Solar UV exposure in construction workers in Valencia, Spain.

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ABSTRACT

Exposure to ultraviolet radiation (UVR) has long been recognized as the most important environmental risk factor for melanoma and skin cancer. Outdoor workers are among the groups most at risk from exposure to solar UVR in their daily activities. Sensitive spore-film filter-type personal dosimeters (VioSpor) were used to measure the biologically effective UVR received by construction workers in the course of their daily work. The study took place in Valencia, Spain, in July 2010 and involved a group of 8 workers for a period of 5 days. The median UV exposure was 6.11 SED/day, with 1 SED defined as effective 100 J/m^2 when weighted with the CIE erythemal response function. These workers were found to receive a median of 13.9% of total daily ambient ultraviolet erythemal radiation (UVER). Comparison with the occupational UVR exposure limit showed that the subjects had received UVER exposure in excess of occupational guidelines, indicating that protective measures against this risk are highly advisable.

Introduction

The epidemiological and biological evidence and a large body of literature support a causal link between UVR exposure and melanoma and non melanoma skin cancers (Lucas et al., 2006).

The 2006 WHO report (Lucas et al., 2006) was the first-ever systematic examination of the global health burden attributable to UVR and researched nine adverse health outcomes from excess UVR exposure. The three most important were found to be cutaneous malignant melanomas and non-melanoma skin cancers (squamous cell carcinomas and basal cell carcinomas). UVR can also cause sunburn, skin photoageing and cortical cataracts, among others.

According to the Lucas report, the most serious consequence of excessive UVR is malignant melanoma, which has high cure rates only when detected early. Up to 90% of the global burden of disease from melanoma and other skin cancers are estimated to be due to UVR exposure (Lucas et al., 2006).

Skin cancer and melanoma are a growing problem in Spain and the rest of Europe as its incidence has increased significantly in the last 20 years (Birch et al., 2010; de Vries et al., 2003; Fuglede et al., 2011; Garbe et al., 2009; Madan et al., 2010; Medhaug et al., 2009).

Regarding non-melanoma skin cancer (NMC), there are significant variations in incidence rates between Europe, the USA and Australia: these are about 5 times higher in the USA and 20–40 times higher in Australia than in Europe (WHO, 2008). A continuous increase in incidence over time has been observed in different parts of the world, particularly in Spain, where in the period 1985-87 the age-standardised incidence rate (european standard population) presented for men a maximum of 72.04, while in the period 1992-98 the maximum was of 105.2 (Cabanes et al., 2009).

However, NMC, the most common malignant tumour of all, are rarely a cause of death (WHO, 2008). In Spain the NMC mortality rate has been halved in the last 35 years. This decrease in annual mortality has been confirmed in the last decade (-2.8% in men and -4.4% in women) (Cáncer en cifras, 2011).

Regarding melanoma, there are about 160000 new cases worldwide each year, of which almost 80% are in North America, Europe, Australia and New Zealand (WHO, 2008). In Europe, the incidence of melanoma has nearly tripled in the last 40 years at a rate of 4% per year (WHO, 2008). For melanoma, Spain presented an age-standardised incidence rate (world standard population) of 3.2 in 1985 and 5.2 in 2008 (GLOBOCAN, 2008), lower than in Europe (7.2) and Scandinavia (12.7) and of course Australia and New Zealand (36.6), with the highest figures in the world (GLOBOCAN, 2008).

Melanoma, the most aggressive cutaneous cancer, is responsible for up to 80% of all deaths from skin cancers (Lucas et al., 2006), with 60000 deaths per year worldwide caused by solar UVR.

In Spain the mortality rate from melanoma has quadrupled in the last 35 years (Cáncer en cifras, 2011), although there has only been a slight increase in annual mortality (0.14% in men and 0.62% in women) in the last decade. Despite this increase, the mortality rate from melanoma in Spain is still among the lowest in Europe, probably due to the population’s skin characteristics.

During the 90's a group of international experts (CAREX project) met to evaluate exposure to carcinogens in the workplace (Kauppinen et al., 1998) within the European Union program

"Europe against Cancer". According to the criteria established by these experts, the highest number of cases of occupational exposure occurred in Spain (Maqueda et al., 1998). The CAREX project found that in Spain 25% of the working population, i.e. 3.1 million workers between 1990 and 1993, were exposed to agents considered to be carcinogens by the IARC (IARC, 2000; Maqueda et al., 1998). Solar radiation was the agent more important, as is main source of human exposure to UVR, with approximately 1 million workers affected between 1990 and 1993 (Maqueda et al., 1998).

It is therefore generally accepted that constant exposure to solar UVR, especially in unprotected outdoor workers, is a significant risk factor. High occupational UVR exposure is assumed to be associated with skin cancer (Bauer et al. 2011; Downs et al., 2009; Hakansson et al., 2001; Kenborg et al., 2010; Lichte et al., 2010; Radespiel et al., 2009).

Some recent studies show that the incidence of melanoma is related to both altitude and latitude (Aceituno et al. 2011; Boniol et al. 2005; Chang et al., 2009; de Vries et al., 2004; Downs et al., 2011; Micu et al., 2011; Moehrle and Garbe, 1999; Pfeifer et al., 2006).

Due to its geographical situation, for most of the year the Valencia Region (Spain) receives large doses of UVR. Outdoor workers receive regular and significant solar UVR in their course of their activities (Gies and Wright, 2003; Gies et al., 2009; Glanz et al., 2007; Hammond et al., 2009; Milon et al., 2007; Moehrle et al., 2003; Schmalwieser et al., 2010; Serrano et al., 2009; Siani et al., 2011; Siani et al., 2008; Thieden et al. 2005) especially when solar radiation is intense.

Otherwise, solar exposure is known to have positive effects on human health, such as, for example, the synthesis of Vitamin D_3 (de Gruijl, 2011; Webb et al., 2011), essential for bone mineralization (Norval et al. 2007). Appropriate vitamin D levels, besides being required for skeletal health, have also been suggested as beneficial against multiple sclerosis (Kampman et al., 2010; Van Amerongen et al., 2004), cardiovascular disease (Zittermann and Gummert, 2010) and the development of breast, prostate and colon cancers (Gilbert et al., 2009; Grant, 2010; Grant and Holick, 2005; John et al., 2007). In the case of depressive disorders, there is evidence that supports the role of suboptimal vitamin D levels, although the data are not conclusive and further studies are necessary (Humble, 2010).

International campaigns, such as the Euromelanoma (Euromelanoma, 2011) have been set in motion to prevent and detect massive melanoma. Since the year 2000, Spain has participated in three of these campaigns, proving their value by the number of new early detections and successfully excised melanomas.

The aim of this work was to quantify the ultraviolet erythemal radiation (UVER) exposure of building workers in the course of several days in their regular work schedule during the summer in Valencia (Spain) using personal dosimeters.

Materials and methods

Study location

The study took place in the campus of the Universitat Politècnica de València (UPV) (coordinates 0º 22 ' W, 39º 28 ' N, sea level) to the north of the city of Valencia, far from industrial areas and near open country, in the Spanish region of Valencia in July 2010 and involved a group of 8 building workers over a period of five working days (7, 8,9,12 and 13 July).

Subjects and design

Subjects The subjects completed a questionnaire in which they registered the time that they put on and removed the dosimeter and the number of hours spent outdoors. As the purpose was to determine the maximum solar exposure received during their activities, they were instructed to use the dosimeters at the beginning of their working day if most of the sky was cloudless. They were also asked not to make any changes to their behaviour during the test and to continue with their normal schedules.

1) Eight male workers were selected at random from the employees of a construction company that was putting up a building on the UPV campus at the time. Their work was carried out entirely outdoors during the period of five working days. The group included: one site foreman, one formwork foreman, two security officers, three formworkers and one steel fixer. The two security officers and two formworkers wore the dosimeters on their shoulders throughout their working day, while the others wore the dosimeter on the chest.

The individual cumulative solar UVER exposure was measured by a VioSpor Type II dosimeter, which was changed every day. The subjects wore the dosimeters from 8 a.m. to 7 p.m. (except during the 2 p.m. - 3 p.m. lunch hour), except for 9 July, when it was worn from 7 a.m. to 3 p.m.

Personal UVER dosimeters A UV sensitive spore-film filter system (VioSpor Blue Line Type II Dosimeter, Bio-Sense, Bornheim, Germany) was used in the test. These dosimeters have been proved effective for personal UV measurements in outdoor occupations such as building workers (Milon et al., 2007), lifesaving (Moehrle and Garbe, 2000; O’Riordan et al., 2008; Serrano et al. 2009), or mountain guides (Moehrle et al., 2003; Moehrle and Garbe, 2000).

Spore-film production (DNA repair-deficient strain of *Bacillus subtilis*) and the development of the films are described in Furusawa et al., 1998 and Munakata et al., 2000. The spore films are covered by a filter system with optical properties simulating the erythemal response of human skin, in accordance with the Commission Internationale de L´Eeclairage (CIE) reference spectrum (McKinley and Diffey, 1987) and mounted in waterproof casings with a diameter of 32 mm. The working range used is 0.5-22.5 standard erythema dose (SED), where 1 SED is defined as effective exposure of 100 J/m^2 (CIE, 1997) when weighted with the CIE erythemal response function. The manufacturer declares a measurement error of ±10%. The measurements are expressed as SED of biologically effective solar UVR.

The VioSpor system is subject to constant quality control checks. System validation is carried out using in-vivo comparative measurements (Quintern et al., 1997). The wavelength-specific calibration of VioSpor is carried out using measurements on the Okasaki spectrograph in Japan (lamp performance based on the US radiation strength norm of the National Institute of Standards) (Furusawa et al., 1998; Munakata et al., 2000).

VioSpor has also been validated during several instrument intercomparisons performed under field conditions in which VioSpor data were compared with the minimal erythema dose values calculated from spectroradiometer data (Seckmeyer et al., 1998).

Ambient solar UVER

Ambient UVER was recorded with a UVB-1 radiometer (Yankee Environment System, YES), belonging to the Valencia regional government’s (GV) UVB measurement network (*Programa Meteorología*, 2011) located at 00º20'09'' W 39º27'49'' N, on a flat roof without obstructions or shade on a building in the city of Valencia.

The sensor is a UVB-1 YES model broadband radiometer that measures in the range 280-400 nm by providing a single integrated value for the whole measurement range. The instrument response is similar to the erythemal action spectrum, so that the sensor is capable of measuring the biologically effective solar UVR.

The measuring station also includes a stabilised uninterruptible power supply, a mast assembly platform for the radiometer, a communication antenna, and a compartment for elements with pre-installation of electrical and mechanical components. The UVB-1 pyranometer is designed to be stable for long periods and for field work without supervision.

The calibration uncertainty is approximately 10%. The cosine response is less than 4% for solar zenith angles below 55º (manufacturer's specifications). Calibration consists of measuring the spectral response of the radiometer indoors and a comparison with a Brewer MKIII spectroradiometer outdoors (Hulsen and Grobner, 2007; Vilaplana et al., 2006).

It should be noted that the YES UVB-1 presents non-negligible errors for high zenith angles unless a double entry zenith angle–ozone calibration matrix is used (Vilaplana et al., 2006). For a constant ozone value of 300 DU, the error given by the calibration matrix remained below 9% for zenith angles below 70°. Additional calibration of this radiometer was carried out by the Earth Physics Department of the UV by comparison with an Optronic OL-754 spectroradiometer equipped with a double monochromator with a spectral range that extends from 250 nm to 800 nm. The values given by the Optronic spectroradiometer were convolved with the erythemal action spectrum and then integrated and compared with the values obtained from the UVB-1 (Cañada et al., 2008; Tena et al., 2009).

UV exposure limits

The International Radiation Protection Association established exposure limits (EL) in its recreational/occupational UV exposure standard in 1985 (IRPA, 1985). These were later adopted by the International Commission on Non-Ionizing Radiation Protection and updated in 2010 (ICNIRP, 2010). The ICNIRP recommends a maximum personal daily exposure of 30 J/m^2 effective UV dose within an 8-hour period for sensitive unprotected skin using the American Conference of Governmental Industrial Hygienists (ACGIH) action spectrum (ICNIRP, 2007). This limit is equivalent to approximately 1.0-1.3 SED using the CIE action spectrum (ACGIH, 1999).

However, the ICNIRP report (2007) also found that skin adapts to frequent UV exposure not only by the obvious effect of skin darkening but also by increasing its thickness, which can lead to a significant increase in UV protection by a factor of five or greater.

According to ICNIRP (2010) for Mediterranean subjects with skin phototype III/IV a value of 12 SED is assumed to be the average threshold exposure for sunburn of sun-adapted skin. For the same type of skin but without adaptation a value of 5 SED is adopted. Exposure higher than 12 SED denotes high risk.

The exposure measured in the workers in our study was compared with the value of 12 SED, since we considered that due to their work they already had sun-adapted skin. It was also compared with the EL value.

Skin Exposure factor

A semi-quantitative hazard assessment for outdoor workers can be provided by using a skin exposure factor (EF), as reported by ICNIRP, 2007:

Skin Exposure factor $= f_1\, f_2\, f_3\, f_4\, f_5\, f_6$

where f_1 is the factor indicating geographical latitude and season, f_2 is the cloud cover, f_3 is the duration of exposure, f_4 is the ground reflectance, f_5 refers to clothing and f_6 to shade.

The values adopted for this study were the following:

f_1= 7 (mid-latitudes in summer) f_2= 1 (clear sky); f_3= 1 (all day); f_4=1 (various surface);

f_5= 0.5 (trunk protected but arm exposed); f_6= 1 (no shade).

Skin EF was determined for the building workers and was compared with the guide suggested by ICNIRP (2007) to ascertain the minimal level of protection required for the workplace**.**

Statistical analysis

Data were analysed using the Statgraphics Plus Statistical Package v5.1 software and are expressed as median (minimum-maximum). The Mann-Whitney test (Wilcoxon) was used to compare differences between subjects in terms of SED, SED per hour outdoors and ER. Statistical significance was set at $p \leq 0.05$ for all analyses.

Results

Ambient solar UVER

Measurements of daily ambient solar UVER were recorded by the radiometer at the GV station. These are shown in Table 1 for each day of the study.

Also shown in Table 1 is the actual temperature data provided by the State Agency for Meteorology (AEMET, 2011), ozone data from the Ozone Monitoring Instrument (OMI), (NASA, 2011) and the maximum ultraviolet index (UVI) (ICNIRP, 1995; WHO, 2002) calculated from the noonday UVER (W/m^2) measurements at the local weather station for the entire period of the study.

As shown in Table 1, solar UVI is quite high, between 8 and 9, and is characteristic of the summer figures in Valencia. The total column ozone from the OMI measurements for Valencia is between 315 to 325 D. U. Mean solar height at noon in Valencia during the study period was 72.8 degrees.

<Table 1>

Measured UVER exposures

Table 2 shows the recorded median daily dosimeter exposures, 6.11 (0.98-24.5) SED. Per hour outdoors was 0.68 (0.10-2.56) SED, where data are expressed as median (minimum-maximum). The exposure ratio (ER) was also calculated, defined as the ratio between the personal dose on a selected anatomical site and the corresponding ambient dose on a horizontal plane during the same day. Table 2 lists the median of the exposures recorded for the corresponding day as a percentage of the measured daily total ambient UVER. Median ER for the entire study period was 13.9% (2.3-55.0).

<Table 2>

The UVER exposure received on the first and last day of the study is twice that received on the remaining days, as is the exposure ratio (see Table 2).

The range gives information about how spread out the data is. Daily range gives a measure of the variability between subjects. On July 8, 12th and 13th the UVER exposure range is twice that of the others two days, indicating that on those days, the individuals present less consistent behaviour with respect to their activities.

<Table 3>

Table 3 show the median UVER exposure and exposure relative to ambient for each worker. The variation between the different subjects is of interest, since there are differences between individuals due to their different occupations on the building site. Some of the lowest exposures were found in the foremen, who spent some time under cover. The occupations with the highest UVER exposures were found in those who spent most of their time in sunlight and included the formworkers and the steel fixer. The latter received a UVER dose two to three times higher than the rest. The range for each worker gives a measure of the variability in each subject. The formworkers and steel fixer present a range of UVER exposure twice that of the others, indicating that their occupations presented less consistent behaviour than the other activities.

<Table 4>

The results discussed above are sub-classified by dosimeter position in Table 4. No significant difference was found in terms of SED received ($p=0.92$), SED per hour ($p=0.92$) or ER ($p=0.99$) regarding the dosimeter position, using the Mann-Whitney (Wilcoxon) test to compare medians.

Skin Exposure Factor

The application of this term gives a result of 3.5, in accordance with the values adopted for the study. According to the guide suggested by ICNIRP (2007) the workers involved in this study should use long-sleeved shirt, trousers, brimmed hat and SPF15+ sunscreen to reduce skin exposure.

<Table 5>

Discussion

A number of studies have measured UVR exposure in building workers. Milon et al., 2007 studied the effective exposure to solar UVR in building workers in the Swiss Alps in the summer, in which mean concurrent (during the same exposure period) ER ranged between 27% and 54%, measured at five positions on the body. Our median ER measured on two parts of the body ranged between 2% and 55% and was calculated for a 24 h. period.

Hammond et al., 2009 reports the summer UVR exposure among a sample of outdoor workers in New Zealand. For building workers, the mean daily concurrent ER was 19.6 % on the back, with a range of 1.6 to 66.4, whereas we obtained a median ER of 14.5% (range 2.3-55.0) on the shoulder (comparable to the back area).

Gies and Wright, 2003 examined UVR exposure in some groups of outdoor workers related to the construction industry in Australia in the spring. They found that a formworker received a median concurrent ER of 30% and a steel fixer of 33%, both on the chest, whereas we measured a median ER of 9% and 42%, respectively, on the chest. For foremen, they found a median concurrent ER of 18%, while we obtained a median ER of 11-14%. Except for the formworkers, the values can be considered similar.

In other outdoor occupations, Schmalwieser et al., 2010 studied facial solar UV exposure of Austrian farmers and found that they receive on average an ambient daily dose between of 3% and 26%. Siani et al., 2011 quantify the UV exposure of vineyard workers in Italy, who in summer received a median concurrent ER of 29% on the arm and 50% on the back. Gies et al., 2009 measured the UVR exposure of Antartic workers on the chest in summer and obtained a mean ER ranging from 9 to 20%.

A study or gardeners in Ireland and Denmark (Thieden et al., 2005) found median ER values ranging from 4.5 % to 8 %. We conducted a previous study (Serrano et al., 2009) comparing the UV dose received by gardeners and lifeguards and recorded ER values of 9% and 27%, respectively.

The median daily UV exposure for building workers in our study was 6.11 SED, which therefore exceeded the EL by a factor of 6, so that the individuals engaged in these activities received 6 times the expected occupational UVER load for outdoor workers. This outdoor group thus had measured UVER exposures in excess of occupational guidelines, indicating that protective measures are highly advisable.

The skin exposure factor calculated for this study gave us a result of 3.5. In accordance with ICNIRP (2007) recommendations these workers should use long-sleeved shirt, trousers, brimmed hat and SPF15+ sunscreen.

This organisation also found that the skin adapts to frequent UV exposure and can significantly increase UV protection by a factor of five or more (ICNIRP, 2010).

For Mediterranean subjects with skin phototype III/IV a value of 12 SED is assumed to be the average threshold exposure for sunburn in sun-adapted skin type III/IV (ICNIRP, 2010). According to the above results, the median UVER exposure of the workers in this study does not exceed the recommended threshold value.

The building workers in this study received a median of 13.9% ambient UVER, with a range between 2.3 and 55%, and a median daily UV exposure of 6.11 SED, with a range between 1 SED and 24.5 SED. Such a large range in both measurements could be caused by different orientation of the dosimeters relative to the horizontal, due to the different postures adopted by the workers and their orientation on the site, as was also observed by Milon et al., 2007. The effect of the different working locations can also be important, since the foremen, who spent some time in the shade, had lower exposures, while the formworkers and steel fixer, who spent most of their time exposed to sunlight, had the highest UVER exposures. We also found that the activities of these workers presented less consistent behaviour than the other activities.

There are two days when both the UVER exposure and the exposure ratio are twice that of the other days, indicating that the various individuals did not display consistent behaviour on these dates, probably due to a different working location, or possibly because ambient UVR was higher on these two days.

Since building workers can spend up to 9 hr per day exposed to UVR, it is not possible for this population to completely avoid UV exposure, so that the use of sunscreens, sunglasses and protective clothing are advisable protective strategies.

In conclusion, a personal VioSpor film dosimeter was used to measure the occupational UV exposure of building workers, who were found to far exceed occupational UV exposure limits (ICNIRP, 2010). It is therefore clear that permanent and constant exposure to solar radiation without protection by outdoor workers involves a notable risk factor and can be assumed to be associated with skin cancer.

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