Development of a Long Term Solar UVA Dosimeter

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Abstract. Exposure to UV radiation is known to be a causative factor in the induction of skin cancers and other sun-related disorders. Most acute responses of humans to UV exposure occur as a result of UVB (280 to 315 nm) exposures, as these wavelengths are highly sensitive in creating a human biological response. However, this does not mean that UVA radiation has no impact on human UV exposures and health. UVA can cause erythema in human skin, yet, the exposures required to create such a response is much larger than UVB radiation. UVA radiation penetrates much deeper into human skin tissue than UVB, resulting in impacts that are not as acute, taking many years to manifest. Past research has shown that UVA (315 to 400 nm) plays a significant role in human skin carcinogenesis. Studies have also shown that UVA plays an important role in skin damage, immune suppression, DNA damage, photoageing and wrinkling. Researchers at the University of Southern Queensland have developed a personal UV dosimeter that can quantitatively assess long term solar UVA exposures. The chemical polyphenylene oxide, cast in thin film form and which is responsive to both the UVA and UVB part of the spectrum was used and filtered with mylar. This combined system responded to the UVA wavelengths only and underwent a change in optical absorbance as a result of UVA exposure. Preliminary results indicate that this UVA dosimeter saturates reasonably slowly when exposed to sunlight and can measure exposures of more than 20 MJm^{-2} of solar UVA radiation with an uncertainty level of no more than ± 5%.

Introduction

Over exposure to UV radiation can cause serious damage to the human eyes and skin. Skin cancer is considered the most common malignant neoplasm in Australia and the USA (Kricker and Armstrong, 1996; Glanz and Mayer, 2005; NCI, 2007). Over 1,600 Australians die from skin cancer each year and a further 380,000 Australians are treated for skin cancer each year (NCCI, 2003; AIHW, 2004; AIHW, 2005). Estimates put direct health care costs of all types of skin cancer in Australia in the region of $734.9 million per year, with the indirect costs in the form of sick leave and foregone earnings in the region of $1.395 billion per year (Armstrong, 1995). As a result, it is essential to decrease any exposure to damaging solar UV radiation that the population experiences. This requires constructive methods to understand the solar UV radiation environment that humans live in. Quantification of the individual level of solar UV radiation exposure requires personal dosimetry due to changes in the position of people compared to the radiation source.

Commonly used UV chemical dosimeters are polysulphone and phenothiazine. Phenothiazine has been used for measuring UVA wavelengths in various environments (Parisi et al, 2005). However, phenothiazine only has the capability to record a cumulative exposure over a small time period, usually three to four hours. This small dynamic range greatly reduces the amount of time over which a UVA exposure can be measured in the field. Therefore, a chemical dosimeter that can be employed that is capable of measuring large amounts of UV radiation over a long time period would be very useful. Research conducted by Davis et al (1976) showed that Poly (2,6-dimethyl-1, 4-phenylene oxide) (PPO) film could be employed to measure high levels of UV exposure. Further research (Davis et al, 1981; Berre and Lala, 1989; Lester et al, 2003) found PPO to be ideal for this purpose as it would allow for unattended measurements to be made at various locations over extensive amounts of time. PPO dosimeters have been utilised in the measurement of global UV exposures, however, they have not been used to measure long term solar UVA exposures. The aim of this paper was to extend the previous research that has employed PPO dosimeters for the measurement of solar UV exposures to investigate the suitability of PPO for the long term measurement of solar UVA exposures.

Methodology

PPO film of approximately 40 µm thickness was attached with adhesive tape to a plastic holder. The holders for the dosimeters were 3 x 3 cm in size and fabricated from thin polyvinylchloride with an aperture of approximately 1.2 x 1.6 cm. A UV/visible spectrophotometer (model 1601, Shimadzu Co., Kyoto, Japan) was used to measure the pre and post exposure absorbance of the dosimeter. PPO is responsive to both the UVA and UVB part of the solar spectrum, therefore the UVB wavelengths were filtered by placing mylar on top of the PPO film. For each dosimeter, the change in optical absorbance (ΔA_{330}) due to UV exposure was measured at 320nm (with mylar removed) at four different sites over the dosimeter in order to minimise any errors due to any possible minor variations in the PPO film over the size of the dosimeter. The post exposure absorbance was measured at a standardized time following exposure to minimize any error associated with the post exposure 'dark reaction' of the PPO.

The dosimeters were calibrated for UVA exposures by exposing a series of dosimeters on a horizontal plane, to relatively clear sky solar UV from approximately 0800 to 1600 h Australian Eastern Standard Time (EST) for a total of 22 days. The SZA ranged from 30^o to 75^o. The PPO dosimeters were calibrated on a horizontal plane with a UVA meter (501 Biometer, Solar Light Co., Philadelphia, USA). The UVA meter was calibrated against a scanning spectroradiometer (Bentham Instruments, Ltd, Reading, UK). The spectroradiometer is based on a double grating monochromator, a UV sensitive detector and amplifier with software variable gain provided by a programmable high voltage power supply. The interior of the spectroradiometer enclosure is temperature stabilised to 23.0 ± 0.5°C, using a Peltier heater/cooler unit. The input optics of the spectroradiometer are provided by a PTFE (polytetrafluoro ethylene) diffuser and connected by an optical fibre to the input slit of the monochromator. The spectroradiometer is programmed to start scanning at dawn, and thereafter every 5 minutes till dusk. The instrument is wavelength calibrated to the UV spectral lines of a mercury lamp and irradiance calibrated to a 150 Watt quartz tungsten halogen lamp with calibration traceable to the National Physical Laboratory, UK standard.

Results

The calibration of the PPO dosimeters for solar UVA exposure is shown in Figure 1. The data points are the averages of the four ΔA's measured for each dosimeter and the error bars on the x-axis values are the standard deviation of the four measurements. A trend curve was fitted to the calibration data with the form of:

$$UVA = 1.2\times10^{7}(x^{0.51}) \qquad J/m^2$$

The resulting R^2 for the calibration was greater than 0.99. The spectral transmission of the mylar was measured pre-exposure and post-exposure to solar UV to test for any significant changes. The change in spectral transmission of the mylar is provided in Figure 2. The maximum change was approximately 13% at 333 nm.

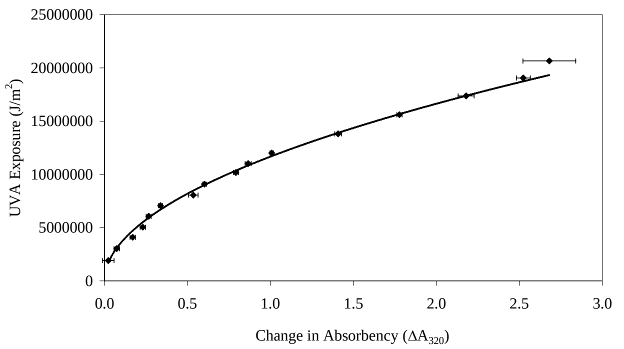

Figure 1. Calibration curve for PPO UVA dosimeter.

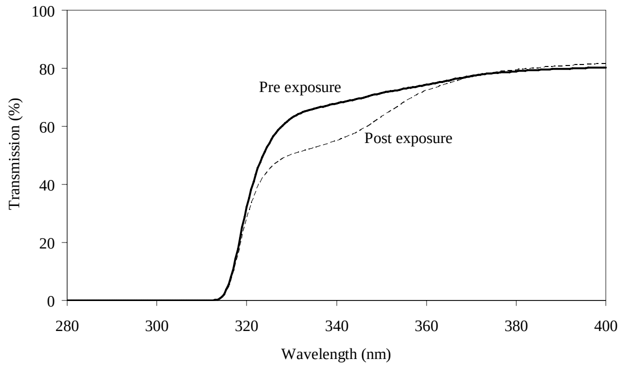

Figure 2. The spectral transmission of mylar pre and post exposure.

For reproducibility tests, ten dosimeters were placed on a horizontal plane and exposed to solar UV. All dosimeters received the same exposure of solar UV producing a mean ΔA_{320} of 0.598 with a standard deviation of no more than ±5%. This variation may be due minor variations over the surface of the sheet of PPO film from which the dosimeters were fabricated and the influence of dust particles that accumulated on the surface of the dosimeters during the exposure period.

Discussion

Preliminary results indicate that this UVA dosimeter saturates reasonably slowly when exposed to sunlight and can measure exposures of more than 20 MJm^{-2} of solar UVA radiation with an uncertainty level of no more than ± 5%. The size and lightweight properties of the dosimeter means that it can be attached to the anatomical sites of life size manikins simulating humans in different environments in order to determine the UVA exposures to those sites. The usage of the dosimeter requires the calibration against a calibrated meter. The profile of the calibration curve will vary with the season and this can be overcome by calibrating the dosimeter in the season that it will be employed to measure the solar UVA exposures.

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