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OPINION ARTICLE

Climate Change and the Thinning of the Ozone Layer: Implications for Dermatology

Implicaciones dermatológicas del cambio climático y de la disminución de la capa de ozono

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In recent years a large number of articles and reports have examined the impact of climate change on human health, particularly the health of the skin.[1-4] Another independent line of research has looked at the health effects of stratospheric ozone depletion.[5,6] Only very recently, however, have researchers begun to look into the impact of climate change on the recovery of the ozone layer and the implications for the environment and public health.[2,7]

In my view, local, national, and international measures to reduce or mitigate global warming are inadequate. By 2020 carbon dioxide emissions should be reduced 25% to 40% below their 1990 level if we are to keep the rise in temperature within 2°C during this century.[8] That threshold for warming is based on scientific reports indicating that a rise greater than that has the potential to cause significant changes in ecological systems on land and in water.[8] The Kyoto protocol nevertheless calls for a global reduction of only 5% (an average of 8% for most European Union countries). This protocol ends in 2012 and although international meetings are being convened to set future goals for reducing the emission of gases responsible for the greenhouse effect, developed countries seem to lack the will to abandon the present model of energy consumption and economic activity.

The recovery of the ozone layer, however, is an encouraging sign, or at least we believed it was until predictive models with coupling between climate change and ozone levels began to appear.[9,10] Annual ozone depletion seems to have stabilized as a result of the 1987 Montreal protocol's achievement of substantial reductions in the gas emissions that were destroying the ozone layer at that moment. We remain very far from recovering 1980 levels, however. The hole over the South Pole station, which fluctuates seasonally, reached its maximum circumference at the end of September 2009 according to researchers working with the United States National Oceanic and Atmospheric Administration (NOAA). At that time, the Antarctic ozone layer's thinnest point was 98 Dobson units (DU), the seventh smallest measurement since 1986.[11] The record low of 89 DU was recorded on October 6, 1993 (NOAA data published in 2010, available from http://www.noaa.gov). Dobson units indicate the amount of ozone in a vertical column of air, 1 DU representing a layer 0.01 mm thick under standard atmospheric pressure (1 atm) at a temperature of 0°C.

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Most reports and articles on changes in the ozone layer foresee recovery within the 21st century (2060-2070).[1,7,12] However, new models that take into account interactions between climate change and stratospheric ozone suggest that recovery will not take place at all latitudes.[9,10] Climate change will lower temperatures and the amount of water vapor in the stratosphere, leading to greater ozone loss in polar regions.[9,10] The opposite effect is expected at middle and higher latitudes of the northern hemisphere, where more ozone is expected to accumulate than was present in 1980. The amount of UV-B radiation reaching the surface will therefore decrease.

Climate change will accelerate air circulation in the stratosphere from the Equator northward, reducing the amount of ozone in equatorial and tropical zones, which are already subject to greater UV-B radiation because light travels less distance through the atmosphere at these latitudes.[10] The northerly shift of ozone will increase the concentration of this gas at higher latitudes in the northern hemisphere. Based on new models, which couple chemical and climatic effects and allow the impact of climate change to be isolated from recovery of flow of ozone from the stratosphere to the troposphere, we can predict that moderate emissions (as defined by the Intergovernmental Panel on Climate Change) will increase this flow attributable to climate change by 23% over the period 1965-2095.[8] During this period the UV index (an indicator of erythematic solar radiation) on clear days will decrease 9% at high northern latitudes and have an effect that is greater than that of the expected recovery of the ozone layer alone. In contrast, the UV index will increase 4% in tropical zones and 20% at higher latitudes of the southern hemisphere by the end of spring and beginning of summer in 2100. Models show that almost half of this increase in UV-B radiation related to climatic phenomena can be attributed to the ozone hole over the Antarctic, the result of the presence of chlorofluorocarbon (CFC) gas.[9] The same models forecast that the ozone layer will be 15 DU thinner than in 1980 by the end of the 21st century in tropical zones but will increase by as much as 16 DU over the middle latitudes of the northern hemisphere. From the predicted ozone-depleting gas concentrations and predictions of the thickness of the ozone layer itself, a lower incidence of squamous cell carcinoma is expected based on the action spectra for skin cancers in the northern hemisphere; the projections foresee a higher incidence in tropical zones and higher latitudes of the southern hemisphere.[7] These models, however, do not take into consideration clouds that may absorb solar UV radiation. Climate change may influence the doses received by affecting such atmospheric variables as the presence of clouds and aerosols.[13] Deserving of mention are studies that show that, surprisingly, certain types of clouds can lead to relative increases in the amounts of both UV-B[14] and UV-A[15] radiation compared to visible light reaching Earth.

Our predictions of the effects of climate change on human health should be revised in the light of such studies. Ambient UV-B exposure in tropical zones and higher southern latitudes will rise in spite of reductions in CFC levels, while they will fall at northern latitudes.[9,10] We might conclude, then, that the incidence of skin cancer in those tropical and southern zones will be higher than the incidence in the northern hemisphere. In contrast, a lower ambient dose of UV-B radiation at northern latitudes may have a negative effect on vitamin D synthesis.

The issue becomes much more complex, in my view, when we consider interactions between different climate-change factors and their effect on increased UV-B dose. Habits of open-air sun exposure and use of protection strategies must be taken into account. Interdisciplinary analyses combining the approaches of experimental and social sciences are required.

Ozone depletion has been associated with the incidence of skin cancer, photoaging, immunosuppression, and cataract formation, but changes in sun exposure related to evolving cultural attitudes (in notions of beauty in relation to tanning), working conditions, and recreational and sports habits have been said to carry greater weight.[2,4-7] A possible increase in the average temperature in Great Britain of 2°C to 3.5°C may change the habits of the British, who might come to spend more time in the sun, increasing their risk of skin cancer.[2] An Australian study found that the incidence of sunburn doubled when temperatures rose from 18°C or under to between 19°C and 27°C, as people began to spend more time in the open air.[16] At temperatures over 27°C, however, sunburns were fewer because people sought shade.

Although the implications of global warming for dermatology are direct ones, they generally interact with other factors in ways that make it very difficult to draw simple conclusions of cause and effect. In broad terms, the World Health Organization has identified 3 types of potential impact of climate change on health[1]:

1. More or less direct repercussions of extreme weather: Sensitive skin is among the health conditions affected by extreme weather. Events can also lead to higher incidences of acne and skin infections by normal flora made up of gram-positive germs (*Staphylococcus aureus* and *Streptococcus pyogenes*) as well as to infections caused by prolonged contact with less common gram-negative germs (*Vibrio vulnificus, Vibrio parahaemolyticus*, and *Burkholderia pseudomallei,* among others) that proliferate in contaminated water after floods, tsunamis, and similar phenomena. Skin conditions related to low humidity (evaporation of sweat) will also be affected, and outbreaks of various types of dermatoses (eg, atopic dermatitis) can be expected.
2. Health consequences arising from various climate change processes and the ecological disturbances they bring about: In the medium and long term, effects of climate change on plants, sources of drinking water, rising sea levels, increasing acidity of ocean water and more would have an impact on quality of life and eating habits, and hence on human health. The gradual rise in temperature would encourage infections, as the vectors or causes of some diseases proliferate. Examples are malaria, dengue fever, leishmaniasis, cholera, Oropouche fever, Lyme disease, and red tide disease.
3. Health consequences (injuries, infections, nutritional and psychological disturbances and more) in populations displaced as a result of economic collapse, environmental

degradation, and conflicts arising in the wake of climate change: Skin diseases and human health in general would be influenced by economic status and the quality of public health systems within nations. Climate change can only exacerbate the enormous inequalities that already abound on the planet, Africa being the continent that suffers the most.

Estimates for the incidence of skin cancer due to ozone depletion assume that other factors will remain stable, oversimplifying the problem. A 9% increase in incidence by 2050 is predicted according to the most optimistic outlook. A 300% rise is foreseen by the most pessimistic.[17,18] Such estimates are the result of extrapolating the carcinogenic dose in hairless mice and adjusting for differences in the human epidermis. Thus, for every 1% decease in ozone layer thickness, the incidence of melanoma is projected to rise between 1% and 2%.[17,18] This ratio between the increase in UV-B radiation and a biological effect is known as the radiation amplification factor. The incidence of squamous cell carcinoma would rise by 3% to 4.6% and basal cell carcinoma by 1.7% to 2.7% for every 1% thinning of the ozone layer.[12,19] Nonmelanoma skin cancer would advance even more.[12] Whereas squamous cell carcinoma is related to the cumulative dose of UV-B radiation over a lifetime,[12] basal cell carcinoma seems to be more closely tied to episodes of high exposure that occur intermittently or suddenly and with sun exposure received in childhood and adolescence.[20] These studies ignore defense mechanisms, such as thickening of the stratum corneum and epidermis, or improvement in behaviors, such as the adoption of measures to reduce sun exposure.

The harmful effects of UV-B radiation become worse at higher temperatures. Experiments in mice have demonstrated that tumor induction increases 3% to 7% for every increase in temperature of 1°C.[21] Assuming a tumor induction efficacy of 5%, we can calculate that for global warming of 2°C, tumors attributable to increased UV-B exposure would increase by 9% to 11% by 2050.[22]

Since vitamin D synthesis is dependent on skin pigmentation and degree of UV exposure from sunlight, it is not easy to make a simple recommendation regarding optimal exposure to UV-B radiation that would produce adequate vitamin D without increased risk of skin cancer. The most recent report by a panel of experts of the United Nations Environmental Program (UNEP) on ozone depletion and its impact on the environment and human health[23,24] established that vitamin D_3 that forms as a result of exposure to UV-B radiation might play a very important role in protecting against a variety of internal organ cancers and autoimmune diseases.

Personal doses received, however, would depend on many factors, both environmental (latitude, altitude, aerosols, cloud cover, and dispersion) and social (occupations, recreational behaviors, notions of beauty, etc). Greater public awareness of the dangers of the sun's UV radiation has led to increased use of preventive and corrective measures (avoiding exposure, using sunscreens, and wearing protective clothing, etc). The UNEP report describes considerable debate within the scientific community,[24] as some researchers assert that the adverse effects of UV-B radiation are being overestimated while the benefits (such as the synthesis and accumulation of vitamin D) are underestimated.[25,26] Epidemiologic studies on the positive and negative effects of UV radiation are now taking the notion of personal dose more seriously, and some even offer projections of risk according to changes that are both environmental (ozone layer recovery, climate change) and sociocultural (greater public awareness). Therefore, we might well ask if greater use of protective measures against erythema (especially sunscreens) will undermine our ability to synthesize vitamin D_3 and enjoy its benefits as the ozone layer is replenished.

The 2007 UNEP report on the impact of UV radiation on the environment and human health highlights the debate between 2 groups of scientists regarding sun exposure and the balance of beneficial and adverse effects:

1. Group 1[7] points to the prejudicial effects of exposure to UV radiation and establishes that although exposure has benefits (vitamin D_3 synthesis) simple recommendations that assure a balance between positive effects of the vitamin and negative effects of overexposure cannot be established.
2. Group 2[25,26] argues that the adverse effects of UV-B radiation are being overestimated and the benefits (vitamin D_3 synthesis) underestimated given that benefits outweigh risks. The incidence of skin cancer and the resulting mortality are less of a burden than the consequences of inadequate sun exposure or dietary intake of vitamin D. The benefits of UV-B radiation and vitamin D have even been quantified for comparison to the risks of overexposure.

Various recommended doses for the production of vitamin D_3 have been put forth:

1. UV radiation exposure amounting to 25% of the minimum erythematic dose (MED) over approximately 25% of the surface of the skin (face, hands, and arms) would produce the equivalent of 1000 units of vitamin D.[27]
2. Fifteen minutes' midday sun exposure over the entire body in the summer (approximately 1 MED) is the equivalent of ingesting 10 000 units (250 µg) of vitamin D_3.[28]
3. Exposure of arms, hands, and face to a dose representing a third or a sixth of the MED produces vitamin D_3 that is equivalent to the intake of 200 to 600 units.[29]

When sun exposure is adequate, the analysis of risk of erythema as opposed to benefit in the form of vitamin D_3 production shows that the best approach would be to have short periods of exposure during peak hours in the middle of the day.[30] In winter it is not possible to synthesize vitamin D_3 at high latitudes, or the time required to do so would make this approach impractical. A study in Manchester, UK, found that around 62.5% of the population have insufficient levels of vitamin D_3 (20-32 $ng \cdot mL^{-1}$) in winter, but that serum levels increased substantially with short artificial UV radiation exposure that simulated summer sunlight.[31] However, the authors found that natural exposure to the midday sunlight of summer continued to produce suboptimal levels even after 15 minutes of sun over 35% of the body.[31] Thus, with low levels of sun exposure such as typically occur at high latitudes, there is only a small window of opportunity for adequate synthesis of vitamin D_3 by this means.

Conclusions

An interdisciplinary approach is necessary for studying the effects of climate change on the ozone layer and, therefore, on exposure to UV-B radiation and human health.[32,33] The most recently developed models of climate change differ from early ones in that they now predict that the ozone layer will not have recovered in tropical zones and the high latitudes of the southern hemisphere by the end of this century. Public health campaigns promoting photoprotective strategies should therefore be intensified in these regions. Meanwhile, in the northern hemisphere not only is ozone replenishment expected but more will have collected than was present in 1980. Recent studies of the immune system and UV-B radiation demonstrate the importance of vitamin D_3 in regulating immunity, activating type 2 T cells (in humoral immunity and anti-inflammatory processes) and therefore helping to attenuate autoimmune responses.[7,26] Epidemiologic studies have shown a link between sun exposure, vitamin D accumulation, and a lower incidence of internal organ cancers.[34] UV-B radiation prevents more cancers than it promotes.[25] Protection against internal organ cancers is achieved with higher doses of vitamin D_3 (1500-4000 units) than those recommended by the US Department of Agriculture's Institute of Medicine.

Protection against UV-A radiation, which is linked to oxidative damage and skin cancer, should be investigated given that the population is more exposed to this type than to UV-B radiation. Tanning lamps emit a light that is UV-A enhanced in comparison with the solar spectrum and this should be noted, as exposure under such lamps is 4-fold higher than in the natural sunlight of June in Malaga, Spain.[35] Exposure leading to photoaging and formation of free radicals is 6- to 7-fold higher, respectively, under lamps than in that natural sunlight of Malaga. More research is needed on the mechanisms by which vitamin D acts as well as on effective doses of both sun exposure and the vitamin if we are to understand the impact of reduced ambient UV-B radiation in the northern hemisphere as a result of climate change.

The appendix offers a list of web pages where further information on the ozone layer, UV radiation, and climate change can be found.

Appendix 1.

Useful Web Pages With Information on Ozone, UV Radiation, and Effects on Human Health and the Environment

http://www.aemet.es; Spanish National Weather Service (Agencia Estatal de Meteorología)
http://www.bom.gov.au; Australian Bureau of Meteorology
http:// www.epa.gov; United States Environmental Protection Agency
http://www.ipcc.ch; Intergovernmental Panel on Climate Change (United Nations)
http://www.mma.es; Ministry of the Environment and Rural and Marine Affairs (Ministerio de Medio Ambiente y Medio Rural y Marino, Spain)
http://www.nasa.gov; National Aeronautics and Space Administration (United States)
http://www.niwascience.co.nz; National Institute of Water and Atmospheric Research (New Zealand)
http://www.noaa.gov; National Oceanic and Atmospheric Administration (United States)
http://ozone.unep.org; United Nations Environment Programme
http:// www.who.int; World Health Organization
http:// www.wmo.ch; World Meteorological Organization (United Nations, for the study of weather, climate, and water, with headquarters in Switzerland)
http://www.woudc.org; Meteorological Service of Canada

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