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Occupational UV exposure of environmental agents in Valencia, Spain.

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ABSTRACT

Excessive exposure to ultraviolet radiation (UVR) is considered the most important environmental risk factor in the development of melanoma and skin cancer. Outdoor workers are among those with the highest risk from exposure to solar UVR, since their daily activities constantly expose them to this radiation source. A study was carried out in Valencia, Spain, in summer 2012 and involved a group of 11 workers for a period of six 2-day recordings. Sensitive spore-film filter-type personal dosimeters (VioSpor) were used to measure erythemal UVR received by environmental agents in the course of their daily work. Median 2-day UV exposure was 6.2 SED, with 1 SED defined as effective 100 J/m^2 when weighted with the Commission Internationale de L´Eclairage's (CIE) erythemal response function. These workers were found to receive a median of 8.3% total daily ambient ultraviolet erythemal radiation. Comparison with the occupational UV exposure limit showed that the subjects had received an erythemal UV dose in excess of occupational guidelines, indicating that protective measures against this risk are highly advisable.

Keywords: Erythemal ultraviolet radiation; UV exposure; personal dosimetry; exposure ratio.

INTRODUCTION

Exposure to harmful ultraviolet radiation (UVR) is the most important environmental risk factor influencing the incidence of melanoma and nonmelanoma skin cancers (NMSC). A large number of studies have shown a causal relationship between UV exposure and skin cancers (1-4). The two most common types of NMSC are basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). UVR can also cause sunburn, skin damage and eye disorders, among others. It is estimated that up to 90% of the global burden of disease from melanoma and NMSC are due to excessive UV exposure (1).

NMSC and melanoma are a significant health problem in Caucasian populations' worldwide, as their incidence has increased significantly over the past 40 years (5-10) and is projected to continue rising due to growing exposure to UVR associated with the depletion of the ozone layer and sunbathing during recreational activities (3,9,11). Besides, the clothing behavior during occupational activities can also be another important factor.

NMSCs are the most frequent cancers in light-skinned populations (1) and BCC incidence rates in Europe are increasing by 20 every 15 years, being between 40 and 130 (per 100,000 inhabitants and standardized to the world population) in 2000 (8). SCC incidence rates are also increasing in different countries and in 2000 were between 10 and 30 (8). Although the mortality rate has remained consistently low (1), these cases cause high morbidity and are a considerable burden on health care services around the world (12, 13). In Spain the mortality rate was halved between 1975 and 2000, and in the last decade has been fairly stable, with an age standardized for the european population rate (ASRe) mortality of 0.7 per 100,000 inhabitants in 2011 (14).

On the other hand, melanoma represents only around 5% of all skin cancers but is responsible for nearly 80% of all skin cancer deaths (1). In Europe the estimated annual percentage change in melanoma incidence is between 1% and 8% in the past few decades (9, 15), with an estimated ASRe incidence of 11.1 in 2012 (16). The European ASRe mortality of 2.3 in 2012 (16) was the third highest in the world (11) and 50% higher than 30 years ago, although a stabilization has been observed in the last decade (17). In Spain, ASRe mortality is among the lowest in Europe, about 1.4 in 2012 (16), probably due to the population's skin characteristics, but it quadrupled in the period 1975-1995, with a slight increase since 1995 (14).

However, it should be noted that a small daily dose of solar radiation is regarded as beneficial for people's health, including effects such as the synthesis of Vitamin D_3 (18, 19), essential for bone mineralization (3), since dietary vitamin D is insufficient to cover daily needs (2). There is evidence that inadequate vitamin D increases the risk of catching many diseases in adulthood (20-23) and high vitamin D levels can reduce specific disease mortality rates (2), although more studies are necessary in this field.

Given the alarming growth in the number of cases in previous decades, the Euromelanoma campaign (24) was established in Belgium in 1999 with the aim of preventing and detecting massive melanoma and has now spread to 29 other countries. Spain has participated in several of these campaigns and their success is shown by the number of new early detections and excised melanomas (25).

Within the European Union program "Europe against Cancer", a group of international experts (26) gathered to study exposure to carcinogens in the workplace (27). The results of this meeting showed that the highest number of cases of occupational exposure occurred in Spain, with approximately 1 million workers exposed to solar radiation between 1990 and 1993 (28),

with a total of 3.1 million workers exposed to agents considered to be carcinogens by the IARC (29).

Various studies have shown that outdoor workers regularly receive significant solar UVR in the course of their daily work (30-40), especially when solar radiation is high. It is known that intermittent intense UVR exposure (typical of leisure activities) is a risk factor for melanoma (41-44), while the NMSC risk seems to be more closely related to the cumulative lifetime UV exposure (41) (typical of outdoor work) although intermittent exposure is also a BCC risk factor (43,45,46). According to several authors (43, 46-49), occupational outdoor solar exposure is a substantial risk factor in the development of SCC and a significant risk factor in BCC. However, some studies found there was no increased risk of NMSC among outdoor workers (41, 44), and another indicated this lack of association only for BCC (50). One study found an association between high occupational UV exposure and increased prevalence of precancerous skin lesions and skin cancer, related to severe sunburn during an entire lifetime (45). On the other hand, many authors (41-44, 49) have not found any association between outdoor work and the risk of developing melanoma.

Due to its geographical situation, Valencia has a subtropical climate on the borderline of the Mediterranean climate, with very mild winters and long warm-to-hot summers, meaning that the region receives large UVR doses throughout the year. In the Valencia Community, the work of environmental agents is directly related to the protection, care, and custody of natural areas, state-owned forests and natural resources. Also their functions are related to the prevention, detection, extinction and investigation of forest fires. Their work is often in mountainous areas, and it is known that UV irradiance increases with altitude due to reduced dispersive and absorptive material in the air, known as the *altitude effect* (51). This is of great

importance as shown by the increasing trend of melanoma cases in those who spend time at high altitudes (52).

The purpose behind this work was to study the erythemal UV exposure by means of personal UV dosimeters attached to environmental agents for 12 days in summer during of their usual work schedule, with the aim to ccompare with the occupational UV exposure limits and show if protective measures are advisable.

MATERIALS AND METHODS

Study location: The study took place in two areas of Valencia; one of which, the *Plana de Utiel* (coordinates 1º 11' W, 39º 30' N) is in the westernmost part of the province and forms a plateau with a mean altitude of 750 meters. This region has hot dry summers in which temperatures can reach 40°C, even though the Mediterranean is only 70 km away. The other location, the *Valle de Cofrentes* (coordinates 1º 3'' W, 39º 3'' N), is in the south west of the province, about 70 km from the capital, cut off from the influence of the Mediterranean by a barrier of mountains stretching towards the coast. The region is mostly mountainous, reaching a height of 1200 m, with a central valley and has hot dry summers.

Subjects and design: Eleven (8 male and 3 female) environmental agents participated in the study, although only between five and seven participated in each 2-day recording period. The subjects, who were asked to carry out their normal schedules, kept a diary of the times they put on and removed the dosimeter, their work area, the number of hours spent outdoors, type of activity involved and weather conditions. Most of their work is outdoors, but some of their

working hours are spent in the office and in travelling to work sites. Each subject wore two dosimeters during each 2-day recording period, six participants on the wrist and head during one period, while the remainder attached the dosimeters to the wrist and shoulder.

Personal UV dosimeters: Individual cumulative solar erythemal UV exposure was measured by a VioSpor Blue Line Type I dosimeter (53), which was changed every two days. These dosimeters have been proved to give satisfactory results in measuring personal outdoor UV doses in previous studies (34, 38, 54, 55). Since two shifts were involved, measurements were made both in the morning and in the afternoon, although more recordings were taken in the morning shift as more workers were involved. The dosimeters were worn from 8 a.m. to 3 p.m and from 3 p.m. to 10 p.m in each shift.

The development of the films and the spore-film production (DNA repair-deficient strain of *Bacillus subtilis*) can be found in several studies (56, 57). Briefly, the spore films are covered by a filter system with optical properties close to the erythemal response of human skin, in accordance with the Commission Internationale de L´Eeclairage (CIE) reference spectrum (58). The measurements are expressed as a standard erythema dose (SED) in which 1 SED is defined as an effective exposure of 100 J/m^2 (59) when weighted with the CIE erythemal response function. According to the manufacturer, the dosimeter's working range is 0.5-30 (SED) with a measurement error of ±10%.

The VioSpor system is validated using in-vivo comparative measurements (60). The wavelength-specific VioSpor calibration is performed using the Okasaki (Japan) spectrograph measurements, details of which can be found in (56, 57). VioSpor was also validated in several

instrument intercomparisons carried out under field conditions, in which VioSpor data were compared with the minimal erythema dose values obtained from spectroradiometer data (61).

Ambient solar UV: Ambient erythemal UV irradiance was obtained from UVB-1 radiometers (Yankee Environment System, YES), belonging to the Valencia regional government's (GV) UVB measurement network (62). This network consists of several radiometers, one in the city of Valencia (00º20'09" W, 39º27'49" N, 0 m), used in the Valle de Cofrentes calculations. Another radiometer, used in the Plana de Utiel calculations, is located at Aras de los Olmos (01º06'332 W, 39º57'01" N, 1277 m) in a rural area. Both stations are on a flat roof without obstructions or shade and were chosen for their proximity to the work areas involved in the study. The UVB-1 YES is a precision meteorological instrument for the measurement of biologically effective solar UV-B, capable of measuring erythemal solar UV irradiance since the instrument response is similar to the CIE erythemal action spectrum. According to the manufacturer, calibration uncertainty is approximately 10%, calculated by comparing the measurement of the spectral response of the radiometer indoors with a Brewer MKIII spectroradiometer outdoors (63, 64). The cosine response is less than 5% for solar zenith angles below 60º, and for zenith angles above this value a double entry zenith angle–ozone calibration matrix is used (63). The error given by the calibration matrix stays below 9% for zenith angles below 70°, considering a constant ozone value of 300 DU. Another calibration of this radiometer was performed by the Earth Physics Department of the Universitat de València (65, 66).

Also, the daily ambient erythemal UVR was obtained using the Ozone Monitoring Instrument (OMI)-derived data (67). Erythemal daily dose (EDD) was obtained from the Giovanni online

data system, developed and maintained by the NASA GES DISC (68). OMI level 3 global gridded data with a spatial resolution of 1x 1 degree was used. The input data for the calculation were the geographical coordinates of the study site. The EDD obtained from OMI was used only for comparison with that obtained from the GV UVB measurement network.

To verify the cloud conditions given by the study participants, the OMI Lambertian Equivalent reflectivity (LER) at 360 nm was used (69), considering a cloudless day when LER was lower than 10% (70). The cloud fraction from Aerosol Robotics Network (71) was also used when LER was not available. As a result, we were able to verify that June 13, August 30, 7 and 13 September were cloudy days in both locations, and also June 22 in the Valencia area.

UV exposure limits: Exposure limits (EL) were established by the International Radiation Protection Association for recreational/occupational UV exposure in 1985 (72) and adopted for outdoor workers by the International Commission on Non-Ionizing Radiation Protection, updated in 2010 (73). The ICNIRP 2007 report (74) suggested a maximum personal daily exposure of 30 J/m^2 effective UV dose, calculated by the American Conference of Governmental Industrial Hygienists action spectrum (75) for a period of 8 hours and sensitive unprotected skin. This EL can be considered equivalent to approximately 1.0-1.3 SED when using the CIE action spectrum (74).

The ICNIRP 2010 report (73) also indicates that skin adapts to frequent UV exposure by thickening, which increases UV protection by a factor of five or more. This report suggests a value of 12 SED as the average threshold exposure for sunburn for Mediterranean subjects with sun-adapted skin phototype III/IV. For the same type of skin without sun adaptation a value of 5 SED is assumed.

The exposure recorded by the subjects in the present study was compared with the value of 5 SED, since we considered no sun-adapted skin, and was also compared with the EL value.

Skin Exposure factor (EF): A UV risk assessment for outdoor workers can be supplied by a factor defined by ICNIRP 2007 report (74) as:

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.

According to our study environment we adopted the following values:

f_1= 7 (mid-latitudes in summer) f_2= 1 (clear sky); f_3= 0.5 (one hour or two around midday); f_4=1 (various surface);

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

Skin EF was calculated for the enviromental agents to determine the minimum level of skin protection suggested by ICNIRP 2007 (74).

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 UVR

210 The ambient erythemal UVR for each day and maximum ultraviolet index (UVI) (76,77),
211 calculated from the noonday UV irradiance (W/m^2) measurement at the corresponding GV
212 weather station, are shown in Table 1 for both stations. The actual maximum temperature
213 provided by the State Agency for Meteorology (78) and ozone data from the OMI (79) are also
214 given.
215 It is noteworthy that June was the second hottest in the last 42 years in the province of
216 Valencia, because of the successive waves of westerly winds that affected the area on days 2,
217 7, 11, 21, 28 and 29 June (78). In addition, on 28th June there were two massive wildfires in the
218 province, which occurred quasi-simultaneously in two different places in Cortes de Pallás (in
219 the Valle de Cofrentes region) and Andilla, both situated in the west of the province,
220 approximately 70 km from the city of Valencia. These were considered the most severe to have
221 happened in Spain since 2004 and destroyed a total area of 48,500 hectares. On 29 and 30 June
222 the fire was at its worst around the Valencia metropolitan area, covering the city and a large
223 part of the province with a dense cloud of smoke and ash, which explains the very low
224 erythemal UV irradiance recorded by the Valencia station on the 29th of that month.
225 August was also the hottest in Valencia for the last 42 years, but on the 30th and 31st
226 there was a considerable drop in temperature, especially in inland areas, hence the very small
227 erythemal UV irradiance at the Aras station on the 30th.
228 The comparison of the ambient erythemal UVR of the OMI satellite and the ground-
229 based stations shows for the city of Valencia an overestimating by OMI, with a bias range of
230 between 8 and 30% for cloud-free days and up to 40% for cloudy days. According to several
231 studies (80, 81), varying cloud conditions within the satellite pixel can lead to large differences
232 between the data from OMI and ground-based stations. June 28 and 29 were not taken into

account due to the wildfire in the area, leading to a difference of from 150 to 600%. The smallest biases were found at the rural Aras station, where the relative differences are between 2 and 25% for all sky conditions, also overestimated by the OMI. The largest relative differences are observed at the Valencia station, perhaps because it is in an urban area where the characteristic aerosols tend to reduce UVR as measured by ground stations, but have so far not been allowed for in satellite UV algorithms. These results are consistent with recent studies obtained at other sites (82, 83).

<Table 1>

Measured UVR exposures

Table 2 shows the statistical data expressed as median (minimum-maximum) of the measured 2-day exposures, 6.2 (14.9-0.3) SED, while per-hour outdoors was 1.16 SED. The exposure ratio (ER), defined as the ratio between the personal UV exposure and the corresponding UV ambient dose on a horizontal plane during the same 2 days, is also shown in Table 1. Median ER for the whole period of the study was 8.3 (29.3-0.3) %.

<Table 2>

The erythemal UV exposure received every 2 days is similar throughout the entire study period, not so for the exposure ratio, which was twice as high at the beginning of September than in late June, probably due, among other things, to the intense heat of late June.

Since the range of erythemal UV exposure gives information about how spread out the data is, the 2-day range gives a measure of variability between individuals. On June 28/29th and in September, the UV exposure range is almost twice that of the other 2-day periods, indicating

254 that on those days the agents' behavior was different from other days, probably due to, among
255 other factors, the forest fire that started on the 28th.
256 <Table 3>
257 The results discussed above are sub-classified by dosimeter position in Table 3, although
258 in the statistical comparative analysis we have not considered the measurements recorded by
259 the head-attached dosimeters, due to insufficient data. Using the Mann-Whitney (Wilcoxon)
260 test to compare medians, no statistically significant difference was found in terms of SED
261 received (p=0.15), SED per hour (p=0.07) or ER (p=0.11) regarding the positions of the
262 dosimeter on shoulder and wrist.
263 <Table 4>
264 We also studied the doses received in each work shift and in each of these the results
265 were sub-classified by dosimeter position (Table 4). The Mann-Whitney (Wilcoxon) test
266 results showed no significant statistical difference regarding the median dose received
267 (p=0.58), the outdoor dose received per hour (p=0.20), nor did the ER (p=0.87) between the
268 two shifts. Since we observed that the dose received on the shoulder on the afternoon shift was
269 higher than that on the wrist, we studied whether these differences were significant with the
270 Mann-Whitney (Wilcoxon) test and the results showed that the median doses received were
271 not statistically different (p=0.30) and nor was the ER (p=0.43), although the dose received per
272 hour outdoors was statistically different (p=0.02).
273 <Table 5>
274 The dose received analyzed by gender (Table 5) shows that women received statistically
275 significant higher doses in terms of the median (p=0.00), of ER (p=0.00) and dose received per

hour outdoors (p=0.02), although these results should be judged with caution, since fewer women participated in the study than men.

Skin Exposure Factor

The calculation of this factor gives a result of 1.75 in terms of the values adopted for this study described above. The ICNIRP 2007 Guide (74) recommends wearing shirt and brimmed hat to reduce skin exposure (Table 6).

<Table 6>

DISCUSSION

Many studies have been carried out on UV exposure in outdoor workers. In New Zealand a mean daily concurrent ER of 20.5 % (measured on the back) was obtained for these workers in summer (37). In another study (39) Austrian farmers received an average ambient daily dose of between 3% and 26% on the face. An Italian study (40) reports a median concurrent ER of 29% on the arm in vineyard workers in summer. Median ER values ranging from 4.5% to 8% were found in gardeners in Ireland and Denmark (32). In a previous work (38) the authors of this paper studied the UV dose received by Spanish gardeners and lifeguards and obtained ER values of 9% and 27%, respectively.

The median 2-day UV exposure for the environmental agents in our study was 6.2 SED, representing a daily value of 3.1 SED, which exceeds the EL by a factor of 3. This means these workers exceed the international recommendation for solar occupational exposure of unprotected skin by three orders of magnitude. Environmental agents can not usually choose

their work location and decide whether to perform their labor in the shade or in the sun. Hence, protective clothing and sunglasses remain the main individual measures against UV exposure. However, as the ICNIRP (2010) assumes a value of 5 SED to be the average threshold exposure for sunburn in non sun-adapted skin type III/IV, the subjects involved in this study do not exceed the recommended threshold value.

The environmental agents in this study received a median of 8.3% ambient erythemal UVR, with a range between 0.3 and 29.3%. This wide range could be attributed to the different orientation of the dosimeters relative to the horizontal, due to their different postures and working environments.

A recent study has found that outdoor workers protective measures are quite inadequate and sunburn episodes remain high (84), indicating the need for specific campaigns to further adequate protection. It may be useful to remind outdoor workers of the risks associated spending too much time in the sun between 11 am and 3 pm in summer. It should be recommended to them to seek shady areas to perform their work whenever possible, such as the shade of a tree, suitable in the case of our environmental agents, or around the shade of a building. Anyway, as these workers can spend about 4 hr per day exposed to UVR it is difficult for them to completely avoid UV exposure, so that the use of protective clothing, a wide-brimmed hat and sunglasses are appropriate protective strategies. As an adjunct protection is the use of broad-spectrum sunscreens, although its actual use by outdoor workers has proven to be unreliable, and it is recommended only when the other mentioned measures are unsuitable (73). Furthermore, according to a recent article (85) the use of adequate protective measures could lead to reductions of up to 27% in skin cancers by 2050.

Comparing the ambient erythemal UVR from ground-based stations and the OMI-derived erythemal daily doses shows an overestimation bias of the OMI, larger for the Valencia station because of its urban location. Similar results can be found in other papers (80-83).

The results have been sent to the organization responsible for the agents that took part in the study, so that they should be aware of the radiation the agents are exposed to and take the appropriate preventive measures, such as educating workers about the danger of excessive sun exposure without protection, and encourage the adoption of protective strategies and the use of protective measures, among others.

Finally, a personal dosimeter was used to measure the occupational UV exposure of the enviromental agents, who exceed occupational UV exposure limits (73).

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