An evaluation of Genipin gel as a water equivalent dosimeter for megavoltage electron beams and kilovoltage x-ray beams

Tina Gorjiara¹, Robin Hill¹, ², Zdenka Kuncic¹, Stephen Bosi¹, ³ and Clive Baldock¹

¹ Institute of Medical Physics, School of Physics, University of Sydney, NSW 2006, Australia
² Department of Radiation Oncology, Royal Prince Alfred Hospital, Sydney, NSW 2050, Australia
³ Department of Radiation Oncology, Prince of Wales Hospital, Randwick, NSW 2031, Australia

clive.baldock@sydney.edu.au

Abstract. Genipin gel is a radiochromic gel with the potential to be used as a three dimensional (3D) dosimeter. An ideal dosimeter should present radiologically water equivalent properties. In this work, we have evaluated the water equivalency of genipin gel by calculating its radiological properties, such as mass and electron density, effective atomic number, fractional interaction probabilities, mass energy absorption coefficient and mass stopping powers as well as depth doses for kilovoltage x-ray and megavoltage electron beams. Based on the results of this study, we conclude that genipin gel is a water equivalent dosimeter.

1. Introduction

Genipin, extracted from the fruits of Gardenia jasminoides Ellis, has been used widely in herbal medicine [1]. Genipin can form molecular cross links with gelatin’s proteins. The result is a light to dark blue radiochromic gel with the property that its colour bleaches after irradiation. By quantifying the change in colour using imaging modalities such as optical CT, it is possible to determine the delivered radiation dose [2, 3]. Radiochromic genipin gel has a fast bleaching process which produces a dose image with sufficient stability and sensitivity to be used as a 3D dosimeter [4].

Water equivalency is one of the characteristics of an ideal dosimeter and can be assessed by determination of mass density and electron density; effective atomic number; mass energy absorption coefficient; mass stopping power and relative dosimetry measurements such as depth dose [5-7].

Water equivalency of PRESAGE and several polymer gel dosimeters have been investigated previously [5, 8, 9]. In this work we have evaluated the water equivalency and radiological properties of genipin gel by calculating a number of parameters such as: electron density, effective atomic number, photon interaction probabilities, mass energy absorption coefficient and mass stopping power. We also determined depth doses in each of the dosimeters using Monte Carlo calculations for 6 and 12 MeV electron beam and 50 and 280 kVP x-ray beams.

2. Material and Methods

The genipin gel was made using a previously described methodology [2]. The mass density of the genipin gel was measured using a helium multi-pycnometer (Quantachrome instruments, Florida,
USA). Once the mass density was known, the elemental composition and electron density were calculated. Effective atomic number was calculated using Mayneord formula [10].

The probability of photon attenuation by photoelectric absorption, Compton scatter and pair production is defined by their fractional interaction cross sections. The cross sectional data were obtained from the NIST XCOM database over the energy range 1 keV - 20 MeV [11]. The NIST x-ray attenuation database was also used to obtain elemental energy absorption coefficients. The energy absorption coefficients of genipin and water were calculated using the mixture rule [12]. The mass stopping powers were similarly calculated using the NIST ESTAR database [13].

Relative depth dose calculations for the genipin gel dosimeter and water were performed using the EGSnrc/BEAMnrc Monte Carlo package (Version 4, NRC, Ottawa, Canada) [14]. The 6 and 12 MeV electron beams were produced by a Varian 21iXs linear accelerator (Varian Medical Systems, city, state, USA). The beams were modeled using BEAMnrc with a field size of 10×10 cm² and the electron and photon energy cutoff parameters, ECUT and PCUT, were set to 0.561 MeV and 0.01 MeV, respectively. For the electron beam simulation, the incident beam was a parallel electron beam with 0.5 cm radius and 6.7 MeV kinetic energy for 6 MeV. For 12 MeV electron beam, incident beam had 0.6 cm radius and 13.2 MeV kinetic energy. The kilovoltage x-ray beams were generated by a Pantak Therapax DXT300 kilovoltage x-ray therapy unit with a tube potential varying from 50 to 280 kVp [15].

We calculated depth dose curves in the genipin gel and water using the DOSXYZnrc user code and the phase space files generated by BEAMnrc for the electron and x-ray beams. For the electron beams, a 60×60×30 cm³ phantom was defined which had a 0.25 cm voxel size in the buildup region. For the kilovoltage x-ray beams, a 20×20×10 cm³ phantom was defined in DOSXYZnrc with a total of 20 voxels of 0.5 cm thickness in the depth direction.

3. Results

Table 1 shows the calculated elemental composition, mass density, electron density and effective atomic number of the genipin gel dosimeter and water. The effective atomic number of genipin gel is 1.4% higher than water while its mass density is almost equal to that of water.

The calculated fractional interaction probabilities for the genipin gel and water over the energy range 1 keV - 20 MeV are plotted in Figure 1. The maximum difference in the photoelectric absorption and Compton scattering fractional interaction probabilities of the genipin gel compared to water are less than 0.1%.

Table 1- Elemental composition by fractional weight (w_k), mass and electron densities and effective atomic number for genipin gel and water.

| Material       | w_H | w_C | w_N | w_O | w_S | Mass density (×10^23 e.cm⁻³) | Electron density (×10^23 e.cm⁻³) | Effective atomic number |
|----------------|-----|-----|-----|-----|-----|-------------------------------|-----------------------------------|------------------------|
| Genipin gel    | 0.1105 | 0.01522 | 0.005216 | 0.8696 | 0.003108 | 1.001 | 3.352 | 7.518 |
| Water          | 0.1119 | - | - | 0.8881 | - | 1.000 | 3.343 | 7.417 |
Figure 1. Fractional interaction probabilities for the genipin gel dosimeter and water.

The ratio of the mass energy absorption coefficients of the genipin gel and water are presented in Figure 2 for the photon energy range 10 keV - 20 MeV. In this plot, a peak is noticeable from 10 – 100 keV which is less than 3% higher than water. This can be attributed to the small amount of the high atomic number components.

Figure 2. The mass energy absorption ratio for genipin gel relative to water.

Figure 3 shows plots of the ratios of the collisional, radiative and total stopping powers for genipin gel to that of water. It is evident that the stopping power of genipin gel has a maximum difference of 0.3% compared with the value of water.
Figure 3. The collisional, radiative and total mass stopping power ratios for the genipin gel to water.

Figure 4 shows the Monte Carlo calculated depth doses for the genipin gel and water using 6 and 12 MeV electron beams. The relative dose differences with the value of water are up to 2% for the genipin gel dosimeter at a radiological depth of 10 cm.

Figure 4. Monte Carlo depth dose curves for the 6 and 12 MeV electron beam for the genipin gel dosimeter and water.

Figure 5 shows the kilovoltage Monte Carlo calculated depth dose curves for the genipin gel and water. For 50 kVp, the relative dose difference with the value of water is less than 0.5% while for 280 kVp, the relative dose differences with the value of water is negligible.

4. Conclusion
Our results demonstrate that genipin gel can be considered a radiologically water equivalent dosimeter. In comparison to PRESAGE and polymer gel dosimeters such as MAGAT, MAGIC and PAGAT, genipin gel shows more water equivalent radiological properties as well as dose response [5, 8].
Figure 5. Monte Carlo calculated relative depth dose curves for 50 kVp and 280 kVp x-ray beams for the genipin gel and water.

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