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Solar ultraviolet A radiation and nonmelanoma skin cancer in Arica, Chile

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A R T I C L E I N F O

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A B S T R A C T

In this work, we present the maximum daily values of solar ultraviolet A radiation (UV-A) as a function of time. The results indicated that such values reached a maximum of 93.9 W/m^2 in 2010 and a minimum of 16.5 W/m^2 in 2012. The annual averages of both UV-A and solar ultraviolet B radiation (UV-B) from 2007 to 2013 were recorded. UV-A was always higher than UV-B. However, UV-B is more energetic due to its intrinsic wavelength. The nonmelanoma skin cancer mortality incidences per 100,000 inhabitants in Arica and in Chile as a function of time between 2007 and 2013 indicated that these mortality rates varied from 3.12 (Arica) to 0.88 (Chile) in 2007 and 2.71 (Arica) to 0.88 (Chile) in 2013. The nonmelanoma skin cancer prevalence rates per 100,000 inhabitants in Arica were 22.2 in 2007 and 19.5 in 2013. The relationship between NMSC and exposure to UV-A is given. In Arica, we report high levels of UV-A and the highest NMSC rates compared with other regions in our country.

1. Introduction

Skin cancer is the most common malignancy in the white population, and the incidence rates of melanoma skin cancer (MSC) and nonmelanoma skin cancer (NMSC) are increasing worldwide [1]. Solar ultraviolet radiation (UVR) exposure is one of the most important environmental factors that can affect skin physiology. Exposure of human skin to solar UVR rays can induce short- and long-term consequences, including erythema (or sunburn reaction), photo-aging, photo-immunosuppression, and skin cancers [2,3].

UVR wavelengths range from 100 to 400 nm [4]. For scientific purposes, UVR has been conventionally categorized into three ranges: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm) [5]. Only at the top of the atmosphere is approximately 5% of solar-terrestrial radiation UVR. The UVR component of terrestrial radiation from the midday sun comprises approximately 95% UV-A and 5% UV-B; UV-C and most UV-B are removed from extraterrestrial radiation by stratospheric ozone [1].

The quantity of solar UVR is modified by interactions in the stratosphere (absorption by ozone and by molecules such as N_2 and O_2) and in the troposphere (absorption by pollutants and scattering by particulates and clouds) [6]. UV-A can penetrate deeper within the skin and is mostly responsible for the generation of reactive oxygen species (ROS) and can also induce DNA damage. UV-B radiation displays beneficial effects such as the production of several antimicrobial peptides and previtamin D; it is more energetic than UV-A radiation and can directly damage the DNA of epidermal cells and induce sunburn reactions [7]. Previous research indicated an association between NMSC and MSC incidences, vitamin D and latitude [8], and our previous results showed that the high values of UV-A present at the latitude of Arica (18.0°S) might be related to skin cancer incidence in relation to UVR [9]. The aim of this study was to analyze UV-A radiation in Arica, Chile (18.0°S).

2. Materials and Methods

Arica is a city located in the subtropical zone of northern Chile (25 m above sea level, latitude: 18° 49′S; longitude: 70° 19′W) presenting a stable microclimate, with approximately 11.3 sunshine hours, lack of rainfall (less than 5 mm per decade), a predictable wind regime, a high percentage of clear sky days and high soil reflectivity, mainly due to desertification and composition, especially of very reflective sand, throughout the year. The range of temperature slowly oscillates, such that in the last ten years, the average high has been 24 °C and the

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average low has been 14 °C. The city is by the seaside, and due to its pleasant climate, the population performs a large number of outdoor activities for much of the year. The population of Arica is 226,068 inhabitants, of which 112,581 are men and 113,487 are women. The population distribution by age range is 59,207 inhabitants under 18 years old, 142,284 inhabitants between 18 and 65 years old, and 24,577 inhabitants over 65 years old [10].

There are several methods to measure solar UV radiation, and there are two types of physical devices to measure solar UV irradiance: Narrowband and broadband instruments. Narrowband instruments have a very good spectral resolution that allows covering a region of the spectrum with a fixed spectrum separation regarding wavelengths. Broadband instruments measure a wide band of wavelengths simultaneously with a spectral response close to the response function of some biological systems (usually called biometers). The present study used a broadband YES UV-A biometer, which is an instrument with meteorological precision for measuring solar UV-A radiation; it has a colored glass filter with a UV-A-sensitive phosphor and converts UV-A light into visible green light measured by a solid-state photodetector [11].

The calibration was made by comparison with a multiband GUV-2511 instrument. The biospherical instrument allows the measurement of seven wavelengths: 305, 313, 320, 340, 380, 395 nm, and PAR. The measurements were taken from January 5th, 2007, to December 31st, 2013. This device is a reasonably stable instrument capable of measuring adverse weather conditions for long periods of time. An amplifier provides an output signal between 0 and 5 V. The UV-A solar radiation measurement is in ($Watt/m^2$), abbreviated (W/m^2).

The output of the instrument is millivolts, and a sensitivity of 0.040 ($Volt\ m^2 Watt^{-1}$) was used to indicate UV-A solar radiation. The calibration of the instrument is equivalent to a GUV multispectral device. All the components of the detector were stabilized at a temperature of +45 °C. The skin cancer report was conducted by the Ministry of Health and included cases from the population of Chile from 2003 to 2007 [12]; other studies for recent periods can be found in the Health, Statistics and Information Department (DEIS) of Chile [13]. Note that for a long time, the measurement of UV-A has not been frequent in our country in other locations. This is the reason for this study's relation to this UV-A measure, made in Arica and compared to the NMSC. The comparison to the NMSC rate with other countries' locations is not possible because these rates are reported only by the Chilean Minister of Health, with the same methodology. Furthermore, the present study also considers UV-B data, which were already published in our previous work [9]. A comparison of both will be presented in the next section.

3. Results

Fig. 1A shows the maximum daily values of solar UV-A radiation as a function of time. The results indicated that such values reached a maximum of 93.9 (W/m^2) in January 2010 and a minimum of 16.5 (W/m^2) in August 2012. Fig. 1B displays the maximum average values of solar UV-A per month with their respective standard deviations. These values had two local maxima of 73.7 (W/m^2) in January and December and a minimum of 41.3 (W/m^2) in June.

The annual average of both UV-A and UV-B from 2007 to 2013 is shown in Fig. 2. UV-A is always higher than UV-B because UV-B is approximately 6% of the whole spectrum of radiation. In contrast, UV-B is more energetic due to its intrinsic wavelength. To compare both time series, Pearson's coefficient was used to define a correlation between series

$$\rho(m_a, m_b) = \frac{\langle (m_a - \langle m_a \rangle)(m_b - \langle m_b \rangle) \rangle}{\sqrt{\langle (m_a - \langle m_a \rangle)^2 \rangle}\sqrt{\langle (m_b - \langle m_b \rangle)^2 \rangle}}$$

where m_a and m_b are both time series and $<\ >$ denotes the mean value [14]. A value of ρ = 0 means no correlation, whereas when ρ = 1, it is perfectly correlated. Note that the Pearson's coefficient for the UV-A and UV-B time series is 0.41, showing a weak correlation between them.

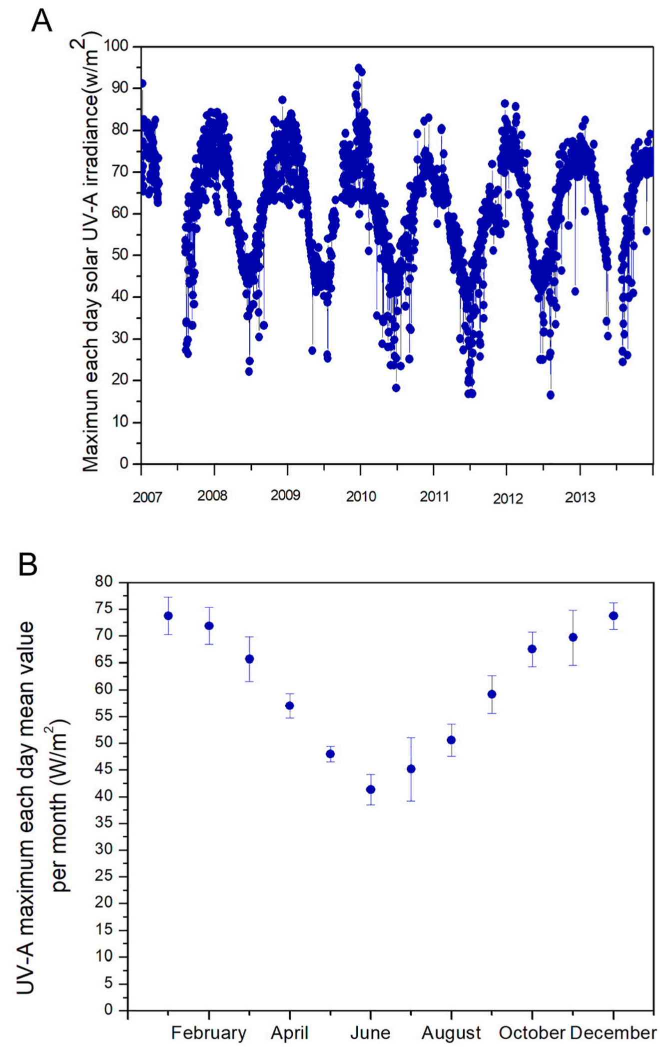

Fig. 1. A: UV-A, maximum achieved each day value (W/m^2) in Arica, Chile, from 2007 to 2013. B: UV-A mean values of maximum achieved each day (W/m^2) per month in Arica, Chile, from January to December from 2007 to 2013.

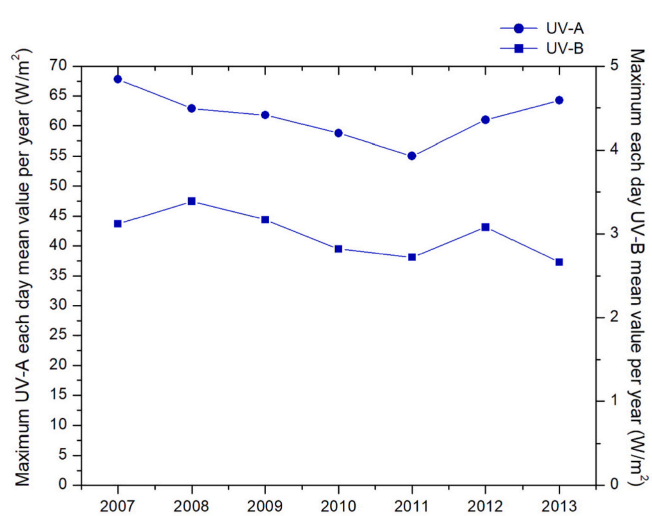

Fig. 2. Maximum UV-A and UV-B achieved each day (W/m^2) per year from 2007 to 2013. The data were taken in the city of Arica.

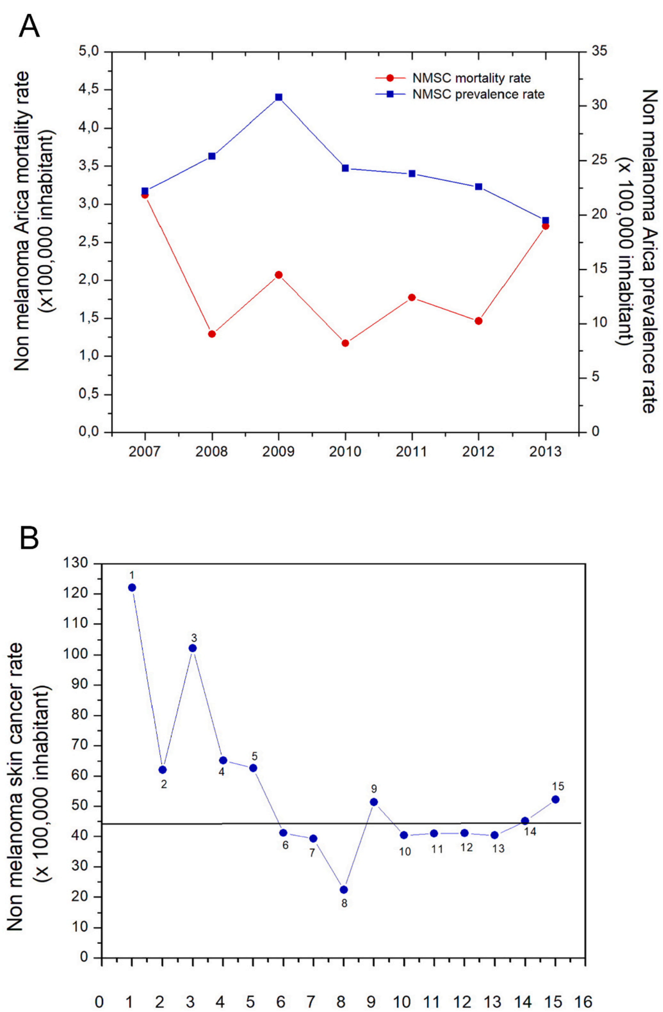

Fig. 3. A: Nonmelanoma skin cancer mortality and prevalence rate per 100,000 inhabitants in Arica, 2007 to 2013 [27]. B: Nonmelanoma skin cancer rate per 100,000 inhabitants in different regions of Chile: 1. Arica, 2. Tarapacá, 3. Antofagasta, 4. Atacama, 5. Coquimbo, 6. Región Metropolitana, 7: Valparaíso, 8. O'Higgins, 9. Maule, 10. Bio-Bio, 11. Araucanía, 12. Los Ríos, 13. Los Lagos, 14. Aisén, and 15. Magallanes from 2007 to 2013 [12].

The weak correlation between UV-A and UV-B is calculated from measurements using pyranometer ultraviolet: UVA-1 (YES) and UVB-1, simultaneously, in Arica North of Chile (Latitude 18° S) from 2007 to 2013, in different weather conditions. The ratio between (UV-A)/(UV-B) solar radiation at noon in this location is near 20 and can vary depending on several local conditions, including cloudiness, aerosols, and the ozone layer.

Fig. 3A shows the NMSC mortality incidence per 100,000 inhabitants in Arica between 2007 and 2013 and NMSC prevalence rates as a function of time. The results indicated that these mortality rates, average and standard deviation values in Arica varied from 1.94 ± 0.74. Moreover, Fig. 3B indicates that the NMSC skin cancer rate per 100,000 inhabitants in Arica was 122.1, which is the highest value in the country; in fact, it is almost a factor of three in comparison with the national average, 44.6. The minimum incidence was 22.4 in the O'Higgins region. The reason the NMSC is decreased for higher latitudes is to agree with the lowest UVR solar radiation values at higher latitudes. In the case of Antofagasta (point number 3), arsenic pollution has been reported and blamed for at least some skin cancers. At point 3, arsenic pollution corresponds to the Antofagasta region, where numerous mining projects have been developed in this zone, and during multiple years in the past, Antofagasta has had high contents of arsenic in water. The explanation in Arica is that the NMSC rate by 100,000 inhabitants is due to high levels of UVR in this location.

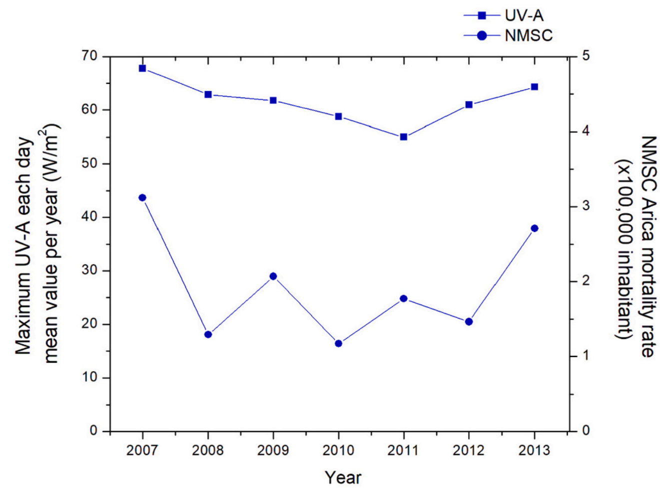

Fig. 4. Nonmelanoma mortality rate per 100,000 inhabitants and maximum UV-A each day mean value per year (W/m^2) as a function of time from 2007 to 2013 and nonmelanoma skin cancer mortality rate (x100,000 inhabitants) per year. The data correspond to Arica city.

Finally, Fig. 4 presents UV-A and the annual value of the NMSC mortality rate per 100,000 inhabitants in Arica as a function of time from 2007 to 2013. The time series did not show a simple behavior that could fit a linear regression or with a power law. There were variations among the years with some oscillatory changes. Nevertheless, the absolute value of Pearson's coefficient [14] was approximately 0.89. We can infer that there is a strong correlation between both time series.

Table 1 shows the NMSC prevalence rate per 100,000 inhabitants for each Chilean region as well as its latitude coordinates. Additionally, the rate of the country is given. Notably, the values of the Chilean NMSC prevalence rate are less than half of Arica's value.

4. Discussion and Final Remarks

The results obtained are essential for their applications in photomedicine and photobiology. The potentially harmful high levels of UV-A and UV-B solar irradiance that are received in the extreme north of Chile confer importance to this type of study regarding the health effects in the people who live at this latitude.

The effects of overexposure to UVR on people's health are multifactorial, and many of these effects in the skin are cumulative. In this

Table 1
NMSC prevalence rates, 2003–2007 [12], and the latitude of each Chilean region.

N°	Region	NMSC prevalence rate	Latitude (°)
	Pais Chile	44.6	
1	Arica-Parinacota	122.1	−18.5
2	Tarapacá	62.0	−20.2
3	Antofagasta	102.2	−23.7
4	Atacama	65.1	−27.4
5	Coquimbo	62.6	−30.0
6	Región Metropolitana	41.2	−33.5
7	Valparaíso	39.3	−33.0
8	O´Higgins	22.4	−34.2
9	Maule	51.4	−35.4
10	Bío-Bío	40.4	−36.8
11	Araucanía	41.0	−38.7
12	Los Ríos	41.1	−39.8
13	Los Lagos	40.4	−40.6
14	Aisen	45.1	−45.6
15	Magallanes	52,2	−53.2

zone, due to the high UV-A and UV-B levels to which people are exposed, the different effects could appear at an early age, and the high NMSC rate in this location is one of these effects. Exposure to high levels of UV-B and UV-A solar radiation can occur for a long time. This has multiple effects on the health of people who live in this zone. One of these various consequences is considered in this study: the relationship of high UV-A exposure and NMSC. This relationship has been reported in the literature, and this condition is present in Arica. Over several years, high levels of UV-A were measured by calibrating the instrument and based on the statistical rates of NMSC reported by the Chilean Health Minister. The skin cancer data are measured in our country; we consider the types of skin most frequently present in our country to be skin type III in females and skin type IV in males [15].

Individuals are classified according to their sensitivity to ultraviolet radiation. Characteristics such as skin, hair and eye color are associated with prototypes. There are six types of prototypes [16]. Photocarcinogenesis follows a multistep model of cancer development in which UVR-induced DNA damage leads to mutations resulting in the activation of oncogenes or silencing of tumor suppressor genes. This ends in a cellular mutator phenotype that is even more prone to the acquisition of mutations [17]. UV-A causes DNA mutations that are associated with defects in immunity and alterations in skin repair mechanisms [18]. According to the authors [19], spending 15 days at the beach each year increases the risk of skin cancer fivefold. Overexposure to UV-A radiation has a vital role as a factor in the presence of neoplasms such as melanoma. UV-A photons that are only partially absorbed by the upper layers of the skin can penetrate deep into the dermis, in contrast to the UV-B radiation that is absorbed mainly in the epidermis. Therefore, UV-A rays are implicated in the two main cutaneous effects of excessive exposure to sunlight: cancer and aging [20]. This is the first study of the association between UV-A and its effects on people's health in Chile.

There are three major types of skin cancer: melanoma, basal cell carcinoma (BCC), and squamous cell carcinoma (SCC). BCC and SCC are often referred to as nonmelanoma skin cancer (NMSC). NMSCs are relatively nonlethal and curable by surgery. Hence, there are no reports in most cancer registries worldwide. Melanoma is the deadliest skin cancer. Its incidence rate (case number) is approximately 1/10th of that for NMSC, yet its death toll is ~8-fold higher than that for NMSC. These three types of cancer, even though they share many characteristics, differ in their etiology and progression. Both types of UV radiation are caused by solar or artificial ultraviolet radiation (UVR). UV-A and UV-B from solar UVR are the major UV bands reaching the Earth's surface. Both UV types cause DNA damage and immune suppression, which play crucial roles in skin carcinogenesis. UV-B can be directly absorbed by DNA molecules and thus causes UV-signature DNA damage; UV-A, on the other hand, may function by inducing cellular ROS, which then causes oxidative DNA damage [21].

Although solar UV-B radiation plays a role as a carcinogen for NMSC, it has been suggested that solar UV-A radiation can initiate different molecular events [22], playing an essential role in skin carcinogenesis. Previous studies carried out with experimental UV-B measurements in Arica and Valdivia from 2003 and 2006 have corroborated the existence of a correlation between skin cancer incidence and latitude [9,23]. Epidemiological studies have revealed a high incidence of skin cancer in the northern part of Chile; thus, out of 100 cases, 37 malignant tumors corresponded to skin tumors, and 4 of them can lead to death [24].

The available epidemiological evidence shows that prolonged and repeated exposure of humans to artificial UV-A light from sun lamps or tanning beds constitutes an essential risk factor for the induction of skin cancer, such as melanoma [25]. Recently, it was shown that gene damage by oxidation to DNA through the reaction sensitized by melanin to UV-A radiation is involved in melanogenesis. MSC induction by UV-A requires the presence of melanin pigment associated with oxidative damage in melanocytes [26]. The exposure of a matte skin (type IV) for 150,000 h and of a skin type II for 50,000 h would produce epidermal carcinoma [20,25]. BCCs arise from basal cells, a layer of cells located at the deepest part of the epidermis. Basal cells are considered skin stem cells since they are constantly proliferating and generate keratinocytes that are continuously pushed to the surface and eventually become a dead layer of the stratum corneum. Squamous cells are keratinocytes that are initiated from basal cells and differentiated into squamous cells. These three types of cancer share many characteristics, yet they are quite different from etiology to progression. One shared feature of skin cancer is that, according to the current views, they are all caused by solar or artificial ultraviolet radiation (UVR). Let us also comment that skin cancer cases are high in the Antofagasta region. It has been suggested that this incidence is related to arsenic in the environment due to heavy mining that takes place in that city, which does not occur in Arica. It is important to remark that the data were taken daily for several years, which implies that the data have statistical significance.

It can be concluded that the skin cancer mortality incidences per 100,000 inhabitants in Arica and throughout Chile as a function of time between 2007 and 2013 varied from 3.12 in 2007 to 2.71 in 2013 and that the NMSC skin cancer rate in Arica was 122.1, which was the highest in the country in comparison with the national average of 44.6. Then, when comparing the UV-A and the annual average value of nonmelanoma in Arica as a function of time, there were variations among the years, with some oscillatory changes. However, the absolute value of Pearson's coefficient was approximately 0.89, indicating a strong correlation between both time series. Nonetheless, UV-A is continuously higher than UV-B over time, being very energetic due to its intrinsic wavelength that makes it very dangerous. Since cumulative doses of UV-A and UV-B are essential, the pathogenetic pathways of both types of radiation for benign and malignant skin cancer development need to be urgently clarified.

Availability of Data and Materials

The datasets used during the present study are available from the corresponding author upon reasonable request.

Authors' Contributions

MR, ER, GMC, and LH conceived and designed the study. MR and DL analyzed the data. MR, ER, GMC, LH, and DL wrote the manuscript. JM, JH, and MCA reviewed the manuscript. All authors have read and approved the manuscript and agreed to be accountable for the accuracy of any part of the work.

Declaration of Competing Interest

The authors have declared no conflicts of interest.

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