Journal of Photochemistry & Photobiology, B: Biology 159 (2016) 101–105

Contents lists available at ScienceDirect

Journal of Photochemistry & Photobiology, B: Biology

journal homepage: www.elsevier.com/locate/jphotobiol

Optimal vitamin D_3 daily intake of 2000 IU inferred from modeled solar exposure of ancestral humans in Northern Tanzania

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ARTICLE INFO

Article history:
Received 18 November 2015
Received in revised form 4 March 2016
Accepted 21 March 2016
Available online 29 March 2016

Keywords:
UV radiation
Personal exposure
Vitamin D
Oral supplementation

ABSTRACT

Recently, high serum 25-hydroxyvitamin D concentration (~110 nmol/L) was found in the Hadza tribe still keeping ancient hunter-gather life style. This level could serve as optimal vitamin D level that was built during millennia of human evolution. The personal vitamin D_3 effective solar exposures of the Hadza adults are estimated using radiative model simulations with input from the satellite observations over lake Eyasi (3.7°S, 35.0°E). The calculations are carried out assuming the Hadza typical clothing habits and specific scenarios of the out-door activity comprising early morning and late afternoon working time in sun and prolonged midday siesta in the shade. The modeled doses received by the Hadza are converted to the vitamin D_3 effective daily doses pertaining to the lighter skinned persons. We propose a novel formula to get adequate vitamin D level — exposure of 1/3 MED around local noon to 1/3 part of the whole body during warm sub-period of the year in the low- and mid-latitude regions. Such daily solar exposure is equivalent to ~2000 IU of vitamin D_3 taken orally. For many contemporary humans with limited out-door activity habit achieving such daily norm requires vitamin D_3 supplementation of 2000 IU throughout the whole year.

1. Introduction

The growing interest in vitamin D in recent years stems from its importance for health. Low vitamin D status appears to be correlated with higher risks of various diseases [1–3]. There are three basic sources of vitamin D: skin insolation by UV-B radiation, food, and dietary supplementation. Most of vitamin D comes from casual exposure to sunlight [4]. The current style of life, limiting out-door activity plus sun-protective recommendation to avoid skin cancer lead to an inadequate worldwide vitamin D status [5]. The serum concentration of 25-hydroxyvitamin D (25(OH)D) represents an index of vitamin D status.

There is an ongoing debate concerning the 25(OH)D level needed for optimal health. The serum concentration of 25(OH)D below 25 nmol/L is widely accepted as the deficient level related to high risk of rickets and osteomalacia [6]. The sufficient level of 50 nmol/L, which is based on bone health conditions, is recommended by some authors [7,8]. The optimal vitamin D status of ~75–80 nmol/L is deduced from the osteoporosis studies [9]. Much larger optimum of 115–120 nmol/L is proposed by very recent studies [10,11]. The level of about 100–120 nmol/L is supported by various studies dealing with a relation between cancer risks and vitamin D_3 status [12–15].

The mean serum 25(OH)D concentration of 115 nmol/L was found in human ancestral, Massai and Hadza tribes, still practicing traditional way of life in the equatorial Africa [16]. This level could serve as a target of optimal vitamin D status that was built during millennia of human evolution, controlled by natural selection rules. It seems that such optimal level was fixed during human migration out of the equatorial Africa (since ~100,000 years ago) that forced loss of skin pigmentation in populations living out of the tropics. Thus, lighter skin is a result of adaptation to low UV-B intensity that allows the same vitamin D synthesis which previously occurred in the tropics.

We would like to estimate a daily mean vitamin D_3 effective (VD_3E) personal dose received by the Hadza adults during their normal out-door activities. Using a radiative transfer model we calculate the cloud-free ambient irradiance on a horizontal surface, which is multiplied by the action spectrum pertaining pre-vitamin D_3 skin synthesis. The personal dose is obtained multiplying ambient VD_3E dose by weights related to the Hadza's habits of clothing and out-door activity. Taking MED values for unexposed skin according the Fitzpatrick photo-types [17] and MED value for VI photo-type (typical for the Hadza) after photo-adaptation, we convert the daily mean VD_3E personal dose received by the Hadza to an optimal VD_3E personal dose to be received by other lighter skinned populations to keep healthy vitamin D level.

2. The Hadza Tribe

The Hadza are the Bushmen tribe, living in a wild and remote surrounding of Lake Eyasi (3.7°S, 35.0°E, 1027 m a.s.l., north-central Tanzania). Their skin is highly pigmented (deeply black) and belongs

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http://dx.doi.org/10.1016/j.jphotobiol.2016.03.029
1011-1344/

to type VI of the Fitzpatrick's classification of the skin sensitivity to erythemal irradiation. The Hadza are the last true nomades of the world, still practicing hunter-gather life style as their ancestors did ~10,000 years ago.

Their food is a poor source of vitamin D, so all of their vitamin D is due to the solar exposure. They have a mean 25(OH)D concentration of 109 nmol/L regardless of age, sex or BMI [16]. It is much more than the present 25(OH)D level in populations worldwide [5]. The Hadza spend most of their days in the sun but they avoid direct exposure to the midday sun staying in the shade. Most of the daily activities are organized in the early morning and late afternoon while middle part of the days is reserved for a prolonged siesta. The duration of an active part of the day for adults is around 6 h, regardless of sex and season, i.e. about half of the day duration [18].

In calculation of VD_3E daily doses we assume the following scenario of their out-door activity: staying in sun is symmetrical around local noon with equal duration of the morning and afternoon exposure. We examine various durations of the resting time in the shade, 4 h, 5 h, 6 h (the most probable), and 7 h. Fig. 1 shows the modeled ambient erythemal irradiance on September 1, 2007 for 6 h of siesta. It is practically impossible to calculate precisely the ambient UV irradiance in a shady place without on-site measurements of UV irradiance. We assume that during the midday siesta in the shade, the level of UV irradiance is the same as that at the moment of going for a rest in the late morning. In the afternoon they go back to work in sunny places as the UV irradiance falls to the same late morning value.

There are number of factors important for the radiation attenuation due to trees including foliage density, height of the canopy, solar elevation, and surrounding ground albedo. Previous studies showed that the exposure in the tree shade varied in the wide range between 5% and 50% of that measured in full sun [19,20]. For the assumed 6 h midday siesta the Hadza adults stop working when the ambient erythemal irradiance is equal about 5 UV index (UVI) ~40% of the UVI maximum on September 1, 2007 (Fig. 1). Thus, it seems that the Hadza's resting sites were under not so dense tree canopy.

Uncovered part of body surface area (BSA) is necessary for a calculation of personal VD_3E doses. The Hadza clothing covers mainly their upper body and upper legs. Frequently men wear only short trousers. It is worth mentioning that the Hadza do not use sunscreens. The revised Lund and Browder diagram suggests that uncovered BSA in this case is ~33% including: hairless head anterior (~3%), arms (18.8%), and shanks (13.8%) [21]. Uncovered BSA for men dressed only in short trousers (covering thighs) is about 60% but they have the same 25(OH)D serum concentration as women [16]. It suggests that increasing uncovered BSA above 33% does not improve vitamin D_3 and the selection of 33% uncovered BSA is the optimal choice for vitamin D_3 synthesis. This finding agrees with a hypothesis that the skin synthesis of vitamin D_3 reaches a plateau when uncovered BSA is larger than 33% [22]. Moreover 35% of irradiated skin area was selected in model studies and recommended for solar exposure to improve vitamin D status [23,24].

Surface temperature (Table 1) of Northern Tanzania allows one to use thin clothing throughout the whole day. The Hadza stay in shelters, built from local wood, leaves, and grass, only during rain and night. Cloudiness and rain are rare in the dry and sunny period starting in June up till the end of October. Sunshine duration is ~80% of the day length, whereas ~65% in the wet season culminating in February and March (Table 1).

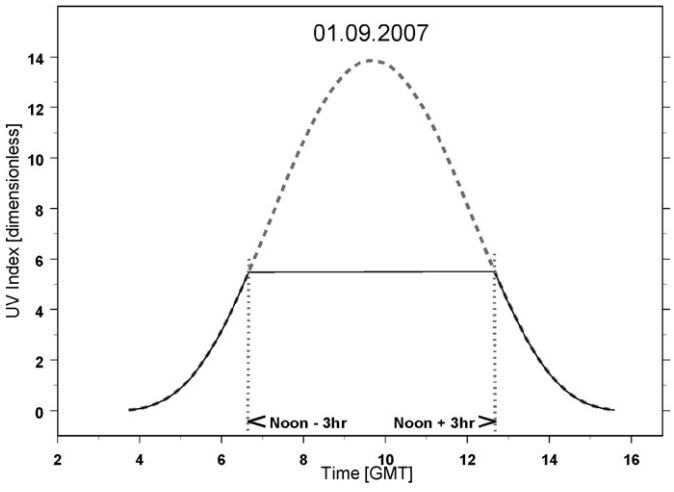

Fig. 1. The modeled ambient erythemal irradiance on September 1, 2007 over Lake Eyasi for the proposed schedule of the Hadza out-door activity with midday 6 h siesta (solid curve) superposed on the cloud-free daily irradiance (dashed curve).

3. The Personal Dose Calculation

The daily estimates of ambient VD_3E doses over the Hadza territory for cloud-free conditions are calculated for the period 2005–2014 using the UV spectra (290 nm–400 nm) derived by the Tropospheric Ultra Violet and Visible (TUV) radiative transfer model conditions [25]. Model input consists of daily means of total ozone, aerosol characteristics at 388 nm (optical depth and single scattering albedo), and the radiative cloud fraction taken by the ozone monitoring instrument (OMI) on board of the Aura spacecraft launched 15 July 2004.

The erythemal irradiances for all-sky conditions are obtained by multiplying the cloud-free irradiances by the so-called cloud modification factor (CMF) equal to 1 for cloud cover up to 2 octas [26]. For larger cloud cover, *CC* in percent, the empirical relationship derived for near equatorial region, $CMF = 1 - 0.0056 \times CC$ is used [27]. Table 1 shows that UVI is almost constant throughout the whole year as it varies ~1.5 UVI around the yearly mean. Moreover, it is found that the UVI yearly mean (11.5) agrees with the UVI mean (11.6) calculated for the dry period. The cloud-free model can be used for the period June–October as the cloud fraction is around 20% (Table 1) and corresponds with the sunshine duration measured at Dodoma airport (6°S, 36°N) as the sum of both values is ~100%. The monthly mean total ozone shows only a small seasonal variation within the range ~20DU.

We use web based data exploring tool — GIOVANI, http://giovanni.sci.gsfc.nasa.gov/giovanni/, to collect the model input data: total ozone amounts, aerosol optical depth at 388 nm, single scattering albedo at 388 nm, and radiative cloud fraction. The data were averaged over the domain {4.7°–2.7°S, 34°E–36°E} with Lake Eyasi in the centre.

The modeled spectral UV irradiance is weighted using the action spectrum of pre-vitamin D_3 formation from 7-dehydrocholesterol in

Table 1
The long-term (2005–2014) monthly mean values and the yearly mean measured at Dodoma airport (the maximum and minimum temperature at 2 m level, sunshine duration in percent of the whole day) and calculated from satellite observations averaged over 2°×°2 domain centered on Lake Eyasi (radiative cloud fraction, total ozone, and UV index for cloud-free and all-sky conditions).

Month	Temp. max °C	Temp. min °C	Sunshine duration (%)	Cloud fraction(%)	Total ozone (DU)	UV index clear	UV index all
Jan	29.9	19.3	68	27	246	13.5	11.5
Feb	29.8	18.9	63	26	249	14.3	12.2
Mar	29.5	19.0	64	28	254	14.2	12.0
Apr	28.8	18.3	71	26	257	13.0	11.1
May	28.3	16.9	76	24	256	11.3	11.3
June	27.4	15.7	82	16	257	10.1	10.1
July	26.8	14.4	86	16	260	10.2	10.2
Aug	27.5	15.2	83	20	263	11.6	11.6
Sep	29.3	16.2	82	21	265	12.8	12.8
Oct	30.9	17.6	83	21	262	13.2	13.2
Nov	31.6	18.9	72	33	257	13.1	10.7
Dec	30.4	19.4	68	37	249	13.1	10.4
Year	29.2	17.5	75	25	256	12.5	11.4