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Study of PVA-GTA Fricke Gel Dosimeters Exposed to ^{60}Co SourceUsing Magnetic Resonance Imaging

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ABSTRACT

This study was conducted to evaluate the response of PVA Fricke gel dosimeters by two different methods, optical spectroscopy and magnetic resonance imaging. At first, samples of PVA Fricke xylenol orange gel dosimeters were prepared in our laboratory. Then, the samples were irradiated up to 25 Gy by gamma rays. Finally, studies on the optical absorbance and magnetic resonance of the prepared Fricke gel dosimeters were carried out. Optical absorbance measurements of the samples were performed with a spectrophotometer. Magnetic resonance measurements of the gel dosimeters were carried out by means of a 1.5 T scanner. Radiation induced oxidation of ferrous ions with the yield proportional to absorbed dose was observed. The dosimeters were found to offer good linearity in the range of 0-15 Gy. MRI scans of the dosimeters also showed that the longitudinal relaxation time is dose dependent. The findings suggest PVA Fricke gel dosimeters as a dosimetric tool for medical applications like radiation therapy

Keywords: Fricke Gel Dosimeter; Absorbance Spectra; Magnetic Resonance Imaging; Dose Response.

1. Introductions

One of the most common chemical dosimeters consists of aqueous solution of ferrous ions infused in a gel matrix, called Fricke gel dosimeter [1]. These dosimeters have a good potential for recording three-dimensional dose distributions as they can be served in any shaped tissue equivalent phantoms [2]. Therefore, they are usually suggested for radiotherapy dosimetry [3]. The dosimeters also show excellent soft tissue equivalence for X-rays below 100 keV which makes them interesting for diagnostic radiology applications [4].

Irradiation of the Fricke gels induces a dose dependent oxidation of ferrous (Fe^{+2}) to ferric (Fe^{+3}) ions, which can be detected through optical absorbance or magnetic resonance [5-6]. The metal ion indicator xylenol orange forms a complex with ferric ions which shows radiation absorption at wavelengths above 500 nm [3]. The oxidation of ferrous ions also brings about a reduction of the longitudinal nuclear magnetic relaxation time (T1)

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which can be measured by means of nuclear magnetic resonance relaxometry (NMR) or magnetic resonance imaging (MRI) [7-8]. MRI with clinical scanners offers three-dimensional measurements with high spatial resolution [9]. Researchers evaluated Fricke gel dosimeters to X-rays generated by a medical linear accelerator with energies of 6 MV [7,10] and 10MV [8], as well as to gamma rays from a ^{137}Cs source [1].

The ^{60}Co source is used extensively to irradiate samples in our laboratory. Fricke gels do not respond well to dosimeters for irradiation quality control in dose ranges between a few and several tens of Gy. PVA-GTA Fricke gel dosimeter is chosen in this study as it is the latest introduced gel dosimeter with the most advanceddosimetric features [11-13]. There is no data on the response of the PVA-GTA Fricke gel dosimeter to the ^{60}Co source as demonstrated by the authors' research. Hence, the response of Fricke gel dosimeters to ^{60}Co sources was examinedin our work. In this study, the dosimetric features of PVA-GTA Fricke gel dosimeters exposed to a ^{60}Co source were investigated with two different methods, optical spectroscopy and magnetic resonance imaging.

2. Experimental

2. 1. Dosimeter Preparation

Fricke xylenol orange gel dosimeters were prepared from 1.5 mM ferrous ammonium sulphate hexahydrate (Merck), 25 mM sulphuric acid 96% (Merck), 0.165 mM xylenol orange sodium salt (Sigma-Aldrich), 10% w/v aqueous solution of 99% purity polyvinyl alcohol (PVA) with molecular weight between 85000 and 124000 (Sigma–Aldrich) and 1% w/v glutaraldehyde (GTA) (Sigma–Aldrich), following the procedure described by the references [5-6, 14-15]. The final compound was then poured into standard spectrophotometry cuvettes with a 10 mm optical path and 4 cm height (Fig. 1). The cuvettes are also suitable for subsequent MRI scans. I To minimize oxidation of Fe^{2+} ions induced by temperature or light, the filled cuvettes are maintainedin a dark environment under refrigeration both after preparation and between irradiation and measurement.

Fig. 1. Some of the gel filled cuvettes.

2. 2. Irradiation of Dosimeters

Using a Gammacell-220 (Nordion, Canada), the prepared gel dosimeters were irradiated in the dose range from 0 Gy to 25 Gy. For each dose value, three cuvettes were irradiated and analyzed to reduce the statistical errors. At the time of irradiation, the dose rate was 1.1 Gy/sec.

2. 3. Dosimeter Readout

The prepared dosimeters were surveyed by two methods, optical spectroscopy and magnetic resonance imaging. The two methods are independent experimental methods based on different physical principles. While dose measurement canbe performed with both, each has its advantages and limitations. MRI scans allow3D dose mapping but the scanner is only available in equipped clinical centers. There is more simple accessibility to a spectrophotometer in a common laboratory, but dose measurement is limited..

Optical absorbance measurements of the samples were performed with a spectrophotometer

(BECKMAN COULTER- DU-800) thirty minutes after irradiation, the time required for achieving a chemical equilibrium.

The quantities measured via MRI in gel dosimetry experiments are the nuclear magnetic relaxation times T1 and T2. These depend on the presence of paramagnetic agents and the mobility of hydrogen nuclei in the sample. T1 is spin-lattice relaxation time and T2 is spin-spin relaxation time. The inverse of longitudinal nuclear relaxation time (T1) is the relaxation rate (R1). In this work, magnetic resonance measurements of gel dosimeters were carried out by means of a 1.5 T Philips scanner using an eight-channel head coil. All cuvettes were placed upright and centered on the head coil. The samples were kept at room temperature before the scans. The measurements were done one hour after irradiation. In particular, T1-weighted MRI sequences can effectively discriminate between regions with different absorbed doses [9]. T1-weighted images were acquired using an Inversion Recovery sequence optimized for brain scans. Echo time set 15 ms and repetition time set 2500 ms. For each dose, three cuvettes were also irradiated and scanned. Data analysis was performed using ImageJ software using MRI analysis calculator plugin. [14]. In order to perform statistical analysis, all measurements such as optical spectroscopy and sequence imaging were repeated at least three times to reduce the possibility of errors or prevent anomalous results. At last, standard deviation was calculated using software. Radiation systems laboratory, radiation applications research school, and nuclear science and technology research institute conducted all the experiments.

3. Results

The optical measurement of the Fricke gel dosimeters was carried out in the wavelength range from 350 nm to 650 nm. The obtained absorbance spectra are reported in Fig. 2a. Also, Fig. 2b illustrates absorbance at a wavelength of 585 nm versus the absorbed dose as a dose response of the gel. The response of Fricke gel dosimeters as a function of absorbed dose was also surveyed by MRI. Fig. 3 shows a scanned image of three dosimeters irradiated at the same dose. Analysis of T1-weighted images was done with ImageJ software using the MRI analysis calculator plugin. Fig. 4 illustrates the relaxation rate versus absorbed dose as an MRI response of the gel.

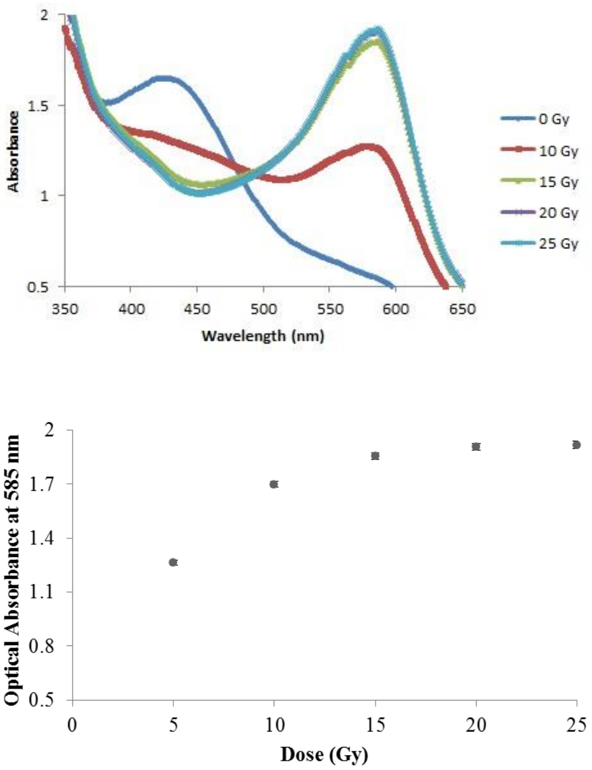

Fig. 2. a) Absorbance spectra obtained with the prepared dosimeters for different doses. **b)** Dose response of the gel.

Fig. 3. A sample of MR images of the gel filled cuvettes.

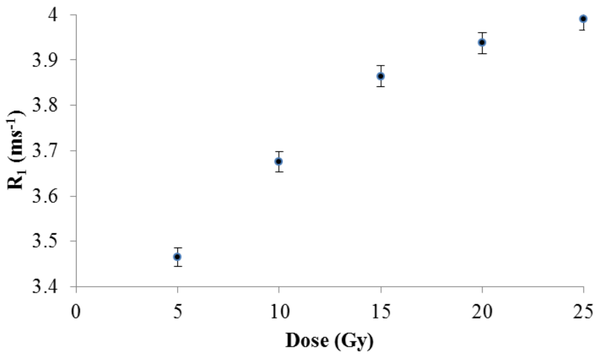

Fig. 4. MRI response of the gel.

4. Discussion

This study is the first evaluation of the PVA-GTA Fricke gel dosimeters exposed to a ^{60}Co source. As can be seen in Fig. 2a, Frick gel dosimeters present two absorption bands: one in the range from 435 to 445 nm corresponding to initially existing Fe^{2+} ions in the unirradiated gel (0 Gy curve in Fig. 2a) and the other at the range from 575 to 585 nm corresponding to Fe^{3+} ions generated by radiation-induced Fe^{2+} ions oxidation. Indeed, xylenol orange sodium salt can bind ferric ions giving a peak wavelength at 585 nm. The first band tends to disappear depending on the absorbed dose as the second band intensifies with increasing doses.

Fig. 2b shows the dose-response of PVA-GTA Fricke gel dosimeters. Each point is the mean of measurements on three samples at 585 nm. The precision of dose-response estimation is assessed by the coefficient of determination (R^2) of each dose-response curve. A value of R^2 close to 1 signifies an adequatefit of the dose-response curve to the measured points. The increase in dose increases the optical absorbance with a linear trend (R^2= 0.988). On the other hand, the measured absorbance of the gel was linearly correlated to the radiation dose up to saturation. The saturation can be attributed to a limited initial number of ferrous ions. As soon as all the ions have oxidized to ferric ions, the dose increase does not have any effect.Such a finding is in agreement with Gallo et al's results.about the dose-response curve of similar gel dosimeters studied in the range 0.5-15 Gy using 6 MV and 15 MV X-rays [7]. Also, the results obtained with the PVA-GTA matrix are in line with those published by Gallo et al. about the dose-response curve of similar gel dosimeters irradiated with a ^{137}Cs blood irradiator in the range of 4.8–36.0 Gy [1]. As mentioned before, there is no data on the response of the PVA-GTA Fricke gel dosimeter to the ^{60}Co source for comparison.

We also performed an MRI analysis of the response of Fricke gel dosimeters. Analysis of T1-weighted images with ImageJ software. Irradiation induces the oxidation of Fe^{2+} to Fe^{3+} and the presence of this paramagnetic species reduces the relaxation time T1. Indeed, the produced Fe^{3+} ions operated as T1contrast item making the longitudinal relaxation of H-proton magnetization faster. Thus, R1 is an increasing function of dose as illustrated by Fig. 4.

5. Conclusions

The dosimetric properties of Fricke gel dosimeters based on PVA as a gelling agent and glutaraldehyde as a cross-linker were surveyed. Samples of PVA Fricke gel dosimeters were prepared in our laboratory. Studies of the optical absorbance and magnetic resonance of the Fricke gel dosimeters were conducted. The absorbance spectra showed the same trend with the dose increase. The absorbance at 585 nm increased linearly with the dose in the range of 0-15 Gy. MRI scans showed that the longitudinal relaxation time and sequence relaxation rate aredose-dependent. The PVA Fricke gel is a promising tool for medical dosimetry. Diffusion effects hinder accurate measurements in the steep dose gradient regions; however, they should be further reduced by modifying the gel matrix or by minimizing the delay between irradiation and imaging. The results also verified that the dosimetric features of the gel can be measured through independent experimental methods based on different physical principles.

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