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Spectral response of radiochromic gel detector in the near-ultraviolet region (200–400 nm)

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HIGHLIGHTS

- Spectral response of FXG gel material at monochromatic wavelengths in the near ultraviolet spectrum was investigate.
- Changes in optical absorbance at 560 nm were considered as indicator for FXG gel detector response to ultraviolet radiation.
- The influence of optical path on FXG response was studied.
- FXG gel detector response in near ultraviolet spectra is related to the gel thickness and the exposure radiation wavelength.

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ABSTRACT

Tissue-equivalent radiochromic gel detector is sensitive in the regions of ultraviolet radiation (UVR) and gamma and X-rays. This study aims to investigate the spectral response and other optical properties of the ferrous sulphate, xylenol orange and gelatin (FXG) radiochromic gel dosimeter at particular UVR wavelengths. A total of nine monochromatic wavelengths were selected in the range of 240–400 nm with an increment of 20 nm. The FXG spectral response was estimated from the variation of spectral absorbance at 560 nm resulting from 1 h exposure to UVR beam at each chosen wavelength. Experimental results show that the FXG responsivity depends on the wavelength of the radiation and the optical path in the gel material. UVC and UVB photons have relatively higher photochemical effect than UVA; however, UVA penetration is deeper. Investigations showed that the FXG gel response is relatively constant between 240 and 320 nm, but it varies rapidly with wavelength in the UVA range and takes a minimal value at 360 nm. UVR spectral absorbance curves for different gel sample thicknesses were examined. The experiment showed that 6 mm of neutral gelatin or FXG gel samples was capable of absorbing >99.7% of the beam in the UV range of 240–290 nm.

1. Introduction

Near-ultraviolet radiation (UVR) (200–400 nm) is non-ionising radiation (NIR) produced by natural sources such as Sun and lightning, and by artificial sources such as xenon or xenon–mercury arc lamps, welding arcs and lasers, which have diverse applications (Diffey, 2002). UVRs are mainly composed of UVC (100–280), UVB (280–320) and UVA (320–400 nm) (CIE, 1987). Tissue-equivalent radiochromic gel material, which comprises ferrous ions, xylenol orange ion indicator and gelatin host agent (FXG), is known to be sensitive to ionising radiation, gamma and X-rays. The radiochromic FXG gel was originally developed for measuring three-dimensional dose distributions of high-energy photons (Bero et al., 2000). The ability of the FXG gel material to absorb UVR more than water was investigated (Bero et al., 2000; Ching-Shen et al., 1996; Diffey, 1999). Moreover, the FXG gel was reported to possess very good sensitivity to UVRs, and it has relevant metrological properties that are useful for the assessment of UVA dose (Abukassem and Bero, 2010, 2012). Changes in the optical properties of the FXG gel material caused by the photochemical excitation of UVR exposure occur in the visible region between 400 and 600 nm. Maximum optical changes induced at 560 nm makes the UVR effect visible to the human eye; hence, it would be suitable for direct dose estimation. It was reported that the variations of the optical absorbance of FXG gel with UVA exposure follow a second-order equation. This phenomenon is relatively independent of the applied UVR levels. The accuracy of UVA dosimetry using FXG gel is

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related to the radiometric properties of the gel, which include the linearity of the gel response, the dark-induced reaction and the temporal stability of the FXG gel material. Moreover, UVA dose assessment is influenced by the properties of the UVA source and the measurement reference instrument (UVA radiometer). The results proved that the studied radiochromic gel material delivers good repeatability and reproducibility of UVA dose measurements with maximum relative dispersion of about 5% between samples studied from different batches (Abukassem and Bero, 2010, 2012).

The purpose of this study was to better understand the FXG response to UVR to introduce the technique for UVR measurements. Therefore, a detailed investigation of the spectral properties of the FXG gel material in the near-UV spectrum is required. Experimental set-ups were designed for achieving the FXG gel spectral responsivity between 200 and 400 nm. Absorbance spectrum of neutral gelatin medium, which is 5% gelatin in triple-distilled water, and its stability under high UVR exposure were studied. Considering the fact that neutral gelatin is the main component of FXG gel detector, different thicknesses of neutral gelatin and FXG gel detector were tested and the effects of thickness of the samples were compared.

2. Materials and methods

2.1. Radiochromic (FXG) gel materials

An optimised procedure was followed for the preparation of FXG gel sample, which was described by Bero et al. (2000). In general, the prepared radiochromic FXG gel detector is composed of triple-distilled and deionised water produced by Sartorius laboratory purification system (Sartorius, Model Arium-611, Gottingen, Germany) and gelatin powder with high gelling strength index (Scharlau Chemie, Gato Perez, Spain). Additional active chemical substances included in the gel are analytical grade ferrous ammonium sulphate hexahydrate (FEROSA Scharlau, Barcelona, Spain), xylenol orange sodium salt ion indicator (Sigma–Aldrich Chemie, Steinheim, Germany, purity 90%) and concentrated sulphuric acid (Surechem Products Ltd, Suffolk, England). Samples, while the mixture is still in liquid form, were placed in standard-size UV-grade quartz cuvettes (Hellma GmbH Co., Mulheim, Germany). The effects of monochromatic UVR on the gel material were studied quantitatively by analysing the optical changes of gel samples in the visible region of the spectrum using a standard UV–Vis spectrophotometer.

2.2. Optical absorbance measurement set-up

Optical absorbance measurements of neutral gelatin and FXG gel samples were made using a double-beam UV–Vis spectrophotometer (SPECORD-210, Analytik Jena AG, Jena, Germany) with an absorbance photometric accuracy at 546 nm $\leq \pm 0.005$ nm (measured using a Hellma F4 neutral density filter). All absorbance measurements were made over the range of 200–800 nm with 1 nm scanning step according to the measurement procedure described elsewhere (Bero and Abukassem, 2009; Abukassem and Bero, 2010, 2012).

2.3. UVR set-up

The irradiations of the studied samples at different monochromatic UV wavelengths were achieved using the set-up depicted in Fig. 1. A xenon arc lamp (300 W, UXL-306, No. IE 2481, Japan) was used to obtain a continuous spectrum with uniform and stable monochromatic beam. A high-performance monochromator (HORIBA Jobin Yvon Inc., TRIAX550) was used. The xenon arc lamp

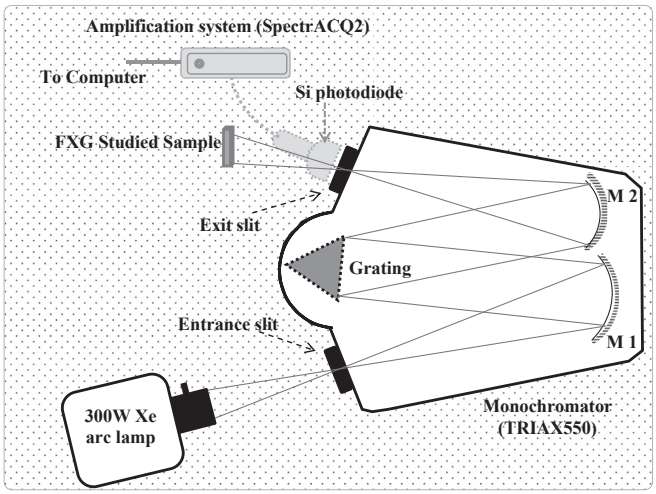

Fig. 1. Monochromatic ultraviolet radiation exposure set-up.

emission spectrum was registered before starting the irradiation of samples. Monochromatic light beam at the monochromator exit slit was measured by an adapted silicon photodiode (10 × 10 mm and spectral range 200–1100 nm) equipped with high-speed and high-performance spectral data acquisition controller designed for application in advanced spectroscopy and light measurement (SpectrAcq2). This optional photon-counting detection module allows measuring the light level by counting the number of photons. Absolute spectral counting values between 200 and 740 nm are presented in Fig. 2. The FXG gel samples were fixed on an adapted support frame at a distance of 15 cm from the exit slit in order to make the samples entirely exposed to the monochromatic irradiation beam. This set-up allows the irradiation of studied samples with about 2 nm bandwidth light beam at each selected wavelength between 240 and 400 nm.

3. Results and discussion

3.1. Spectral absorbance of neutral gelatin and FXG gel samples

The neutral gelatin and FXG gel detector were prepared, and three samples of each material were placed in standard-size UV-grade quartz cuvettes. The absorbance spectra of these samples between 200 and 800 nm were recorded with 1 nm measurement steps before irradiation, and the average values are presented in Fig. 3. These spectra show that the studied 10-mm-thick samples are opaque in the UVC and part of UVB regions. Neutral gelatin and FXG gel samples absorb the spectrometer light beam completely for all wavelengths <290 nm. Although neutral gelatin has relatively moderate transparency in UVB and UVA regions (transparency values varies from 10% to 55% between 290 and 320 nm and from 55% to 80% between 320 and 400 nm), its transparency is appreciable in the visible spectrum. However, the un-irradiated FXG gel absorbs the UVB and UVA wavelengths very well and has specific absorbance behaviour in the visible region with a maximum value at 445 nm. These FXG absorbance spectrum features are due to the active chemical additives, ferrous ammonium sulphate hexahydrate and xylenol orange sodium salt in the acid medium.

3.2. Stability of neutral gelatin under high UVR

Dose estimation of the UVA beam using FXG gel detector was studied and reported previously (Abukassem and Bero, 2010, 2012).