

Water equivalence of micelle gels for x-ray beams

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Abstract. Micelle gel is a radiochromic hydrogel with the potential to be used as a three dimensional (3D) radiation dosimeter. Since an ideal dosimeter should present water equivalent properties, in this study the water equivalence of two formulations of micelle gel has been investigated by calculating electron density, effective atomic number, fractional interaction probabilities, mass attenuation coefficient. The depth doses for kilovoltage and megavoltage x-ray beams have also modelled using Monte Carlo code. Based on the results of this work, micelle gels can be considered as water equivalent dosimeters.

1. Introduction

Polymer gel dosimeters are manufactured from radiation sensitive chemicals, which upon irradiation polymerize as a function of the absorbed radiation dose [1]. These gel dosimeters which record the radiation dose distribution in three-dimensions (3D) have specific advantages when compared to one-dimensional dosimeters and two-dimensional dosimeters [2]. These 3D dosimeters are radiologically soft-tissue equivalent [3] with properties that may be modified depending on the application. The 3D radiation dose distribution in polymer gel dosimeters may be imaged using magnetic resonance imaging (MRI) [4, 5], optical-computerized tomography (optical-CT) [6, 7], x-ray CT [8, 9], ultrasound [10, 11, 12] or vibrational spectroscopy [13, 14].

The Micelle gel dosimeter is a radiochromic hydrogel containing leucodye which undergoes colour change upon radiation. Jordan *et al* used leuco Malachite Green (LMG) dye which converts to Malachite Green (MG⁺) after exposing to ionizing radiation. This gel (will be referred as LMD1) also contains trichloroacetic, Triton X-100 and gelatine and has an absorption peak of 633 nm which is suitable to be readout by optical scanners [15]. Due to high dose rate dependency of the initial composition of leucodyes gels, a modified composition was suggested [16]. This new formulation of LMG (will be referred as LMD2) contains sodium dodecyl sulphate, chloroform, trichloroacetic acid, gelatine and LMG and shows good spatial stability and no energy dependency for megavoltage x-ray beams [17].

An ideal clinical dosimeter should exhibit water (or tissue) equivalent radiological properties and dose response. Water equivalence of polymer 3D dosimeters has been investigated previously [18-23]. In this study water equivalency and radiological properties of two different formulations of micelle



gels have been investigated by calculating: electron density, effective atomic number, photon interaction probabilities and mass attenuation coefficient. We also determined depth doses in each of the dosimeters using Monte Carlo calculations for 50 kVp, 280 kVp and 6 MV x-ray beams.

2. Material and Methods

Previously published elemental weight fractions and mass densities of two micelle gel formulations (see Table 1) [17] were used for radiological properties and dose calculations.

Mayneord formula was used to calculate effective atomic number [24]. The fractional interaction probabilities for photoelectric absorption, Compton scatter and pair was calculated using the NIST XCOM cross sectional data for 1 keV - 20 MeV energy range [25]. The mass attenuation coefficients of the gels were also calculated using the elemental attenuation coefficients of the NIST database [26].

EGSnrc/BEAMnrc Monte Carlo package (Version 4, NRC, Ottawa, Canada) [27] was used to model Varian 21iXs linear accelerator (Varian Medical Systems, city, state, USA) and calculate the dose delivered to the micelle gels and water for 6 MV and 50 to 280 kVp x-ray beams. The simulation method has been discussed in details in the previously published articles by authors [20, 21].

Table 1: Elemental composition by fractional weight (w_k), density and calculated electron density and effective atomic number for the two micelle gel formulations and water.

Material	w_H	w_C	w_N	w_O	w_S	w_{Na}	w_{Cl}	ρ (g.cm ⁻³)	ρ_e ($\times 10^{23}$ e.cm ⁻³)	Effective atomic number
LMD1	0.1104	0.0229	0.0001	0.8649	-	-	0.0017	1.015	3.388	7.425
LMD2	0.1087	0.0379	0.0001	0.8414	0.0011	0.0016	0.0091	1.012	3.372	7.597
Water	0.1119	-	-	0.8881	-	-	-	1.000	3.343	7.417

3. Results

The calculated electron density and effective atomic number of the micelle gels dosimeter and water are presented in Table 1. Electron density of LMD1 and LMD2 is slightly higher than water by 1.4% and 0.9% discrepancy, respectively. The effective atomic number of LMD1 could be considered similar to water with 0.1% discrepancy while for LMD2 the difference from that of water is 2.4%.

Figure 1 shows the calculated fractional interaction probabilities for the micelle gels and water over the energy range 1 keV - 20 MeV. The maximum discrepancy in the fractional interaction probabilities of LMD1 from those of water are less than 2%. However, for LMD2, the discrepancies up to 17% and 8% for the photoelectric absorption and Compton scattering interaction probabilities are evident, respectively.

4. Conclusion

Our results demonstrate that both micelle gel formulations can be considered radiologically water equivalent for x-ray dosimetry. Micelle gels show more water equivalent radiological properties and dose response compare to PRESAGE[®] and polymer gel dosimeters such as MAGAT, MAGIC and PAGAT [18, 19, 23]. However, genipin gel still could be considered the most water equivalent polymer gel dosimeter [20, 28].

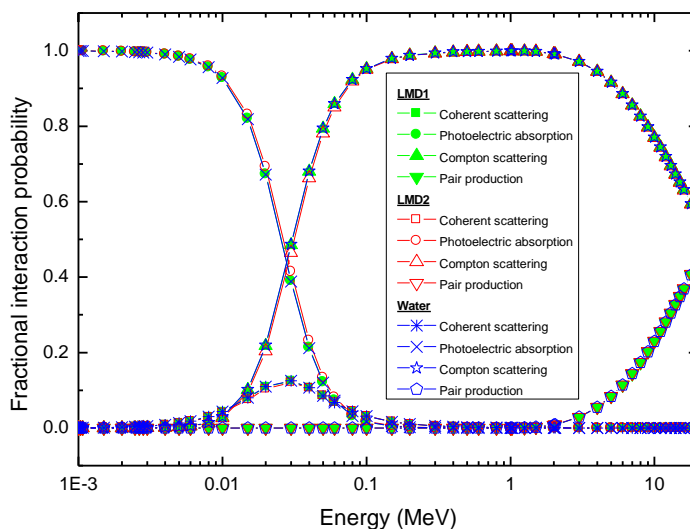


Figure 1: Fractional interaction probabilities for the two micelle gel formulations and water.

The ratio of the mass attenuation coefficients of the micelle gels and water are plotted in figure 2 over the energy range 10 keV - 20 MeV. For LMD2 a peak is noticeable from 2 – 100 keV which is more than 8% higher than water. This can be attributed to the presence of high atomic number component; Cl, Na and S; in the gel. LMD1 has similar attenuation coefficient to water over the entire energy range.

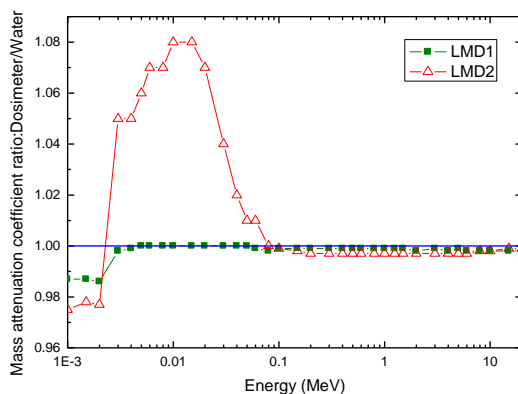


Figure 2: The mass attenuation coefficient ratio for two micelle gel formulations relative to water.

Figure 3 shows Monte Carlo calculated depth dose curves of the micelle gels and water for 50 kVp, 280 kVp and 6 MV x-ray beams. For 50 kVp, LMD1 has less than 0.5% difference from water while LMD2 differs from water by $\approx 2\%$. For 280 kVp, both gels could be considered water equivalent with less than 0.4% dose difference from water. In the buildup region of MV x-rays, delivered dose in both micelle gels is $\approx 1\%$ higher than water due to existence of carbon and higher atomic number components. Consequently, after the buildup region, dose delivered in both gels is slightly less than water (by 0.5%).

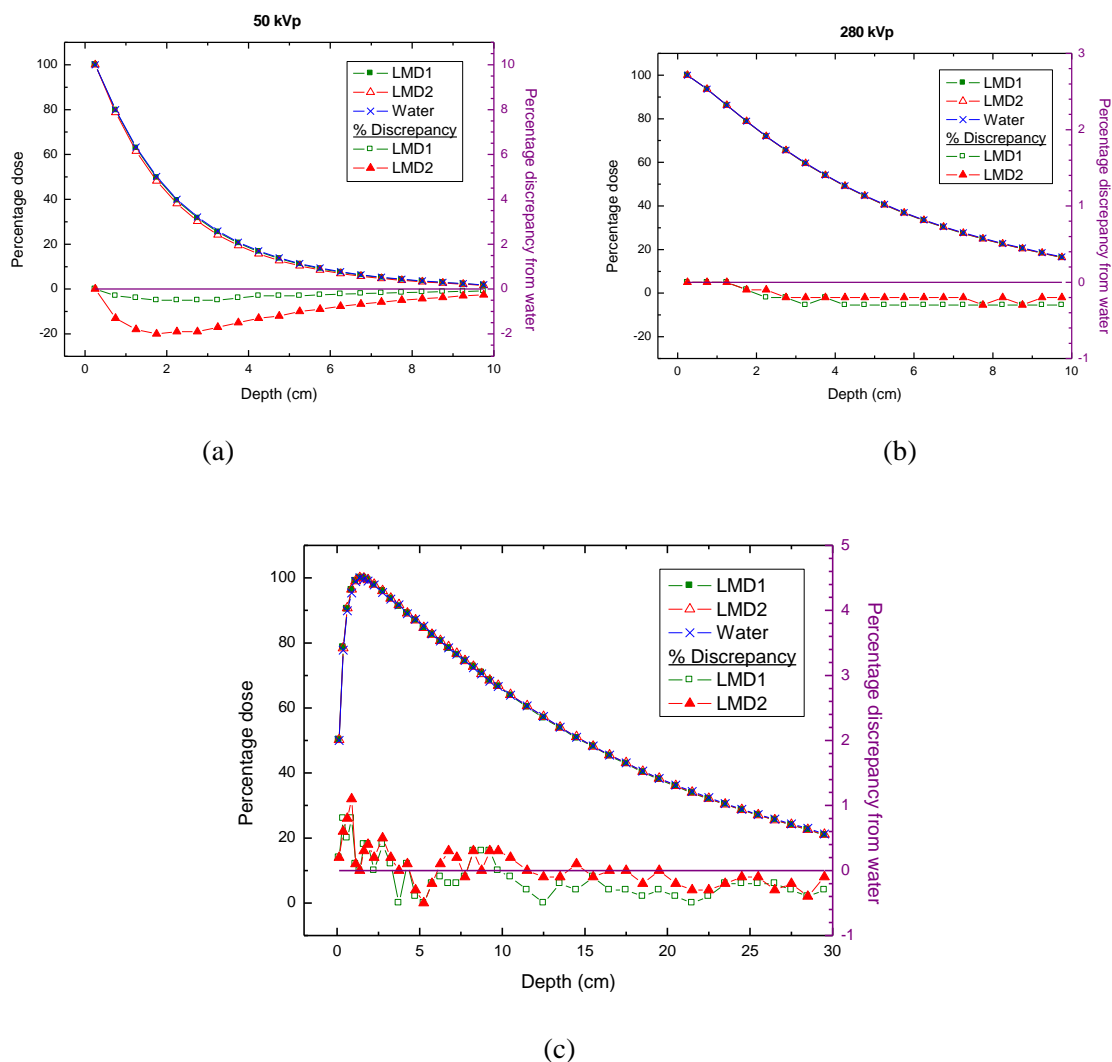


Figure 3: Monte Carlo percentage depth dose curves for (a) 50 kVp, (b) 280 kVp and (c) 6 MV x-ray beams for the two micelle gel formulations and water.

5. References

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