Action Spectra for UV Effects – UV Filtering by Human Skin

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Abstract. Human skin is the interface between man and his environment. One of the environmental factors it has to deal with is ultraviolet radiation. Ultraviolet radiation may cause negative effects such as erythema, skin ageing, skin cancer, etc. Not surprisingly, the epidermis – the upper layer of the skin – acts as a natural UV filter and may thicken or develop a stronger pigmentation as an adaptation to excess UV exposure. On the other hand, UV radiation induces photoproduction of previtamin D_3 in the skin and thus provides the major natural source for vitamin D_3 for humans. Thus, it seems reasonable that skin has not evolved as a mere sun block but as a sun screen which is even adaptable to a certain extent. Using optoacoustics, we have determined the wavelength dependent absorption coefficients of human skin in the UVB and UVA-II. Based on this data for the UV filtering properties of human skin, we calculated the biological effectiveness of solar radiation at different depths within the epidermis and found that UV adaptation more effectively shields the skin from erythemally active radiation than from vitamin D producing radiation. Thus, adaptation to high UV exposure tends to choose beneficial over detrimental UV effects.

Optoacoustic study

Optoacoustics is a fairly new method to study the optical properties of human skin in vivo. Pulsed laser radiation is used to illuminate a sample, i.e. the skin. The radiation is distributed in the sample according to its optical properties and absorbed radiation energy is converted to pressure. This pressure profile (high pressure where a lot of radiation has been absorbed and low pressure at volumes with low absorption) is released as an ultrasound pulse and can be measured above the skin. The initial light distribution in the sample and its optical properties can be deduced from this ultrasound pulse.

We measured the absorption spectra of human skin in a study in twenty subjects belonging to skin phototypes I-IV (phototype I: n=3, phototype II: n=6, phototype III: n=6, phototype IV: n=5). Absorption coefficients were determined in the range from 290 nm to 341 nm (3 nm steps) on the inner and outer side of the forearm and the ball of the thumb. The study was conducted in the summertime and 12 subjects reported more sunseeking behaviour whereas the other 8 subjects said they were office workers and tended to avoid sun exposure.

The optical properties that human skin develops depend on individual native and environmental parameters. Environmental effects may be facultative pigmentation and a thickened horny layer in response to and as an adaptation to higher UV exposure. Because the skin on the inner side of the forearm is relatively thin and normally only weakly exposed to daily sunlight, it is expected to show nearly the native properties of individual skin. On the outer side of the forearm, the skin is much more strongly exposed to sunlight and UV radiation but the skin structure is still similar to that on the volar side. Comparative analysis of these two sites allows insight into how UV adaptation may affect the optical properties of the skin.

Optical properties of skin

Figure 1 shows the absorption spectra of human skin at different skin sites: inner and outer side of the forearm – i.e. skin with low and high natural UV exposure – and the ball of the thumb where the skin's horny layer is especially thick. Data for the outside of the forearm is shown as mean as well as split up into the high and low UV exposure group. Remarkably, the horny layer is a potent UVB screen but is fairly transparent for UVA radiation. Adaptation to higher UV exposure results in higher absorption coefficients especially in the UVB range probably due to epidermal thickening and pigmentation.

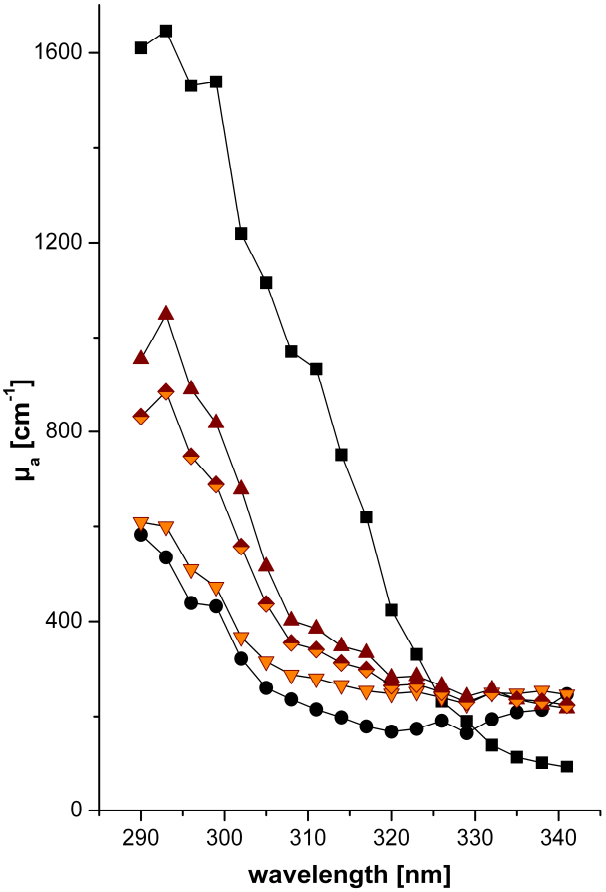

Figure 1. UV absorption spectra from different sites of human skin: inner side of the forearm (black circles), outer side of the forearm (mean: bi-colour diamonds, low UV exposure group: downward triangles, high UV exposure group: upward triangles) and ball of the thumb/horny layer (squares).

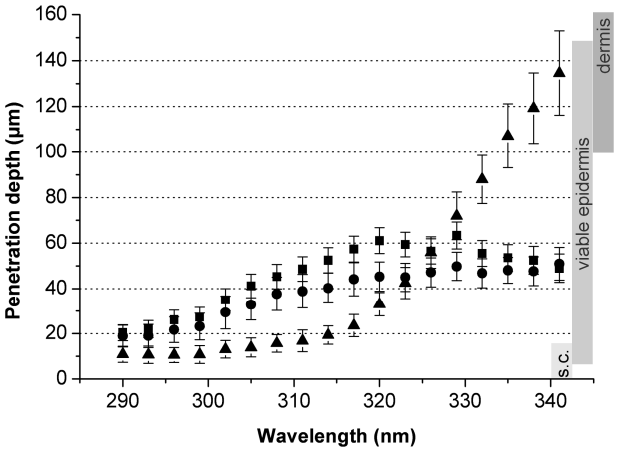

Figure 2. Penetration depths (1/e-level) of UV radiation for human skin at the volar side of the forearm (squares), dorsal side of the forearm (circles) and at the ball of the thumb (triangles).

Figure 2 shows what these absorption spectra mean in terms of penetration depth. In normal skin like on the forearm, UV radiation is strongly attenuated. Only 40 % or less of the incoming radiation reaches a depth of 60 µm – halfway through the viable epidermis. The horny layer very effectively reduces the penetration depth for UVB radiation. A thickened horny layer thus provides an effective screen for the living cells underneath it. On the other hand, it is ineffective in blocking UV radiation.

UV filtering & UV effects

In order to assess the UV filtering potential of human skin we calculated how much of the diffuse solar spectral irradiance weighted by the action spectrum for erythema or previtamin D_3 formation penetrates 20 and 100 µm deep into human skin based on its optoacoustically measured optical properties.

Applying a simple model like the Lambert-Beer law, the global spectral irradiance E(λ) is attenuated exponentially with increasing depth d according to the skin's optical properties (μ_a). This attenuated spectrum is weighted by the respective action spectrum A(λ) and integrated over the relevant wavelength range yielding the biologically effective irradiance at the respective depth:

$$E_{bio}^{skin} = \int_{290nm}^{345nm} E(\lambda) e^{-\mu d} * A(\lambda) d\lambda$$

Figure 3 shows the difference between $E_{erythema}$ ($isE_{erythema}$) and $E_{previtaminD3}$ ($isE_{previtaminD3}$) for two depths within the skin, weakly pigmented vs. UV adapted skin, and for global spectral irradiances from SZA 30°, 50° and 70° as would be expected for summer, autumn/spring, and winter at temperate lattitudes. Only when the sun is low, vitamin D_3 is produced throughout the skin before the minimal erythemal dose is reached. Erythema outweighs vitamin D_3 production for the rest of the year in weakly pigmented skin. The cumulative UV-screening effect of the skin chromophores becomes of course more and more effective with increasing path length – i.e. depth – in the skin. At the basal layer, where protection from detrimental UV effects is most important, the full impact of the filtering properties of UV adapted skin is unveiled. 100 µm of UV adapted skin can shift the dominant effect of UV radiation from erythema to vitamin D_3 production.

Figure 3. Difference between the biologically effective irradiance of one detrimental UV effect ($E_{erythema}$ ($isE_{erythema}$)) and potentially beneficial UV-induced vitamin D_3 synthesis ($E_{previtaminD3}$ ($isE_{previtaminD3}$)). Combinations of solar spectral irradiance from three different SZA and two UV adaptation status of the skin are compared. The upper bar in each row is for a depth of 20 µm within the skin and the lower bar (in red) shows the situation at a depth of 100 µm near the basal layer at the dermal-epidermal-junction.

It is important to notice however that the action spectra used for this calculation can only give a rough idea of the true in vivo situation. The action spectrum for previtamin D_3 production for example marks the dose where 5% of provitamin D_3 are converted to previtamin D_3. It is not clear what this means in terms of vitamin D_3 sufficiency. Besides, all action spectra are based on single dose administration but the factor of time is very important in the in vivo situation. For example, repair mechanisms may take their time to counteract detrimental UV effects. On the other hand vitamin D_3 may just accumulate over time.

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