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VALIDITY AND USE OF THE UV INDEX: REPORT FROM THE UVI WORKING GROUP, SCHLOSS HOHENKAMMER, GERMANY, 5-7 DECEMBER 2011

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Paper

VALIDITY AND USE OF THE UV INDEX: REPORT FROM THE UVI WORKING GROUP, SCHLOSS HOHENKAMMER, GERMANY, 5–7 DECEMBER 2011

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Abstract—**The adequacy of the UV Index (UVI), a simple measure of ambient solar ultraviolet (UV) radiation, has been questioned on the basis of recent scientific data on the importance of vitamin D for human health, the mutagenic capacity of radiation in the UVA wavelength, and limitations in the behavioral impact of the UVI as a public awareness tool. A working group convened by ICNIRP and WHO met to assess whether modifications of the UVI were warranted and to discuss ways of improving its effectiveness as a guide to healthy sun-protective behavior. A UV Index greater than 3 was confirmed as indicating ambient UV levels at which harmful sun exposure and sunburns could occur and hence as the threshold for promoting preventive messages. There is currently insufficient evidence about the quantitative relationship of sun exposure, vitamin D, and human health to include vitamin D considerations in sun protection recommendations. The role of UVA in sunlight-induced dermal immunosuppression and DNA damage was acknowledged, but the contribution of UVA to skin carcinogenesis could not be quantified precisely. As ambient UVA and UVB levels mostly vary in parallel in real life situations, any minor modification of the UVI weighting function with respect to UVA-induced skin cancer would not be expected to have a significant impact on the UV Index. Though it has been shown that the UV Index can raise awareness of the risk of UV radiation to some extent, the UVI does not appear to change attitudes to sun protection or behavior in the way it is presently used. Changes in the UVI itself were not warranted based on these findings, but rather research testing health behavior models, including the roles of self-efficacy and self-affirmation in relation to intention to use sun protection among different susceptible groups, should be carried out to develop more successful strategies toward improving sun protection behavior.**
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Key words: carcinogenesis; exposure, radiation; radiation risk; ultraviolet radiation

INTRODUCTION

THE GLOBAL Solar Ultraviolet Index (UVI) is a unitless quantity describing the maximum intensity of solar UV radiation received during a particular day on the earth's surface. It was introduced in 1995 by the World Health Organization (WHO), the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Commission for Non-Ionizing Radiation Protection (ICNIRP 1995). The primary idea was to develop a harmonized measure, which allowed monitoring long-term changes in UV irradiation and UV spectrum on the earth's surface caused, for example, by ozone depletion. The UVI refers to the daily maximum effective irradiance and serves as an indicator of the impact of UV-radiation on erythema (sunburn), an acute skin effect that is closely related to the potential

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for chronic sun-induced skin damage like skin cancer and photoaging.

In 2002, the concept of the UVI was expanded as a public awareness tool to help the public conceptualize the amount of harmful UV radiation and to alert people to the need for sun protection measures (WHO 2002). After 10 years of use, a systematic review of the effectiveness of the UVI revealed that the UVI has raised public awareness of UV exposure to some extent, but that it has not significantly improved sun protection practices (Italia and Rehfuess 2011). It is, therefore, important to examine possible reasons for this and to define areas in which more research is needed to achieve the final goal of improved sun protection behavior in susceptible populations.

While the adverse effects of excessive solar radiation on the skin, the eyes and the immune system are well recognized (Lucas et al. 2008), possible health effects resulting from insufficient sun exposure are less clear-cut. In 2005, at an "International workshop on UV exposure guidance," experts in the field of UV protection and vitamin D worked toward defining a balance between avoiding skin cancer and maintaining optimal vitamin D status (ICNIRP 2006). The workshop outlined several gaps in knowledge and defined research recommendations (McKinlay 2006). Science has progressed, and the request for revisiting the UV Index in view of recent research results has been raised (The Danish Cancer Society 2011).

A small working group, invited by ICNIRP and WHO, met in December 2011 in Schloss Hohenkammer near Munich, Germany, to revisit the scientific basis for the UVI in view of these recent insights. This paper provides an update regarding vitamin D, summarizes the role of UVA in carcinogenesis, and outlines new approaches on how to improve the effectiveness of the UVI as a public awareness tool toward encouraging sun protection behavior.

VITAMIN D AND THE UV INDEX

Vitamin D deficiency is a serious health issue, but there is very limited knowledge about the possible health effects of "inadequate" or "insufficient" vitamin D levels. Indeed, discussions on "adequate," "sufficient," and "optimal" vitamin D levels are ongoing. In short:

- The *action spectrum for vitamin D synthesis* as published in 1982 (MacLaughlin et al. 1982) is not yet confirmed. A number of epidemiological and experimental studies suggest different effects of intermittent exposure (recreational) compared to continuous (occupational) exposure (Gilchrest 2007). Therefore, further studies should improve our knowledge of the dose-response curve with a special focus on the dose rate;
- Several studies on the *quantitative UV-vitamin D relationship* are initiated, ongoing, or completed in different countries, but data are not yet available. Currently, we have a poor understanding of vitamin D production at an individual level regarding how much UV is needed, over what body surface area, and at what frequency of exposure in order for the skin to generate a given level of vitamin D. Large inter-individual and intra-individual (dependent on age) as well as population-dependent differences (i.e., in skin pigmentation) are expected;
- There are controversies or at least uncertainties about the definition of *optimal vitamin D status* (Vieth 2006; Bischoff-Ferrari et al. 2006), most commonly using serum 25-hydroxyvitamin D levels as an appropriate biochemical marker of the vitamin D status. Uncertainties exist regarding optimal vitamin D levels for different groups in the general population, including children and adolescents (Cashman 2007), pregnant women (De-Regil et al. 2012; Urrutia and Thorpe 2012) and the elderly (Winzenberg et al. 2012), as well as on an individual level (what might be sufficient for one person might not be sufficient for another one). Some of the controversy regarding the definition of optimal vitamin D levels might be due to the widespread variations in vitamin D analyses, and therefore quality control of vitamin D measurements is highly recommended;
- Given the *complexity of the vitamin D metabolism*, one has to keep in mind that the UVB-induced synthesis of pre-vitamin D_3 in the skin is only the first step in the synthesis of biologically-active vitamin D. Vitamin D bioavailability after cutaneous synthesis (or oral ingestion) depends on intestinal absorption, fat storage, and metabolism (Lips 2006; Tsiaras and Weinstock 2011). Thus, a number of factors influence the level of the active form, $1.25(OH)_2D_3$, including the activity of hydroxylases in liver and kidney, the concentration of vitamin D binding protein, and the inactivating cytochrome enzyme CYP24A1 in vitamin D target cells. Further experimental research is needed to elucidate the role of each of these factors in regulating the active metabolites of vitamin D and the extent of individual variability for each of these factors; and
- Finally, and most importantly, there are major uncertainties regarding the *overall importance of vitamin D for human health*. The role of vitamin D in calcium and phosphorus homeostasis, and thus in bone mineralization and skeletal growth, is well recognized (Cranney et al. 2008), but recent data have linked Vitamin D to a wider range of diseases (Chung et al 2009), including various cancers (IARC 2008), cardiovascular diseases (Reid and Bolland 2012), autoimmune diseases (Kriegel et al. 2011), diabetes (Pittas and

Dawson-Hughes 2010; Thomas et al. 2012), and allergies (Jones et al. 2012; Litonjua 2012). As most of these associations are emerging from ecological and cross-sectional studies, known to be subject to bias, the working group sees a need to assess the association between low-level vitamin D and deleterious health effects with more rigorous study designs (see also Cashman and Kiely 2011), including the reanalysis of existing cohort studies against a variety of health outcomes. So far, it remains to be clarified whether vitamin D insufficiency represents a marker of comorbidity or is causally related to adverse health outcomes.

Based on these gaps in knowledge and the point that only small amounts of UVB radiation, well below the minimum erythemal dose (Webb 2006), are needed for vitamin D synthesis, the expert group felt it was not warranted at this stage to modify the UVI to account for issues related to vitamin D.

UVA AND THE UV INDEX

UV radiation is the main etiological factor for skin cancer (Rigel 2008). At the time of developing the UV Index, the less energetic UVA (315-400 nm), which is 1,000-fold less efficiently absorbed by DNA than UVB, was believed to play little or no role in skin carcinogenesis as only UVB (280–315 nm) had been shown to damage DNA directly. On the basis of new data, in 2009, the International Agency for Research on Cancer (IARC) classified UVA, both from sunlight and tanning devices, as carcinogenic to humans (group 1) (IARC 2012). Though less directly damaging to DNA than UVB, UVA is much more abundant in natural light. There is now convincing in vitro and in vivo evidence that UVA is able to cause damage to a variety of biomolecules via photosensitiser-mediated processes, leading to oxidative damage to lipids and protein, and can create a number of molecules, including pyrimidine dimers and base oxidation products associated with DNA strand breaks (Ridley et al. 2009). The genotoxic effects of solar UV radiation may therefore derive from both UVB and UVA with the efficiency of DNA repair pathways such as base excision repair and nucleotide excision repair playing an important modulating role in determining the spectrum of mutations produced (Ridley et al. 2009; Ikehata and Ono 2011).

The facts that UVA is more penetrating than UVB, reaching keratinocytic stem cells and melanocytes of the basal layer, and also substantially contributes to local immunosuppression (Halliday et al. 2011) provide a further layer of complexity in understanding the contribution of UVA to skin carcinogenesis. The working group felt that further experimental studies with UVA+UVB co-exposure are needed, as synergetic effects of UVA and UVB exposure related to DNA damage, immunological, and epigenetic effects are expected. Experiments with either UVA or UVB alone (as frequently carried out in the past) do not reflect environmental exposure, giving potentially misleading results.

The current UVI formula is weighted around the clinical finding of erythema, which is primarily UVB associated. The question has been raised whether this is a reliable basis for assessing skin cancer risk. The working group concluded that, in the absence of sufficient data to support the use of an alternative action spectrum (e.g., based on DNA damage), alteration of the UVI formula was not justified. Moreover, the use of erythema as a surrogate for cancer risk is supported by consistent positive associations between sunburn and both melanoma and non-melanoma skin cancer (Dennis et al 2008). Thus, the current data are in line with sun protection messages promoted at a UVI of 3 and above. Epidemiologic studies, however, are not able to quantify skin cancer risk at low levels of sun exposure (UVI 1-3) and cannot distinguish between the specific impact of UVA and UVB radiation. Outdoors, humans are virtually always exposed to UVA and UVB simultaneously, whose intensities vary broadly in parallel. The UVA-UVB ratio depends on the solar zenith angle and thus on the latitude, altitude, time of day, and season, but these variations are too small to capture as input parameters in epidemiologic studies. Thus, although the contribution of UVA to carcinogenesis has likely been underestimated in the past, minor modifications of the action spectrum to take this into account are not expected to have a significant impact on the UVI.

THE UV INDEX AS A PUBLIC AWARENESS TOOL

The UVI was developed as a tool to conceptualize the amount of harmful radiation and to encourage the general public to use sun protection, and it is recommended to be integrated with broader public health approaches (WHO 2002). A recent systematic review of the effectiveness of the UVI as an instrument to promote sun protection suggests that UVI awareness is low to intermediate in most settings and that levels of UVI understanding are even lower. Studies examining the impact of the UVI on knowledge, attitudes, sun protection behavior and sun exposure generally showed no effect (Italia and Rehfuess 2011). This suggests that the UVI can raise risk awareness to some extent, but given low levels of understanding in the general population, its potential as a tool to change behavior is limited.

Nevertheless, the UVI can indicate usefully when sun protection is required, and several studies have shown population demand for UVI information (Wester and Paulsson 2000; Börner et al. 2010; Bulliard and Reeder 2001). As awareness about skin cancer prevention and vitamin D increases, so will the interest of the general population in the UVI. For this reason, promotion of the UVI is encouraged. Insights from health behavior theory and health communication science and recent developments in information technologies (see below) may offer opportunities to improve the effectiveness of UVI communication efforts.

One important approach to increasing the effectiveness of public health campaigns relies on strategic design of the intervention, including a specific definition of the target group and theory- and evidence-based development of the campaign message (Finnegan and Viswanath 2008). Important theoretical perspectives include communication science (uses and effects of mass media channels and persuasion strategies), cognitive psychology (information processing and retention), as well as health and social psychology. Health behavior theories, such as the Theory of Planned Behaviour (Ajzen 1991), Protection Motivation Theory (Rogers 1975), or the Health Action Process Approach (Schwarzer et al 2007) incorporate three major predictors of intentions: expectations about the positive and negative consequences of a health or risk behavior [Theory of Planned Behavior (TPB) - attitudes; Project Management Team (PMT) - response efficacy; Health Action Process Approach (HAPA) - outcome expectancies], beliefs about one's competency to be able to perform the behavior in the face of difficulties (TPB: perceived behavioral control; PMT/HAPA: self-efficacy), and beliefs about the threat to one's health entailed in a risky behavior (PMT: threat appraisal; HAPA: risk perception). The usefulness of these determinants for the prediction of different health and risk behaviors is well established, showing self-efficacy as the strongest predictor of intention and behavior in the health domain and risk perception playing a subordinate role (Schwarzer et al 2007; Floyd et al. 2000). Similar results are found in studies on sun protection and sun exposure (Myers and Horswill 2006; Craciun et al 2012).

Mobile phones have become a primary means of communication in many parts of the world, and their computing power is increasing (Abroms et al. 2011; Fjeldsoe et al. 2011). The continuous, real-time, portable nature of mobile communication technology allows the integration of UVI messages into individuals' natural communication environment to a greater extent than is possible through traditional broadcast or print media. This increases their ecological validity in individuals' natural social circumstances (Heron and Smyth 2010) and provides more intervention contact time (Abroms et al. in press). Being available throughout the day, UVI information on these mobile devices could provide ongoing social support for sun protection by increasing accountability and emotional support through a virtual relationship with users (Abroms et al. 2011; Fieldsoe et al. 2011; Graham et al. 2011). Sun protection information can be tailored to individuals by combining the forecast UVI for their specific location through GPS data with user-specific information such as skin type, clothing, and sunscreen use, thereby encouraging sun safety when it matters (Heron and Smyth 2010). Moreover, when the UVI is provided to individuals on portable handsets, it requests their attention and creates a sense of urgency to respond (Parrot 1995). Finally, smartphone applications may be useful to reach key target groups (e.g., young at-risk individuals) that tend to be missed by traditional media. However, the effectiveness of mobile smartphone applications in increasing sun protection behavior remains to be scientifically proven.

Within this context, the expert group discussed possible improvements in the utility of the UVI as a public awareness tool and agreed on the following:

- The threshold for recommending sun protection at UVI 3 and above is reconfirmed. Sun protection might also be recommended for those who sunburn easily and who plan to be outdoors for prolonged periods at UVI levels of 1 and 2. Primary research is encouraged to further explore the correct threshold level with respect to both vitamin D insufficiency and skin damage;
- A simple sun protection message is recommended when the UVI is above 3. It was acknowledged that the message of, "Avoid being outside during midday hours! Make sure you seek shade! Shirt, sunscreen and hat are a must!" at a UVI of 8 and above may be difficult for people in regions where the UVI would be either in the "high" or "extreme" range for a large proportion of the day;
- Predicted rather than real-time UVI values are to be promoted, as people's reliance on real-time values might lead to harm in case of sudden weather changes. If a single UVI value for the day is promoted, the predicted UVI value at solar noon should be communicated;
- Indicating times of day when sun protection is required is considered to be helpful as it provides a more informative and prescriptive set of figures that can motivate the general population toward sun protection measures. Correct wording is important, and messages should be simple and not in conflict with other health promotion messages, such as those encouraging physical activity; and
- The UVI and sun protection messages are to be delivered through as many channels as possible including powerful new pathways such as mobile communication technologies.

Well conducted studies are needed on the most effective strategies for using the UVI as part of sun protection efforts. Against background knowledge on major predictors of intention and behavior in the health domain, we can assume that interventions addressing self-efficacy (e.g., by providing information on how to protect oneself against UV radiation) will be more effective than messages trying to increase risk perception or changing attitudes. However, studies that systematically test the mechanisms of sun protection interventions by applying health behavior theory are rare (Reynolds et al. 2006). Therefore, further studies are needed on the influence of increased risk perceptions created by promoting the UVI, as well as on how it can be used in efforts to influence other psychosocial factors (e.g., self-efficacy and outcome expectations). These studies could also identify barriers that interfere with behavioral changes that might occur in response to promoting the UVI. For example, increased self-affirmation may lead to less-defensive processing of health risk information and might be one key toward achieving the goal of behavior change. Moreover, it is recommended that the most effective format to communicate the UVI (text messages and graphics versus the UVI value alone, two-tiered versus three-tiered sun protection scheme, etc.) be explored in important target groups (e.g., children, parents, and the elderly) in experimental settings.

CONCLUSION

The meeting confirmed that sun protection messages promoted at a UVI of 3 and above are of high public health relevance toward reducing skin cancer incidence and do not conflict with other health messages, especially regarding vitamin D and outdoor physical activities. The UVI continues to be a useful tool to estimate risk from solar exposure. However, the impact of the UVI on sun protection behavior is currently very limited, and primary research is needed to improve the effectiveness of the UVI as a public awareness tool. The final goal of changing sun protection behavior in the population might be reached by developing health promotion campaigns that account for personal determinants, such as attitudes, self-efficacy, and self-affirmation.

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REPLY TO WILLIAM B. GRANT

Dear Editors:

THE UVI working group acknowledges the contribution of Vitamin D to bone health as stated in our paper. However, we concluded that an optimal level of Vitamin D for humans has not yet been established with any certainty. Evidence of the health benefits of Vitamin D unrelated to bone health also has not been unequivocally documented (for a comprehensive review on dietary reference intakes, see www.nap.edu/catalog.php?record_id=13050). Contrary to Grant's views, there is scientific agreement that ecological studies should not be the basis of recommendations to the public, since any observed associations are easily confounded and therefore potentially unreliable.

The only way to properly evaluate the evidence of the beneficial effects of solar UVB as Grant requests is through a systematic review of the relevant literature. This must of course be set against the long established body of evidence of the harmful effects of exposure to solar UVB. When a systematic review of Vitamin D and cancer was performed by IARC in 2008, benefits were inconclusive and did not outweigh the harms (IARC Working Group Reports Vol. 5, International Agency for Research on Cancer, Lyon, 25 November 2008). The UVI working group would welcome a fresh systematic review to take account, as necessary, of new high-level evidence regarding the beneficial effects of exposure to solar UVB.

The authors declare no conflict of interest.

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