Determining an effective UV radiation exposure time for vitamin D synthesis in the skin without risk to health: Simplified estimations from UV observations in 3 locations, Japan

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Abstract. UV radiation contains erythemally effective UV, which leads to skin damage as well as UV that synthesizes vitamin D. Here we attempted to determine the relationship between these by numerical simulation, with atmospheric parameters such as total ozone, using a radiative transfer model. It was found these two forms of UV are almost linearly correlated with each other for comparably large UV radiation. This means that if erythemally weighted UV, is known, then UV for vitamin D synthesis in the epidermis could be estimated using this relationship. It was shown that production of 10 μg vitamin D a day inside the body takes about 1/3 of the time that is necessary to reach MED for an effective skin area of 600 cm^2. For an area of 1200 cm^2, 1/6 of MED time is enough. It was also shown that for relatively weak UV, the time to produce vitamin D becomes longer, but the risk for MED becomes smaller. UV is commonly reported to the public in terms of the UV Index, these potential benefits can also be evaluated using the relationship. In this study, using erythemal UV data observed at some sites over the Japanese Archipelago, the time to reach MED and the time to produce 10 μg vitamin D were demonstrated so that people can learn how to treat UV considering risks and benefits.

Introduction

Since ozone layer depletion was first reported in the 1980s, numerous articles about destruction of ozone in the atmosphere and harmfulness of UV radiation have been published. Some of them were used to disseminate to the public that excessive exposure to UV radiation is hazardous for human health (potentially leading to skin cancer, eye cataract, immune suppression etc.), and how to avoid them. Before the time of ozone layer depletion, many people considered that exposure to the sun was preferable to pale skin, so they had been rather active to spend time outdoors. After that, most of Japanese people have turned UV image into "predator" from a healthy image, and have become very nervous about it. It is true that excessive exposure to UV is hazardous for human, but many women became to avoid and hate it especially for cosmetic problem.

On the other hand, UV in solar radiation has a merit to synthesize previtamin D in epidermis (UV_{VitD}) and it metabolizes to 25-hydroxyvitamin D and then to 1α,25-dihydroxivitamin D through a liver and kidneys. Intensive reports have been issued about the merits of UV radiation of the roles on health (Holick, 1995; Vieth 1999) for the diseases caused by the deficiency of serum vitamin D concentration, as well as the merits of vitamin D to reduce the incidence of a number of cancer such as rectal, breast, prostate, colon, etc (Holick, 2004). Although there remains ambiguity concerning optimal concentration of vitamin D for healthy body in serum, proposed guidelines generally encompass the range 10-25 μg a day (Duplessis et al., 2005; Holick, 2007), which differs by researcher and respective country. Dietary intake of vitamin D for Japanese people is shown by Ministry of Health, Labor and Welfare, Government of Japan so that 5.5μg a day is recommended from food for adult who have adequate serum parathyroid hormone originated from enough vitamin D. They state that those with serum 25-hydroxivitamin D more than 50 nmol/L have no diseases originated in vitamin D deficiency, but also states that the amount of necessary vitamin D for healthy body cannot be estimated because of unknown duration when subjects expose to UV for every season.

Since excessive exposure is hazardous, it is important to know the appropriate UV exposure time to obtain the vitamin D needed. Since the Japanese archipelago encompasses a wide range of latitudes, ambient UV levels are much different depending on the district as well as changeable by season. For these questions it is important to let people know and disseminate it to public how to behave to optimise exposure to UV radiation. In this case, it is necessary to know the amount of UV_{Ery} and UV_{VitD} from which the exposure time hazardous to human skin (MED), and the times for adequate amount of vitamin D synthesized in epidermis can be calculated. Those could be calculated if UV spectra are known and be able to obtain by observation of solar radiation. Here we developed a method to numerically obtain UV_{VitD} from UV_{Ery} information such as UV Index those yield appropriate time of exposure.

Necessary data for the analysis, such as UV spectra observed by Brewer spectrophotometers, total ozone by Dobson spectrophotometers, and other meteorological parameters were obtained with observations by Japan Meteorological Agency at three representative observation sites in Japan, Sapporo in the north (43°N, 141°E), Tsukuba in the central region (36°N, 140°E), and Naha in the south (26°N, 127°E). Optical thickness data for aerosols by sun-photometers and direct solar radiation were used to select cloud-free conditions at Tsukuba. This method enables us to propose the appropriate time for vitamin D production to expose to solar radiation without excessive exposure to be harmful. These calculations using here were developed based on the model "SMARTS2" (Gueymard, 1995) which was applied to three representative observation sites above mentioned. The detailed method of the calculation is described in Miyauchi and Nakajima (2016).

Discussion

In Figure 1 we show observed and calculated vitamin D synthesis from UV at 12h LT at Tsukuba, Japan in 2007. The calculated UV intensity agreed well with clear sky observed UV, which is shown at the upper end of observed curves. This result shows the effectiveness of our radiative transfer calculation by SMART2.

Figure 2 shows relationship between erythemal UV (UV_{Ery}) and vitamin D synthesis UV (UV_{VitD}) calculated at three locations, (a) Tsukuba, (b) Sapporo, (c) Naha, and (d) all sites in Japan.

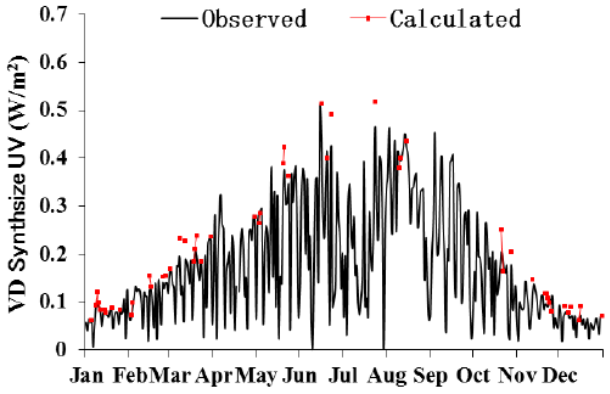

Figure 1. Observed and calculated vitamin-D synthesizing UV at 12h LT at Tsukuba in 2007.

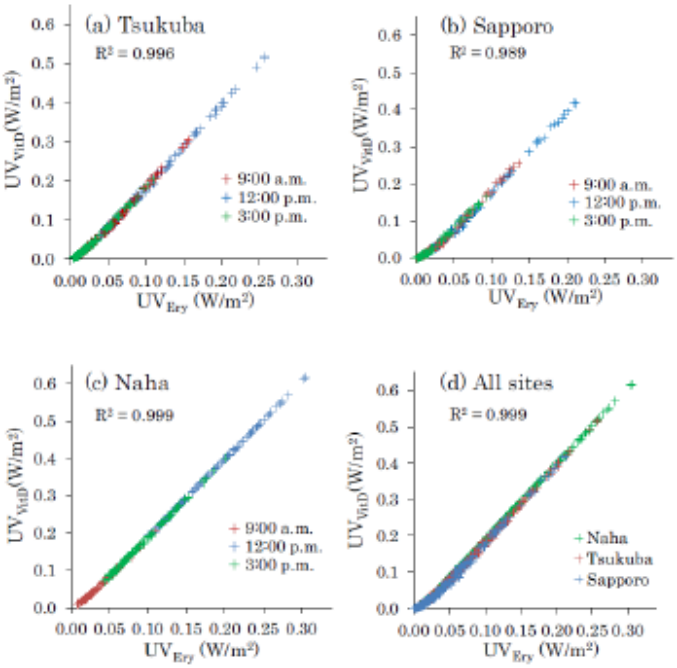

Figure 2. Relationship between erythemal UV and vitamin D synthesis UV calculated at three locations in Japan.

Figure 3 shows the time to produce 10 μg vitamin D for skin areas of 600 and 1200 cm^2 (dotted lines), and the time to reach MED at two locations in Japan in summer and in winter. It was shown that in Cape Ochi-Ishi (near Sapporo) in winter, a long time is needed both to produce vitamin D and to reach MED.

Finally, Table 1 shows the time for 10 μg vitamin D synthesis (600 cm^2 skin exposure) and to reach MED at noon in clear day at the three locations in Japan in July (summer) and in December (winter). It is rather difficult to get enough vitamin D in winter at Sapporo (139 min in clear sky), so additional intake of vitamin D either by food or by supplements may be required. In summer, because of short time to reach MED (less than 25 min) in all 3 sites, protection against UV is recommended.

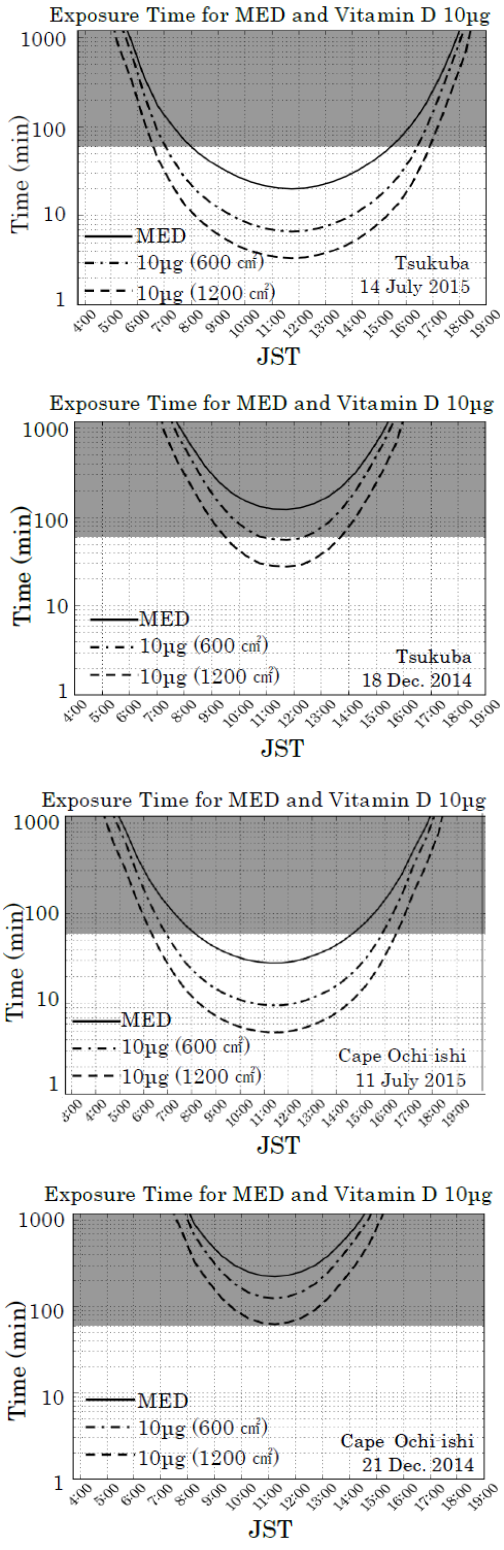

Figure 3. Time for 10 μg vitamin D synthesis and time to reach MED at two locations in Japan for clear days in summer and winter respectively. The upper two panels are for Tsukuba; the lower two panels are for Cape Ochi-Ishi (near Sapporo).

The method described is similar to the more general method introduced previously (McKenzie et al., 2009), where times for skin damage and vitamin D sufficiency for various skin exposures were calculated as a function of UV Index. The results shown here for skin type 3 are in good agreement with those.

Table 1. Time for 10 μg vitamin D synthesis and to reach MED at noon in clear day at three locations in Japan.

Time (minutes)	July		December	
	VitD	**MED**	**VitD**	**MED**
Sapporo (43˚N)	8	25	139	227
Tsukuba (36˚N)	6	20	41	98
Naha (26˚N)	5	16	14	42

Conclusions

We estimated sun exposure time to produce 10 μg vitamin D in the skin, and to reach MED at three locations in Japan. There exists a suitable sun exposure time, which is about 2-3 times less than the one to get MED, depending on season, time, and location, as well as area of skin exposed (i.e., attire). We constructed a web page to provide near-real-time information for vitamin D synthesis and MED by using the actual UV measurements at 5 locations in Japan as follows:

http://db.cger.nies.go.jp/dataset/uv_vitaminD/en/

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