Patterns in Surface Distribution of Human Exposure to Solar Ultraviolet

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Abstract. A method for the three dimensional representation of erythemally effective ultraviolet radiation (UV_{ery}) incident to the human body has been developed from a series of polysulphone dosimeter (PS) measurements to the face, neck, arms, legs and hands of a manikin model. The technique has been used to represent a series of human UV_{ery} exposure patterns in the solar zenith angle (SZA) range 30^o-50^o measured in an open environment in Toowoomba, Australia (27.5°S 151.9°E). The human body representations of exposure presented here improve upon existing techniques to represent the UV_{ery} exposure to complex body shape topography, providing for the first time, estimates of exposure that take whole body shading effects into account from high density PS dosimeter measurements.

Introduction

Solar UV induced exposures to the human body have previously been measured extensively using PS film badges placed on manikin and human subjects (Diffey, Tate and Davis 1979; Rosenthal et al. 1990; Kimlin Parisi and Wong 1998). This previous research has measured UV exposure at a limited number of locations. Variations in human topography, especially to regions such as the face, however, have made the accurate estimate of UV_{ery} surface distribution difficult without the extensive collection of measurements made over a large number of closely spaced body sites. An alternative approach has been to measure exposure at surfaces oriented in various planes relative to the horizontal plane (Hoeppe et al. 2004), however such approaches require taking into account the influence of body shading to specific sites. The approach presented here utilises measurements of the UV_{ery} exposure with PS dosimeters from an extensive number of body sites to provide contours of the UV_{ery} exposures. These are weighted with body topography and improve upon techniques, such as simple linear interpolation, to estimate exposure over widely spaced measurement sites.

Polysulphone UV_{ery} exposure measurement

PS dosimeters having a response to UV radiation similar to human skin, (Davis, Deane and Diffey, 1976) measuring 10x15 mm with a clear circular aperture of 6 mm were manufactured from PS film cast to an approximate thickness of 40 µm at the University of Southern Queensland and mounted to flexible frames to fit life size manikin models. Changes in PS dosimeter optical absorbency measured at 330 nm were calibrated to the erythemally weighted spectral response:

$$\mathrm{UV_{ery}} = \int_0^T \int_{UV} \mathrm{S}(\lambda,\mathrm{t})\mathrm{A}(\lambda)\mathrm{dtd}\lambda$$

Spectral measurement uncertainty in instrument stability and wavelength response has been determined at 6.3% (Parisi and Downs 2004). Calibrated UV_{ery} exposure has been represented on a three dimensional contour wireframe representation of the exposed manikin. The UV_{ery} exposure as a percentage of the received horizontal plane ambient (ER) has also been determined and calculated using the approximation of Diffey (1989):

$$ER = \frac{(9\Delta A_{330}{}^3 + \Delta A_{330}{}^2 + \Delta A_{330})}{(9\Delta A_{330hor}{}^3 + \Delta A_{330hor}{}^2 + \Delta A_{330hor})} \times 100$$

The calibrated UV_{ery} exposure and ER values were determined by the placement of a high density network of PS film dosimeters measured across the face, neck, arms, legs and hands, regions known to suffer long term skin defects (Lee 1989). UV_{ery} exposure was then represented as a series of coloured contours in three dimensional space over each of these body regions. Figure 1 depicts arm ER contours measured over the SZA range 45^o-42^o on 30 April 2007.

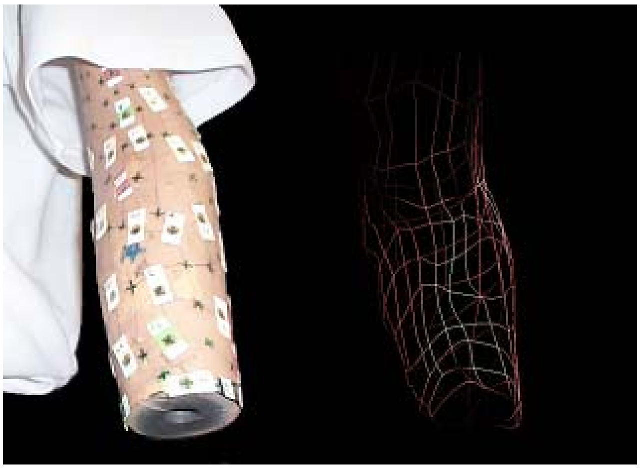

Figure 1. Photographed manikin arm dosimeter sites (left) and three dimensional model exposure contours (right). ER was measured for the arm in a vertical position (alongside the manikin as photographed). The ER depicted here ranges from 0 to 51% (dark to light) of the measured horizontal plane UV_{ery} exposure.

Specific ER colour levels represented along exposure contours ranging from 0 to 100% are interpolated between measured dosimeter sites. Each interpolation between adjacent measurement sites consists of 5 evenly spaced coloured segments and is represented accordingly:

$$x_i = x_{i-1} + \left(\frac{A-B}{5}\right)$$

where points A and B represent the measured ER at two adjacent sites located at contour mesh intersections on the model wireframe and values x_1 through x_4 are spaced evenly in the adjacent dosimeter site interval (Figure 2).

The exposure ratio level (ER) and subsequent colour assigned to each of the 5 segments spaced between measurement sites is calculated as the average of the value assigned to each segment x_i and $x_{(i+1)}$, represented in the range x_1 through x_4.

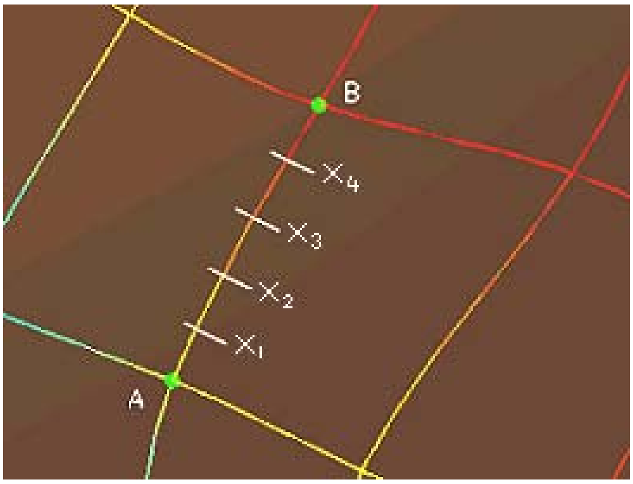

Figure 2. Exposure contours and representative colour ER segment divisions interpolated between two adjacent measurement sites, A and B are highlighted in the figure. For the case shown here, points A and B are separated by approximately 5 mm and represent ER to the forehead.

Solar UV Exposure Environment

For the study results presented here, exposure to the manikin model was recorded for a general case only. Due to high density spacing of PS dosimeters, measurements to each of the face, neck, arm, hand and leg models were often not recorded at each adjacent dosimeter measurement site (see Figure 1) during exposure. Rather, experimental UV_{ery} exposure, expressed as a percentage of the horizontal plane ambient UV was recorded under clear sky conditions within the SZA range 30^o-50^o and was collated with further ER data measured within the SZA range to complete a contour network. Exposures were recorded at the same open location in Toowoomba and extended from between 1 and 4 hours, provided clear sky conditions and the SZA remained within the 30^o-50^o limit. The measurement location at the University of Southern Queensland is located at an altitude of approximately 693 m and located within the city of Toowoomba (population approximately 100,000), experiencing limited pollution, low aerosol concentrations and a high number of sunshine days. The ER contour representations presented in this research are therefore complete for the stipulated general case only, however, the technique presented may be applied to other manikin models in different locations and under different exposure conditions. The results presented, minimise the interpolation estimates of Downs and Parisi (2007) developed previously for the face and provide reasonable estimates of human body UV_{ery} exposure distribution that may be applied in other research applications.

Conclusion

Detailed solar UV induced exposures to a manikin model have been measured in a series of clear sky experiments conducted over the SZA range of 30^o-50^o. A technique for the estimation of exposure to body parts has been developed that can be applied in other research applications such that body surface exposures can be estimated in accordance with changing topography. Further applications of the developed technique may include modelling of UV_{ery} exposure patterns to the human body with variation in body position relative to changes in SZA, atmospheric conditions, the surrounding environment and different forms of personal solar UV protection.

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