Sunlight exposure assessment: can we accurately assess vitamin D exposure from sunlight questionnaires?1–3

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ABSTRACT

The purpose of this review is to summarize the peer-reviewed literature in relation to sunlight exposure assessment and the validity of using sunlight exposure questionnaires to quantify vitamin D status. There is greater variability in personal ultraviolet (UV) light exposure as the result of personal behavior than as the result of ambient UV light exposure. Although statistically significant, the correlation coefficients for the relation between personal report of sun exposure and ambient UV light measured by dosimetry (assessment of radiation dose) are relatively low. Moreover, the few studies to assess the relation between sunlight measures and serum 25-hydroxyvitamin D show low correlations. These low correlations may not be surprising given that personal factors like melanin content in skin and age also influence cutaneous synthesis of vitamin D. In summary, sunlight exposure questionnaires currently provide imprecise estimates of vitamin D status. Research should be directed to develop more objective, nonintrusive, and economical measures of sunlight exposure to quantify personal vitamin D status. Am J Clin Nutr 2008; 87(suppl):1097S–101S.

KEY WORDS Sunlight, environmental exposure, vitamin D, film dosimetry, ultraviolet rays, questionnaires

INTRODUCTION

One of the Healthy People 2010 objectives is to “increase the proportion of persons who use at least one of the following protective measures that may reduce the risk of skin cancer: avoid the sun between 10 a.m. and 4 p.m., wear sun-protective clothing when exposed to sunlight, use sunscreen with a sun-protective factor (SPF) of 15 or higher, and avoid artificial sources of ultraviolet light.” in large part to lead to a reduction in melanoma cancer deaths (1). In 1998, 47% of adults reported that they regularly used at least one protective measure (1). At odds with these public health sun-protection measures are concerns about the vitamin D requirements necessary to prevent disease and optimize health (2). Vitamin D is synthesized in the skin through exposure to ultraviolet B (UVB) radiation, and solar UVB radiation is the primary source of vitamin D for most persons (2). The avoidance of sun exposure may partially explain the recent observed vitamin D deficiencies throughout the world (3).

Research is ongoing to quantify vitamin D status in the population and to study its relation to disease outcomes. Therefore, assessment of vitamin D status in populations must consider sunlight exposure. Sunlight is a complex exposure to measure because simply asking persons where they live or how much time they spend outside may not correctly classify UVB exposure, and thus an individual’s ability to synthesize cutaneous vitamin D. The purpose of this article is to review research on the validity of sun exposure questionnaires and to discuss whether sunlight exposure questionnaires can be used to quantify vitamin D status. It is not meant to be an exhaustive review of the literature, but rather an overview and discussion of the issues involved in sunlight exposure assessment as it relates to vitamin D quantification.

A basic epidemiologic principle to keep in mind when reviewing exposure assessment tools is the ecologic fallacy and the need for individual-level data. The ecologic fallacy is a “bias that may occur because an association observed between variables on an aggregate level does not necessarily represent the association that exists at an individual level” (4). For example, in skin cancer research that relies heavily on assessment of sunlight exposure, the ecologic fallacy may explain disparate findings between environmental UV radiation, latitude, and melanoma incidence where studies did not include personal-level data (5–7). Personal sun protection has a greater influence on personal UV exposure than do ambient UV levels, which demonstrates why results from studies that include personal-level data differ from studies that include only environmental-level data. These concepts will be further demonstrated in this review.

MEASURES OF ULTRAVIOLET RADIATION

For sunlight, it is important to remember that the electromagnetic spectrum is defined by wavelength and that only the visible light waves can be seen by the human eye. UV radiation has shorter wavelengths than does visible light, with UVA (320–400 nm) and UVB (280–320 nm) being the wavelengths of primary importance for human health. Vitamin D is produced on exposure of the skin to solar UVB radiation in the ranges of 290 to 315 nm (8).

Research has been conducted for decades by using sunlight exposure assessment and relating it to risk of skin cancers (9) and

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eye disease (10). Studies have generally estimated UV exposure by using the following measures: latitude of residence, ambient (ie, environmental) UV exposure, personal ambient UV exposure, and considerations about the anatomical distribution of UV. Overall ambient exposure is measured objectively and quantitatively by dosimetry, a method to quantitatively assess radiation exposure, which accounts for environmental influences such as cloud cover or surface. Ambient UV levels vary up to 30-fold by latitude, season, time of the day, ground surface (due to reflectivity), and cloud or tree cover (11–13). Personal ambient exposure refers to the personal influences that further affect ambient exposure levels, such as personal sun-protection behaviors. Personal ambient exposure can be calculated by knowing the amount of time spent outdoors (at specific times of the day and year), the use of sun protection (clothing, hats, sunscreen, etc), and the available terrestrial UV (11, 12). The anatomical distribution of UV has been shown to vary 10-fold by standing or sitting postures (14) and body site (15, 16). Sunlight exposure questionnaires need to account for these environmental and anatomical influences on ambient UV levels.

VALIDITY OF SUNLIGHT EXPOSURE QUESTIONNAIRES

No standard, validated sunlight questionnaires are routinely used to quantify exposure. Because latitude is important, prompts are often used in questionnaires to help respondents recall when in their lives they moved. Typically, this is done by asking the respondents to recall the years that they were in school and where they lived and the years that they changed jobs and where they lived during that time frame. It is often assumed that outdoor activity varies the greatest by location lived and job, and so specific questions about personal protection are asked for the time frames between latitude or job moves. To improve accuracy, sunlight questionnaires are often interviewer-administered and can take up to 30 min to complete, with respondent fatigue a potential problem, especially in the elderly. Typical questions used to assess sunlight exposure are listed in Table 1.

Two methods have been used to validate self-reported sunlight exposure questionnaires: observed exposure and personal UV dosimetry. Neither is considered a gold standard. A study of self-reported versus observed sun habits in beachgoers in Honolulu revealed correlations of 0.54 to 0.72 between self-reported use of sunscreen and objective measurement of sunscreen use, correlations of 0.21 to 0.39 between self-reported and observed sunburn (with subjects over-reporting sunburn), and correlations of 0.11 to 0.79 between self-reported and observed articles of clothing (17).

A large body of literature compares self-reported sunlight exposure with personal UV dosimetry, an objective measure of ambient UV levels (18–28). Although most researchers report statistically significant correlations between self-reported and objective measures of UV exposure, the correlation values show that self-reported measures leave a relatively large proportion of the variation in objective UV measures unexplained. For example, a study conducted in Australia found similar, statistically significant but modest agreement between estimated UV exposure from diaries when compared with dosimeter readings in mothers ($r = 0.32$) and children ($r = 0.34$) (20). Another study conducted in Australia reported correlation coefficients of 0.36 for girls and 0.23 for boys for the relation of erythemally effective dose to questions on habitual sun exposure (19). A study conducted in the United States found markedly different correlations between UV monitor measurements and self-reported behaviors by anatomic site, $r = 0.12$ for the arm and $r = 0.49$ for the leg (28). These data suggest that the precision of UV estimates based on self-reported sunlight exposure would not be great.

Regardless of the reliability of self-reported behaviors related to UV exposure by age, one study conducted in Denmark found no correlation between annual UV dose and age, meaning that cumulative lifetime UV exposure is distributed relatively evenly across quarters of a person’s life (29). One caveat to consider is that the research subjects in the Denmark study resided at the same latitude, so the results may not apply to more mobile populations or to people residing at other latitudes. However, these results may have implication for study design. If the results are valid for other populations, these data suggest that questionnaires could be shortened to focus on a recent period of time in adulthood and the data extrapolated to estimate lifetime exposure to that age. This would result in shorter questionnaires, which may also lead to higher accuracy due to reduced respondent fatigue.

### TABLE 1

<table>
<thead>
<tr>
<th>Components of personal UV exposure and modifying factors</th>
<th>Items to assess exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ambient UV</strong></td>
<td></td>
</tr>
<tr>
<td>Time of day</td>
<td>From ___ to ___ how much time did you spend outdoors between the hours of 7 and 9am? Between 9 and 11 am? Between 11am and 1pm? Between 1 and 3pm? Between 3 and 5pm? Between 5 and 7pm?</td>
</tr>
<tr>
<td>Latitude</td>
<td>Where did you live during this time period?</td>
</tr>
<tr>
<td>Season of year, vacation time</td>
<td>Ask the previous questions for each season of the year as well as for vacation periods.</td>
</tr>
<tr>
<td>Available terrestrial UV</td>
<td>What percent of this time did you spend under shade (eg, tree or beach shade)? How would you describe the weather conditions?</td>
</tr>
<tr>
<td>Cloud, tree cover</td>
<td>What percent of this time was spent over water?</td>
</tr>
<tr>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>Personal sun protection</td>
<td>What percent of time did you wear a brimmed hat?</td>
</tr>
<tr>
<td>Hats</td>
<td></td>
</tr>
<tr>
<td>Clothing</td>
<td>What percent of time did you wear long sleeves? Long pants?</td>
</tr>
<tr>
<td>Sunscreen</td>
<td>What percent of time did you wear sunscreen? What SPF? Did it have UVA and UVB protection?</td>
</tr>
</tbody>
</table>

1 UV, ultraviolet; SPF, sun-protection factor.
In summary, sunlight exposure questionnaires are commonly used to estimate UV exposure and have been shown to be reliable for various age groups and occupations. Although statistically significant, the relatively low correlation coefficients for the relation between personal report of sun exposure and ambient UV exposure measured by dosimetry suggest that measurement error needs to be incorporated into models that include UV exposure and also argue for the use of categorical or ordinal rather than continuous exposure estimates to account for the imprecision of the measures. Researchers should also be aware that as with other exposure assessments, sunlight exposure questionnaires can be susceptible to recall bias. Recall bias was shown in a twin study of melanoma risk factors, with twins recalling childhood sun exposures differently depending on whether they had melanoma (30).

**VALIDITY OF SUNLIGHT EXPOSURE QUESTIONNAIRES TO CATEGORIZE VITAMIN D EXPOSURE**

Researchers may want to use sunlight exposure questionnaires as a proxy measure for vitamin D exposure. Two studies have directly compared relations between serum 25-hydroxyvitamin D [25(OH)D] and sunlight exposure as assessed by using questionnaires (31, 32). A case-control study of multiple sclerosis in Australia found highly significant correlations between various measures of self-reported sun exposure and serum 25(OH)D concentrations (all P values < 0.05, with most < 0.01) (31). However, the largest correlation coefficient was 0.39 (for activities outside in the past 3 y), which means that most of the variation (>85%) in serum 25(OH)D concentrations was not explained by self-reported sun exposure. Thus, the potential for misclassification of vitamin D status by sun exposure levels is very high, even with statistically significant correlations between the 2 measures. Further research from Australia has shown that the contribution of sunlight to 25(OH)D concentrations is very important in the summer months but is less important in the winter months (33). A study in Danish perimenopausal women found that various measures of self-reported sunlight exposure were significantly correlated with serum 25(OH)D concentrations; however, the greatest correlation coefficient was 0.29, leaving much of the variation in serum 25(OH)D concentrations unexplained by self-reported personal sun exposure (32). A study of adolescent girls with polysulphone UV dosimeters and personal sun exposure diaries found variation in previtamin D₃ synthesis by time of day and month of the year (34). Thus, additional factors should be considered, unique to the assessment of vitamin D, when trying to quantify vitamin D exposure from measures of personal UV radiation exposure. Such factors include sunscreen use, clothing, age, and skin color.

**SUNSCREEN AND VITAMIN D**

Several studies have been conducted of the effect of sunscreen on vitamin D synthesis and 25(OH)D concentrations (35–38). Two studies, one with 8 subjects and one with 24 subjects in very controlled situations, found that SPF8 sunscreen use completely suppressed cutaneous vitamin D synthesis (35, 36). Two other studies found no effect on vitamin D when subjects were allowed to apply their own sunscreen (37, 38). In a randomized, double-masked trial of 113 subjects aged 40 y and older conducted in Australia, researchers found no differences in serum 25(OH)D concentrations between subjects randomly assigned to the use of an active sunscreen versus placebo sunscreen over the course of a summer (37). In a small observational study in Spain of 24 elderly sunscreen users and 19 elderly control subjects followed over 24 mo, differences in serum 25(OH)D concentrations at all time points were found to be nonsignificant (38). Inconsistent application of sunscreen in the active groups could have influenced the results in both studies.

In addition to personal differences in the application of sunscreen and its impact on vitamin D synthesis, the UV protection of sunscreens is known to vary across the UV spectrum and does not correlate with the SPF (39). Additionally, even sunscreens labeled as being water resistant lose much of their water resistance after several immersions (40). Although many persons could accurately report whether they wore sunscreen, accuracy in terms of coverage, SPF, water resistance, and reapplication after water immersion may not be as high and would require many more questions in a questionnaire to quantify.

**CLOTHING AND VITAMIN D**

There is a large body of literature on the UV protection of various fabrics. The UV protection of various types of clothes has been shown to vary 1000-fold (41), with the weave and color of the fabric having the greatest effect on UV protection (42, 43). Commercially available UV absorbers that can be added to washing detergents, although initially very effective, are known to lose their effectiveness after repeated washings (44–46). Clothing has been shown to attenuate the photosynthesis of vitamin D in vitro (47) and in vivo (48), with a greater attenuation for black fabrics and for tightly woven fabrics, similar to the UV attenuation observed for such fabrics. Given these influences, it would be nearly impossible to include questions on a questionnaire to adequately address the type of fabric worn outdoors to quantify UV exposure and vitamin D synthesis.

**PERSONAL FACTORS AND VITAMIN D SYNTHESIS**

There have been many reviews of various influences on cutaneous vitamin D synthesis (49, 50). Melanin pigment in skin inhibits photosynthesis of vitamin D because it absorbs UVB radiation. Cutaneous synthesis of vitamin D also decreases with age. Therefore, any sunlight questionnaires would need to include questions about age and skin color to include in a model to quantify vitamin D levels. Alternatively, skin color could be measured objectively with a spectrophotometer (although the equipment purchase would be necessary) or could be estimated subjectively by observers using a color scale, none of which have been evaluated in terms of their association with vitamin D status (51).

**CONCLUSION**

The major strength of using sunlight questionnaires to assess vitamin D status is their cost. They can be self-administered or interview administered via telephone and are therefore less expensive than serum 25(OH)D testing. They can also be used to assess exposure decades in the past. The major disadvantage of using a sunlight questionnaire to assess vitamin D status is the large number of factors that affect personal UV exposure and...
cutaneous vitamin D synthesis. The potential for error is compounded with every personal and environmental factor. Among the sunlight questionnaires or diaries that have been used, the correlation between personal UV exposure and serum 25(OH)D concentrations is not particularly high and varies by factors that affect cutaneous vitamin D synthesis.

In summary, at this time, sunlight exposure quantified through questionnaires is a poor proxy for vitamin D status because of the imprecision of the UV estimates obtained from sunlight questionnaires and the low correlation of sunlight measures with serum 25(OH)D. Given the importance of vitamin D to human health and the fact that sunlight is the major source of vitamin D for humans, particularly in the summer months, further research is needed to develop valid, reliable, inexpensive tools to quantify vitamin D from sunlight.

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REFERENCES


