Journal of Steroid Biochemistry & Molecular Biology 121 (2010) 328–330

Contents lists available at ScienceDirect

Journal of Steroid Biochemistry and Molecular Biology

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

Holick's rule and vitamin D from sunlight☆

John C. Dowdy[a], Robert M. Sayre[a,b,*], Michael F. Holick[c]

[a] Rapid Precision Testing Laboratories, Cordova, TN 38016, United States
[b] Division of Dermatology, Department of Medicine, University of Tennessee Center for the Health Sciences, Memphis, TN 38104, United States
[c] Vitamin D, Skin, and Bone Laboratory, Endocrine Section, Department of Medicine, Boston University School of Medicine, Boston, MA 02118, United States

ARTICLE INFO

Article history:
Received 28 October 2009
Received in revised form 26 March 2010
Accepted 6 April 2010

Keywords:
Vitamin D
Sunlight
Action spectrum
Ultraviolet radiation

ABSTRACT

Holick's rule says that sun exposure 1/4 of a minimal erythemal dose (MED) over 1/4 of a body is equivalent to 1000 International Units (IU) oral vitamin D_3. Webb and Engelsen recently commented that the ultraviolet (UV) spectrum used to establish Holick's rule is unknown. They consequently used a spring midday Boston solar spectrum to estimate ample sunlight exposures for previtamin D_3 ($preD_3$) at various locations. Literature review found the source upon which this rule is based was a fluorescent sunlamp (FS lamp). The FS spectrum is known and its relative weighting against the action spectra for erythema and the $preD_3$ is significantly different from the solar spectrum used to derive the standard vitamin D effective dose (SDD). The $preD_3$ effectiveness of the solar spectrum per unit erythemal hazard is greater than the FS lamp by a factor of 1.32. Consequently, UV exposure estimates based on Boston reference sunlight, instead of the UV lamp employed in the originating experiments, over estimate UV exposure equivalent to ~1000 IU orally by ~1/3. This redefinition of SDD impacts risk/benefit assessments of optimal/feasible sun exposure for vitamin D maintenance and the application of Holick's rule to rational public health messages.

1. Introduction

Holick's rule that exposing 1/4 of our body to 1/4 MED of sunlight will produce vitamin D_3 equivalent to 1000 IU of vitamin D taken orally, has been used for several years [1–3]. In Webb and Engelsen's work on determining periods of sun exposure requisite for healthy vitamin D levels [4], the original UV spectrum upon which this axiom is based was cited as unclear. It is important to establish the spectrum of the UV source upon which Holick's rule is based so that accurate guidelines for needed sun exposure to maintain healthy vitamin D status may be developed. The spectral distribution of the UV source taken together with the action, or response, spectrum for conversion of 7-dehydrocholesterol to previtamin D_3 ($preD_3$) in human skin allows calculation of relative $preD_3$ benefit from exposure. The action spectrum for vitamin D production using ex vivo techniques was originally published in 1982 [5], was reviewed in 2006 by a CIE Technical Committee who issued a consensus action spectrum for $preD_3$ in human skin [6]. Webb and Engelsen's 2006 work used an earlier version, similar to the 1982 curve however, we employ the updated consensus version in this work.

Recent studies are suggesting an ever increasing importance of vitamin D for our health and well being. The importance of vitamin D in controlling a number of cancers and other health problems has been extensively reviewed and analyzed [7–12]. The potential to make adequate vitamin D through sunlight exposure has also been extensively examined [4,13–17]. Kimlin and co-workers and Webb and Engelsen emphasized that optimal $preD_3$ is made during solar noon exposures [4]. Sayre and Dowdy have recently concurred that solar noon exposure is optimal and further cautioned against wearing an SPF ≥15 sunscreen during exposure if making vitamin D is desired [18]. Consequently, it has been suggested that several modifications in the current sun safe public health messages are needed if individuals are to make adequate vitamin D during sunlight exposure. Despite this, a number of "safe sun" advocates have persistently, and erroneously, advocated that casual exposure while adhering to current sun protection guidance would allow adequate vitamin D [19–21]. In this work we identify the UV spectrum that underpins Holick's rule and examine it's implications upon our understanding of sunlight derived vitamin D.

2. Methods

2.1. Literature review

Since the axiom referred to as Holick's rule was not coined contemporaneously with the original research we conducted a retrospective literature review, in collaboration with the original

☆ Special issue selected article from the 14th Vitamin D Workshop held at Brugge, Belgium on October 4–8, 2009.

* Corresponding author at: Division of Dermatology, Department of Medicine, University of Tennessee Center for the Health Sciences, Memphis, TN 38104, United States. Tel.: +1 901 386 0175; fax: +1 901 386 7218.
E-mail address: rptl@aol.com (R.M. Sayre).

0960-0760/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsbmb.2010.04.002

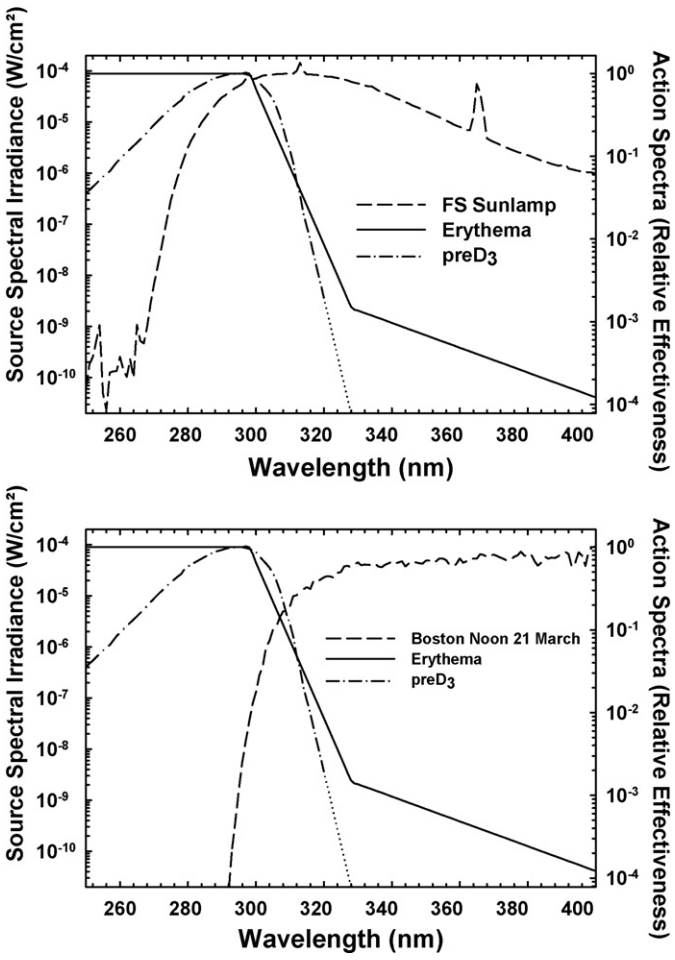

Plate 1. Spectrum of fluorescent broadband UVB phototherapy FS lamp (upper) and model Boston 42.37° SZA solar spectrum for noon on March 21 (lower) compared to relative UV spectral effectiveness for erythema and $preD_3$ in humans.

author (M. Holick). We traced the origins of the axiom from general use in recent reviews back to the original 1982 research article [22] describing the use of a clinical broadband UVB phototherapy booth containing 16 vertically arranged Westinghouse FS40 fluorescent sunlamps. This is a common broadband UVB phototherapy lamp and a representative typical FS spectrum was selected for this investigation from our measurement data archive.

2.2. Solar spectral model

The solar spectrum used to duplicate Webb and Engelsen's reference mid-latitude midday spring was generated using the same FASTRT algorithm (http://nadir.nilu.no/~olaeng/fastrt/fastrt.html). Parameters were latitude 42.2° N (Boston) GMT 17:00 h (local noon) on 21 March, ozone = 350DU, cloudless 25 km visibility, zero surface altitude and albedo and triangular spectral response function of 1.00 nm FWHM. The resultant 42.37° solar zenith angle spectrum is shown in Plate 1.

2.3. Spectral effectiveness

The biological effectiveness of the sources were calculated by Eq. (1), where the source spectrum at each wavelength is E_λ, the response weighting (erythema or $preD_3$) is σ_λ and the resulting sum is E.

$$E = \sum_{\lambda=250}^{400\,\text{nm}} E_\lambda \sigma_\lambda \quad (1)$$

The action, or response, spectra for human erythema and $preD_3$ are described in CIE documents [6,23]. The CIE standard erythema dose (SED) [23] is defined as an erythemal effective exposure of 100 J/m^2 (10 mJ/cm^{2}and is expressed in units of time to accumulate this effective UV dose. The SED is ~1/2 the dose required to produce mild erythema in a sensitive Skin Type-1 individual. We calculated the time to achieve 1/4 MED as 0.5 SED from both the FS spectrum and model solar spectrum and the relative concomitant $preD_3$ effective dose.

Table 1
Comparison of erythemal and $preD_3$ effectiveness of the model Boston sunlight and UVB FS lamp. While the FS lamp is more erythemic than the 42.37° SZA sunlight, the solar spectrum has a proportionally higher $preD_3$ effective irradiance. The ratio of $preD_3$ effective dose per SED corrects the SDD by a factor of 1.32.

	Boston Sun	FS Lamp	Ratio Boston/FS
$PreD_3$ EI (J/m^2)/0.5SED	87.4	66.5	1.32
$PreD_3$/erythema	1.75	1.33	
Erythema/$preD_3$	0.57	0.75	

3. Results

The spectrum of the FS lamp is known and its overlap with the action spectrum for $preD_3$ photosynthesis is shown in Plate 1 (lower). The irradiance of the FS spectrum was rescaled to that of the model solar spectrum to facilitate comparison of relative spectral distributions. The solar spectrum we used to duplicate the spectrum Webb and Engelsen derived their standard vitamin D effective dose (SDD) from is like wise compared in Plate 1 (upper).

The results of our comparative spectral analysis is shown in Table 1. The erythemal effectiveness of the FS lamp was significantly greater than the mid-angle solar spectrum. However the $preD_3$ effectiveness of the solar spectrum per unit erythemal hazard is greater than the FS lamp by a factor of 1.32. Consequently, UV exposure estimates based on reference Boston sunlight, instead of the FS lamp employed in the originating experiments, over estimate $preD_3$ effective UV exposure equivalent to ~1000 IU orally by ~32%.

4. Discussion

Holick's rule was developed from empirical studies using almost pure UVB sources rather than intermediate zenith angle sunlight. Guidance provided by Webb and Engelsen [4] overestimates required exposure by roughly a third due to their choice of Boston sunlight to convert Holick's rule into quantitative units of $preD_3$ effective UV. As noted in their work, the MED of most individuals varies with skin type [23] and efficiency of $preD_3$ photosynthesis decreases with increasing pigmentation. We also point out that the use of 1/2 SED as a surrogate for 1/4 MED also significantly underestimates requisite exposure for darker skinned people.

The work of Webb and Engelsen is increasingly significant because of numerous studies showing that vitamin D deficiency and insufficiency, correlated to many different disease conditions, is pervasive internationally through all skin types and ethnic groups. As public health messages on UV exposure trend toward more balanced assessments of both risk and benefit, refining such guidance continues to gain importance.

Acknowledgment

Supported in part by the UV Foundation.

References

[1] M.F. Holick, Sunlight, "D"ilemma: risk of skin cancer or bone disease and muscle weakness, Lancet 357 (9249) (2001) 4–6.
[2] M.F. Holick, M. Jenkins, The UV Advantage, iBooks, Inc., New York, NY, 2003.
[3] M.F. Holick, Vitamin D deficiency: what a pain it is, Mayo Clin. Proc. 78 (12) (2003) 1457–1459.
[4] A.R. Webb, O. Engelsen, Calculated ultraviolet exposure levels for a healthy vitamin D status, Photochem. Photobiol. 82 (6) (2006) 1697–1703.
[5] J.A. MacLaughlin, R.R. Anderson, M.F. Holick, Spectral character of sunlight modulates photosynthesis of previtamin D_3 and its photoisomers in human skin, Science 216 (4549) (1982) 1001–1003.
[6] CIE Technical Committee 6-54: CIE Technical Report CIE 174:2006, Action Spectrum for Production of Previtamin D_3 in Human Skin, Commission Internationale de l'Eclairage (CIE) Central Bureau, Vienna, Austria, 2006.
[7] W.B. Grant, An estimate of premature cancer mortality in the U.S. due to inadequate doses of solar ultraviolet-B radiation, Cancer 94 (6) (2002) 1867–1875.
[8] W.B. Grant, C.F. Garland, M.F. Holick, Comparisons of estimated economic burdens due to insufficient solar ultraviolet irradiance and vitamin D and excess solar UV irradiance for the United States, Photochem. Photobiol. 81 (6) (2005) 1276–1286.
[9] W.B. Grant, M.F. Holick, Benefits and requirements of vitamin D for optimal health: a review, Altern. Med. Rev. 10 (2) (2005) 94–111.
[10] R.P. Gallagher, T.K. Lee, Adverse effects of ultraviolet radiation: a brief review, Prog. Biophys. Mol. Biol. 92 (1) (2006) 119–131.
[11] W.B. Grant, Epidemiology of disease risks in relation to vitamin D insufficiency, Prog. Biophys. Mol. Biol. 92 (1) (2006) 65–79.
[12] M.F. Holick, Vitamin D deficiency, N. Engl. J. Med. 357 (3) (2007) 266–281.
[13] M.G. Kimlin, The climatology of vitamin D producing ultraviolet radiation over the United States, J. Steroid Biochem. Mol. Biol. 89–90 (1–5) (2004) 479–483.
[14] D.J. Turnbull, A.V. Parisi, M.G. Kimlin, Vitamin D effective ultraviolet wavelengths due to scattering in shade, J. Steroid Biochem. Mol. Biol. 96 (5) (2005) 431–436.
[15] M.G. Kimlin, N.J. Downs, A.V. Parisi, Comparison of human facial UV exposure at high and low latitudes and the potential impact on dermal vitamin D production, Photochem. Photobiol. Sci. 2 (4) (2003) 370–375.
[16] O. Engelsen, M. Brustad, L. Aksnes, E. Lund, Daily duration of vitamin D synthesis in human skin with relation to latitude, total ozone, altitude, ground cover, aerosols and cloud thickness, Photochem. Photobiol. 81 (6) (2005) 1287–1290.
[17] R.M. Sayre, J.C. Dowdy, J. Shepherd, I. Sadiq, A. Baqer, N. Kollias, Vitamin D-vs-erythema: effects of solar angle & artificial sources, in: M.F. Holick, E.G. Jung (Eds.), Biologic Effects of Light 1998, Proceedings of a Symposium, Basel, November 1–3, 1998, Kluwer Academic Publishers, Boston, 1999, pp. 149–152.
[18] R.M. Sayre, J.C. Dowdy, Darkness at noon: sunscreens and vitamin D3, Photobiochem. Photobiol. 83 (2) (2007) 459–463.
[19] H.W. Lim, B.A. Gilchrest, K.D. Cooper, H.A. Bischoff-Ferrari, D.S. Rigel, W.H. Cyr, S. Miller, V.A. DeLeo, T.K. Lee, C.A. Demko, M.A. Weinstock, A. Young, L.S. Edwards, T.M. Johnson, S.P. Stone, Sunlight, tanning booths, and vitamin D, J. Am. Acad. Dermatol. 52 (5) (2005) 868–876.
[20] D Wolpowitz, B.A. Gilchrest, The vitamin D questions: how much do you need and how should you get it? J. Am. Acad. Dermatol. 54 (2) (2006) 301–317.
[21] B.A. Gilchrest, Sun protection and vitamin D: three dimensions of obfuscation, J. Steroid Biochem. Mol. Biol. (2007).
[22] J.S. Adams, T.L. Clemens, J.A. Parrish, M.F. Holick, Vitamin-D synthesis and metabolism after ultraviolet irradiation of normal and vitamin-D-deficient subjects, N. Engl. J. Med. 306 (12) (1982) 722–725.
[23] International Commission on Illumination (CIE): International Standard ISO 17166:1999(E)—CIE 007/E:1998, Erythema Reference Action Spectrum and Standard Erythema Dose, International Organization for Standardization (ISO), Geneva, Switzerland, 1999.