition to the 6 MV photon beam used in the present study, radioactive sources commonly used in Medical Physics were used, as: ^{192}Ir, ^{131}I, ^{137}Cs and ^{60}Co, which have mean effective energies of 0.401, 0.359, 0.662 and 1.253 MeV, respectively. In Fig. 4 a comparison in function of the source type used is presented. As can be observed, the μ_{en}/ρ values are strongly dependent on the source energy.

3.2. Percentage Depth Dose: gel and ion chamber measurements

In this study, the validation of the absorbed dose results obtained in the dosimeters was performed for a (10×10) cm^2 irradiation field and a photon beam with a maximum energy of 6 MV. Fig. 5 presents a comparison among the simulated gel dosimeters (MAGAS, MAGAT and AMPS) with the experimental measurements undertaken with an ion chamber. The results presented in Fig. 5 show the calculated and measured PDD along the central axis of the beam (water phantom depth). The PDD curve gives the dose ratio along the central axis of the beam at increasing depths relative to the dose at a reference depth. Typically, in clinical practice, the reference depth is that of electronic equilibrium, where the maximum dose is obtained. As can be seen in Fig. 5, the PDD curve is described by a region of initial dose growth due to the large amount of ionization, thus increasing the electron fluence up to the maximum dose. However, as the depth increases, the attenuation of the photon beam also increases, and consequently, the electron fluence in the medium and the PDD values decrease.

The relative differences between the simulated gel dosimeter and experimental measurements are presented in Table 2. As may be observed, the simulated and measured values are in a good agreement.

4. Conclusion

In this study, the Monte Carlo simulation was employed to evaluate some dosimetrical properties of the MAGAS, MAGAT and AMPS gel polymers. The μ_{en}/ρ values were determined for several photon energies, with the MCNPX Monte Carlo code. The results presented good agreement with the literature. Comparing these results with water and soft tissue, the maximum difference was 1%. The PDD results also agreed with the experimental measurements, indicating that the computational model may be applied as an alternative method for tests of different dosimetric materials.

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References

Ibbott, G.S., 2004. Applications of gel dosimetry. J. Phys. Conf. Ser. 3, 58–77. https://doi.org/10.1088/1742-6596/3/1/007.

Mobit, P., Nahum, A., Mayles, P., 1998. A Monte Carlo study of the quality dependence factors of common TLD materials in photon and electron beams. Phys. Med. Biol. 43, 2015–2032. https://doi.org/10.1088/0031-9155/43/8/002.

Pelowitz, D.B., 2011. MCNPX User's Manual, Version 2.7.0. Report LA-CP-11- 00438. Los Alamos National Laboratory.

Perini, A.P., Neves, L.P., Fernández-Varea, J.M., Büermann, L., Caldas, L.V.E., 2013. Evaluation and simulation of a new ionization chamber de sign for use in computed tomography beams. IEEE Trans. Nucl. Sci. 60, 768–773. https://doi.org/10.1109/TNS.2012.2233752.

Singh, V.P., Medhat, M.E., Badiger, N.M., 2015. Photon energy absorption coefficients for nuclear track detectors using Geant4 Monte Carlo simulation. Radiat. Phys. Chem. 106, 83–87. https://doi.org/10.1016/j.radphyschem.2014.07.001.