FIELD MEASUREMENTS ON PROTECTION BY STOCKINGS FROM SOLAR ERYTHEMAL ULTRAVIOLET RADIATION

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Running Title: Protection by Stockings from Solar UV

FIELD MEASUREMENTS ON PROTECTION BY STOCKINGS FROM SOLAR ERYTHEMAL ULTRAVIOLET RADIATION

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Abstract - The ultraviolet (UV) radiation protection provided by stockings was measured by simulating as close as possible the real life situation under field conditions in Queensland, Australia. Polysulphone dosimeters were employed for measuring the solar erythemal UV radiation to sites on the leg with a polysulphone dosimeter located both above and underneath the stockings to compare the protected and unprotected erythemal UV exposures. The solar ultraviolet protection factor (UPF) was measured for different stocking thickness or denier and for different colour. Under the field conditions, the highest UPF of 4.6 was provided by the 50 denier stockings with the lowest of 1.4 to 1.8 for the 15 denier. For the 15 denier stockings, there was no significant difference between the lighter colours with only a small increase in UPF to 1.8 for the darker colour. People who require photoprotection to the legs should wear trousers or at least the 50 denier stockings.

INTRODUCTION

Australia has the highest incidence rates of non melanoma skin cancer (NMSC) and cutaneous malignant melanoma in the world, with Queensland having the highest incidence rates of the Australian states[1]. The high ambient ultraviolet (UV) levels[2] and a predominantly fair skinned population combined with an emphasis on an outdoor recreational and sporting lifestyle has contributed to these high disease rates. Sun safety publicity campaigns and media reporting of the ozone hole have increased the public awareness of the dangers of excessive exposure to solar UV radiation along with an increased awareness of the need to employ personal UV protective strategies, such as hats and sunscreens.

Clothing is an important protective strategy for the minimisation of ultraviolet exposure to humans. The UV protection of fabrics has been quantified by the introduction of the ultraviolet protection factor (UPF)[3]. A large number of fabrics have been tested in the literature for their protection against UV with the primary factor affecting the UV transmission being the weave structure with colour being a secondary factor[4,5]. The degree of stretch in the material along with the wetness of the material also affects the UV transmittance[4].

The UV transmittance of different types of stockings has been measured[6] to calculate the sun protection factor of plain knit stockings. This UV transmittance was measured in the laboratory with broad spectrum UV fluorescent lamps as the source. This may be different to the actual transmittance in sunlight due to the angle of the radiation through the material perhaps affecting the UV transmittance. The elevation angle of the sun along with the angle of transmission through the fabric varies with time of day. Variations in the UPF of fabrics by a factor of two or more have been found between laboratory tests and *in vivo* tests of the UV

protection provided by various T-shirt materials[7]. This paper extends previous research in the literature that tested the UV transmission of stockings in the laboratory. The method employed takes into account the angle of transmission, variations in atmospheric conditions during the exposure period and the stretch of the material as it is worn. In this research, the protection from erythemal solar radiation provided by stockings was measured by simulating as close as possible the real life situation under field conditions in Australia and the implications for the prevention of skin cancer are considered.

MATERIALS AND METHODS

Erythemal UV

Polysulphone dosimeters with a response to UV radiation similar to human skin[8] were employed for measuring the solar erythemal UV radiation[9] to specific anatomical sites on the legs. The polysulphone film of approximately 40 μm thickness was mounted in a 2.5 cm x 2.5 cm holder with a central aperture of approximately 1 cm^2. Exposure to UV changes the optical absorbance of the dosimeter. This was quantified by measuring the optical absorbance before and after UV exposure at a wavelength of 330 nm with a spectrophotometer (model UV160, Shimadzu Co., Kyoto, Japan). The degree of change in the dosimeters was calibrated to erythemal exposure in a similar manner to Kimlin *et al*[10] against a temperature stabilised Biometer (model 501, Solar Light Co., Philadelphia, USA).

Field Measurements

The field measurements were undertaken in Toowoomba (27.5 ^oS) with a manikin used in this study to simulate human exposure and each stocking rolled onto a manikin's leg. Care was taken to ensure each stocking was fitted in a similar manner to each other. The manikin was upright on a platform rotating at approximately 1 revolution per minute as employed by

previous researchers[11]. The activity of humans is complex and previous research has employed rotating manikins and headforms to determine the UV exposure to specific sites of the human body (for example, Wong *et al*[11]) as human volunteers wearing dosimeters may not always be feasible nor practical. The UV exposures were measured between 12:00 Australian Eastern Standard Time (EST) and 13:00 EST over a number of days in autumn. The times of the day for the exposure were selected in order to approximately coincide with indoor workers' lunch breaks. On a sunny day, this period also has a high UV irradiance compared to the remainder of the day. This occupational group is the most likely to be both outside at noon and wearing stockings.

An unshaded, grassy area with low UV reflectance (UV albedo less than 5%) was utilised in this project. The manikin was clothed in a dress reaching to 22 cm above the top of the knee cap. The erythemal UV exposures were measured with the polysulphone dosimeters at twelve sites on the manikin left leg, namely, the anterior, posterior, medial and lateral orientations at the ankle and on the shin at 11 cm below the top of the knee cap and on the thigh at 9 cm above the top of the knee cap. The amount of stretching of the stockings was approximately 133%, 211% and 216% at the ankle, shin and thigh respectively. This was quantified by measuring the circumference of the stockings at each of the three points before fitting on the manikin leg and while fitted on the manikin. At each of the twelve sites, a polysulphone dosimeter was deployed both above and underneath the stockings to allow comparison of the erythemal UV exposure underneath the stockings to that above the stockings. At each site, the dosimeters above the stockings were offset by approximately 1 cm compared to the dosimeters underneath the stockings in order to prevent any shading of the dosimeters underneath the stockings by the corresponding dosimeter above the stockings. For each site, the ultraviolet protection factor (UPF) was calculated as:

$$UPF = \frac{UVBE}{UVBE_P} \quad (1)$$

where $UVBE_P$ is the protected erythemal UV exposure underneath the stockings and UVBE is the unprotected erythemal UV exposure above the stockings. The effect of stocking thickness was investigated by employing three pairs of the same nubeige colour, each with a different denier (D), namely, 15, 20 and 50 D. The denier is the industry standard measure of yarn thickness and is defined as the weight in grams of a 9000 m length of fibre[6]. Similarly, for the 15 D stockings, the three colours of nubeige, barely black and smoke were employed to investigate the effect of colour. The stockings were plain knit and the composition of each of the stockings is provided in Table 1. The colour of each of the stockings has been quantified by measurement of the percentage transmission of each stocking in the unstretched state over the 400 to 700 nm wavelength range in the spectrophotometer and is provided in Figure 1.

RESULTS

Field Measurements

The erythemal UV exposures over the one hour period for the anterior, posterior, interior and exterior have been averaged for the thigh, shin and ankle and are provided in Table 2. The UV exposures under the stockings to the thigh are less than those to the shin and ankle. The UV exposures to the shin and ankle for the 50 D stockings range from 0.28 to 0.38 MED. One MED is defined as the amount of biologically effective UV required to produce barely perceptible erythema after an interval of 8 to 24 hours following UV exposure[12]. The UV exposures to these sites for the 15 D and 20 D stockings range from 0.30 to 0.99 MED. These are less than one MED whereas the unprotected UV exposures to the shin and ankle above the stockings are all more than one MED.

Ultraviolet Protection Factors

The UPF's calculated according to Equation (1) for each measurement site have been averaged to provide an UPF for each pair of stockings as shown in Figure 2. The highest UPF of 4.6 was provided by the 50 D stockings with the lowest of 1.4 to 1.8 for the 15 D. For the 15 D stockings, there was no significant difference between the nubeige and smoke colours with only a small increase in UPF to 1.8 for the barely black colour.

DISCUSSION

The research in this paper has quantified in the field the protection from erythemal UV radiation provided by stockings by simulating as close as possible the real life situation. The calibrated polysulphone dosimeters allowed measurements of the erythemal UV exposures to specific anatomical sites simultaneously. The protection provided by stockings depends on the factors affecting the stretch of the stockings. This will vary with the length and circumference of the wearer's legs. Additionally, the length of the dress worn will affect the degree of shadowing along with the elevation of the sun affecting the angle of transmission through the fabric and the consequent UPF of the fabric. The effect of shadowing by the dress was evidenced by the UV exposures to the thigh under the stockings being less than that to the shin and ankle. This is despite the larger diameter of the thigh resulting in the weave being more stretched at this point compared to the shin and ankle.

Nevertheless, the results in this paper provide an indication of the protection provided by stockings. The UPF's for the stockings ranged from 1.4 to 1.8 for the 15 D stockings and increased by approximately a factor of 3 to a UPF of 4.6 for the 50 D stockings. The increase in UPF for the darker colour was consistent with previous research that found an increase in UPF for darker stockings[6] and darker clothing fabrics[4]. The stockings do provide a minor

degree of UV protection, however, it must be noted that these UV exposures are only over a period of one hour in autumn. The UV exposures would be higher and possibly over 1 MED for a longer exposure period or in summer. There was not a great deal of protection provided by the 15 D stockings. Consequently, if stockings are worn, in order to increase the UV protection both during recreational and occupational activities and for patients requiring photoprotection, 50 D stockings are recommended.

Despite the protection provided by the 50 D stockings, appreciable UV cumulative exposures might be received if there are repetitive exposures to solar UV. Each individual UV exposure may be sub-erythemal in exposure, however, research has found that repetitive sub-erythemal UV exposures have a cumulative effect and contribute to skin damage[13]. The protection from solar erythemal UV radiation provided by the stockings, although useful, is not sufficient protection. People requiring photoprotection to the legs are recommended to wear trousers or at least the thicker 50 D stockings in order to reduce the contribution to the risk of skin cancers.

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Table 1. Composition of each of the stockings.

Stockings Type	Composition
50 Denier Nubeige	92.5% nylon, 7% elastane, 0.5% cotton
20 Denier Nubeige	84.5% nylon, 14.5% elastane, 1% cotton
15 Denier Nubeige	80% nylon, 19% elastane, 1% cotton
15 Denier Barely Black	85% nylon, 14% elastane, 1% cotton
15 Denier Smoke	84% nylon, 15% elastane, 1% cotton

Table 2. The erythemal UV exposures for the protected and unprotected sites for a one hour period

Stockings Type	Erythemal Exposures (MED)					
	Protected			Unprotected		
	Thigh	Shin	Ankle	Thigh	Shin	Ankle
50 Denier Nubeige	0.22	0.38	0.28	0.76	1.8	1.7
20 Denier Nubeige	0.28	0.63	0.30	0.45	1.4	1.2
15 Denier Nubeige	0.25	0.53	0.66	0.31	1.1	1.0
15 Denier Barely Black	0.18	0.51	0.45	0.34	1.0	1.1
15 Denier Smoke	0.46	0.94	0.99	0.50	1.5	1.6

FIGURE CAPTIONS

Figure 1. Percentage transmission in the visible wavelengths for the (1) barely black 15 D, (2) smoke 15D, (3) nubeige 15 D, (4) nubeige 20D and (5) nubeige 50D.

Figure 2. UPF's for the different colour and different denier stockings.

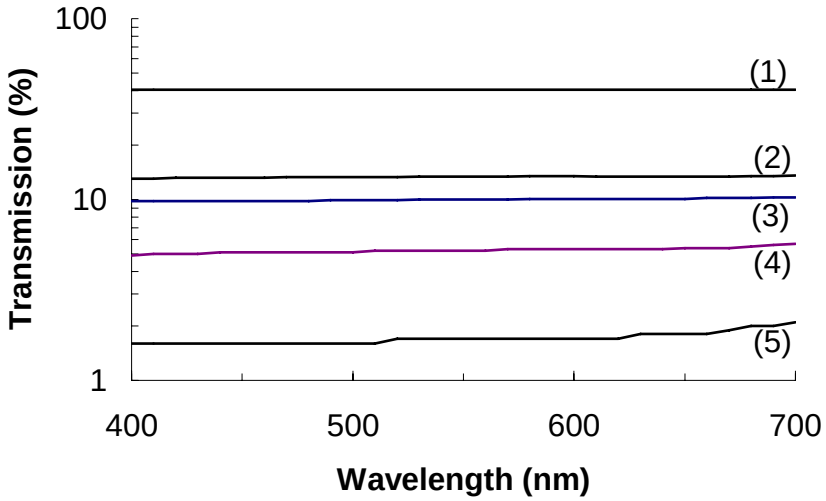

Figure 1

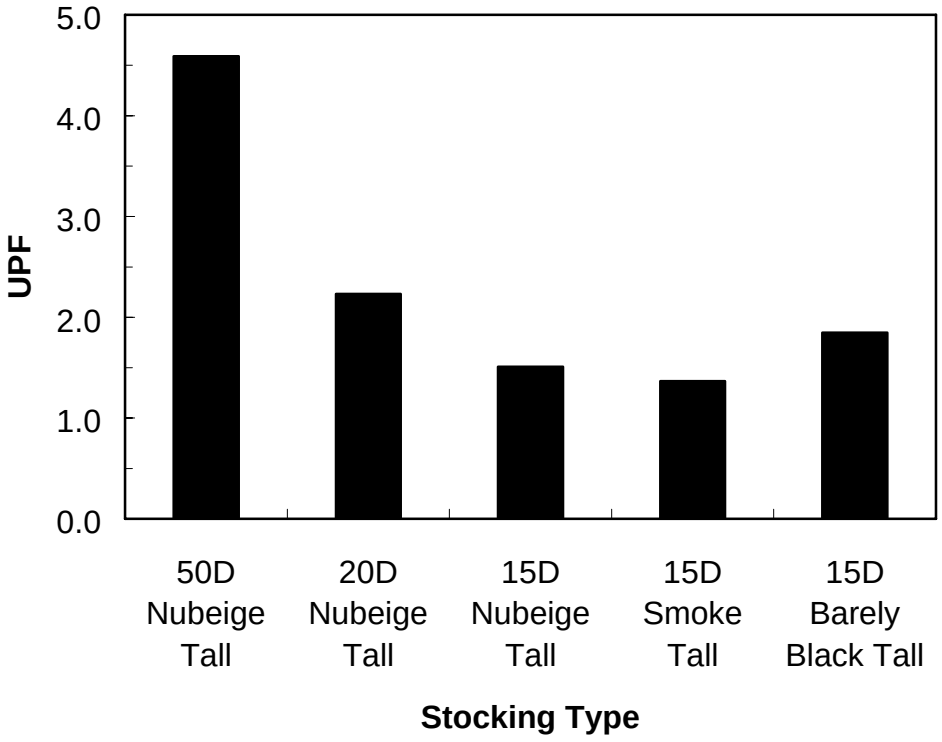
5.0
4.0
3.0
2.0
1.0
0.0
UPF
50D Nubeige Tall
20D Nubeige Tall
15D Nubeige Tall
15D Smoke Tall
15D Barely Black Tall
Stocking Type

Figure 2