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Variability of pre-vitamin D_3 effectiveness of UV appliances for skin tanning☆

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ABSTRACT

While there is limited documentation that certain indoor tanning lamps effectively produce vitamin D, the diversity of such devices has not been extensively surveyed. This study compares the spectral effectiveness of a variety of tanning units, and solar spectra, for ultraviolet (UV) photosynthesis of pre-vitamin D_3 (preD_3) and UV induced erythema. Well-established techniques exist for the calculation of spectral effectiveness for photobiological responses that have defined action spectra. Using spectroradiometric data from sunlamp measurements, and standard solar reference spectra, we computed effective irradiances using the CIE action spectrum for the production of preD_3 in human skin and the ISO/CIE human erythema reference action spectrum. We found, as with sunlight at different times or latitude, the preD_3 and erythemal effectiveness of sunlamps varied as a function of the UV-B proportion of the spectrum. Ratios of sunlamp preD_3 to erythemal effectiveness ranged from ~0.5 to nearly 2.0, similar to ratios for sunlight. Optimal risk to benefit conditions for preD_3 from solar UV exposure occurs under high solar altitude, low zenith angle, midday midsummer sunlight. Analogous optimal preD_3 exposure conditions are provided by low to intermediate pressure sunlamps with greater UV-B spectral overlap with the preD_3 action spectrum. Similar to low altitude or high latitude sunlight, high pressure tanning units, filtered for negligible UV-B emissions, have insignificant vitamin D benefit. We conclude that while vitamin D can be made by both UVB exposure from indoor tanning units and by exposure UVB from sunlight, the effect is also comparably variable. Unlike sunlight, indoor tanning offers privacy and environmental conditions for practical full body exposure, lowering the requisite exposure per skin surface area, and device timers limit the potential of overexposure. Guidance for optimal use of tanning sources for vitamin D benefit is needed.

1. Introduction

The UV spectrum of sunlight varies continuously throughout the day and year, so that a given exposure one day, effective for vitamin D without risk of sunburn, can on another day result in sunburn without significant vitamin D benefit. The difficulty of making natural vitamin D in skin in the winter and at higher latitudes, over 40°, is well documented. For users of UV appliances solely for vitamin D benefit the goal is to achieve adequate UV exposures to induce or maintain sufficient vitamin D without receiving a concomitant injurious level of UV, particularly a sunburn. To achieve this repeated and regular exposures will be required. This means that the same UV doses that can produce vitamin D can also cause additional chronic effects including tanning, skin aging and even skin cancer. However, exposures that minimize erythema risks also minimize chronic confounding problems. Human risk to erythema as well as risks of chronic exposure problems depend upon an individual's skin type and inherent sensitivity of UV injury. The same individuals most sensitive to sunburn are precisely those who are at the greatest risk to developing skin cancer from chronic UV exposure. Lighter pigmented individuals will require less exposure to sunburn but also less exposure to make adequate vitamin D than do darker pigmented individuals [1,2]. Therefore, minimizing chronic UV risks while realizing vitamin D benefits requires sensible exposure habits for all skin types.

2. Methods

This study compared the UV spectra measured from 200 to 800 nm at 1 nm increments with either OL-754 or OL-756 spectroradiometers using ~1 nm band pass slits calibrated against a NIST

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Table 1
Comparison of the percent unweighted UVB (260–320 nm) of total UV (200–400 nm) with the relative proportion of $preD_3$ and erythemal efficacy of sunlight and tanning sources. Representative sources are designated as CIE reference solar spectra or IEC UV-type appliance.

Source	UVB/Total UV (%)	$preD_3$/Ery Ratio	$preD_3$/SED (pD_3eff J/cm^2)
AM1G T7/1 Std. Sun	5.97%	1.97	0.020
AM1.5G T7/2 Std. Sun	4.48%	1.75	0.017
UV Type 4 Facial Lamp	2.11%	1.51	0.015
UV Type 5 Leg Tanner	2.51%	1.35	0.014
UV Type 3 TL-09 Lamp	2.02%	1.15	0.012
UV Type 5 Booth	2.04%	1.13	0.011
UV Type 3 Body Lamp	1.96%	1.09	0.011
UV Type 4 Body Lamp	1.82%	1.08	0.011
UV Type 3 TL-10 Lamp	0.45%	0.90	0.009
UV Type 3 Facial Lamp	0.36%	0.51	0.005

traceable quartz halogen standard. The Air Mass 1.0 and 1.5 solar spectra are described fully in a CIE Technical Report [3] and were extrapolated through shorter wavelengths range to cover more of the measured wavelength range of the lamps. 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.

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

The action, or response, spectra for human erythema and $preD_3$ are described in respective CIE documents [1,2]. The CIE standard erythema dose (SED) [2] is defined as an erythemal effective radiant 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.

All UV sources were compared one to the other by comparing 1 SED equivalent doses delivered. This allows the benefits of the $preD_3$ produced to be related to a specific injury caused by each source. This was graphically expressed by unitizing each spectrum to 1 SED by multiplying the irradiance (W/cm^2/nm) by the time required to deliver 1 SED to yield a spectral distribution of UV dose (J/cm^2/nm/SED). Ratios of $preD_3$ effectiveness to erythemal effectiveness and the $preD_3$ effectiveness per SED were also calculated.

3. Results

Plate 1, upper, provides the action spectra for erythema and also for pre-vitamin D_3. It also shows two different fluorescent lamps among the many types used for indoor tanning the Philips TL-9 and TL-10 bulbs. The TL-9 bulb is often used for PUVA (psoralen + UVA) therapy. It is often mixed with UVB fluorescent phosphors to create high UVB fluorescent sources used in many indoor tanning units. The spectra showed are scaled to 1 SED of erythemal risk. Plate 1, lower, shows two solar spectra (Air Mass 1.0 and 1.5) along with a variety of tanning unit sources including fluorescent lamps, facial lamps and high pressure UV sources. These spectra are also scaled to an equivalent 1 SED of erythemal risk.

The results of the spectral analysis is shown in Table 1. Both the Air Mass 1.0 and 1.5 solar spectra had greater $preD_3$ effectiveness per SED than any of the tanning unit spectra. The $preD_3$ effectiveness of the sources decreases with lower percentage of UVB. Note: The TL-9 produces approximately 1/3 more $preD_3$ effectiveness per the same 1 SED exposure than does the TL-10.

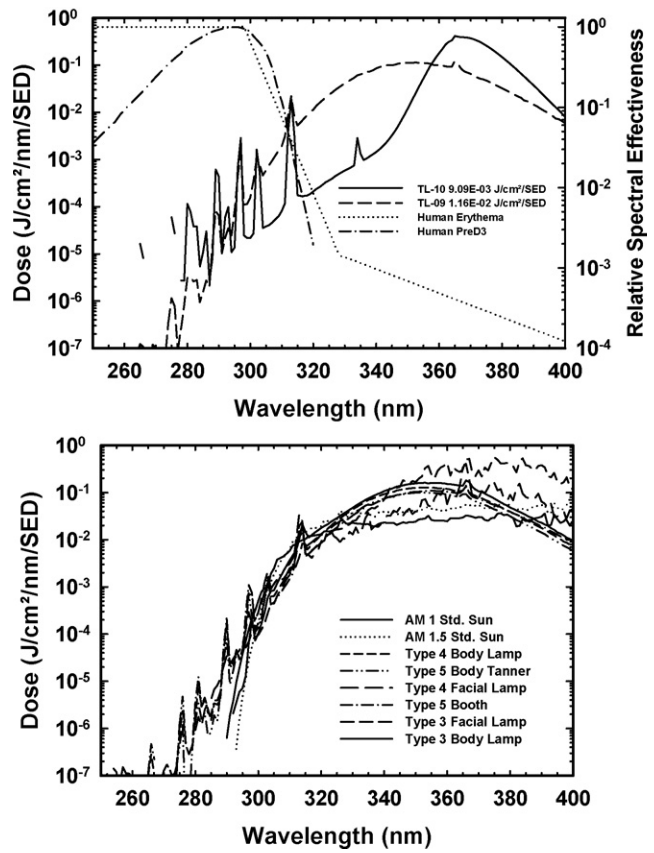

Plate 1. Upper, spectral distributions of TL-10 and TL-09 medical phototherapy lamps compared with action spectra, biological weighting functions, for erythema and $preD_3$ in human skin. Lower, spectral distributions of various tanning lamps compared with standard solar reference spectra. All source spectra are shown rescaled to equivalent erythemic power to enable direct visualization of differences in spectral distribution and overlap with the action spectra.

4. Discussion

As expected the $preD_3$ effectiveness of the sources was found to be a function of the percentage of UVB emitted by the source. Ratios of $preD_3$ to erythemal effectiveness for the tanning sources with ~2% UVB output approach that for the 1.5 atmosphere solar reference. While this is not entirely unexpected, it must be realized that the Air Mass 1.5 sun is more representative of the average daily solar spectrum in mid temperate latitudes than the tropical AM 1.0 overhead sun. Also outside of the tropics only a reasonably small fraction of one's body surface is typically exposed as clothes are generally worn outdoors.

Recently Peterson et al. [4] commented that there was only one other study examining the vitamin D status of regular users of indoor tanning facilities and indicated the study on vitamin D and bone density of Tangpricha et al. [5]. However, there have been a number of studies that use standard indoor tanning equipment and facilities to study UV induced vitamin D in human patients and volunteers [6–12].

What is needed are studies to quantify either the frequency of visits, the exposure doses actually employed, or even the specific type of device. Our work presented herein suggests that the same erythemic risks from exposure will produce very different amounts of vitamin D.

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