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Sunscreen Protection Against *Cis*-urocanic Acid Production in Human Skin

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Commercial sunscreens may offer some protection from immunosuppression induced by ultraviolet (UV) radiation, but agreement concerning the degree of protection is lacking. *Cis*-urocanic acid, formed by the photoisomerization of *trans*-urocanic acid is considered an important mediator of the cutaneous immunomodulation resulting from exposure to UV radiation. We investigated the effect of sunscreens on the isomerization of urocanic acid in 17 human subjects. Two sunscreens containing chemical filters, sun protection factor (SPF) 4 and SPF 10, and a SPF 10 sunscreen with a physical filter were applied at a thickness of 2 mg/cm^2. The effect of a thin layer (0.5 mg/cm^2) of the chemical SPF 10 sunscreen was also evaluated, as the amount of sunscreen applied in practice may be considerably less than recommended. All areas were irradiated with a single UV dose of 3.6 SED (standard erythema doses). In irradiated unprotected skin the median net production of *cis*-urocanic acid was 52% (relative amount). In the sites treated with the chemical sunscreens, the production of *cis*-urocanic acid was 7.4% (SPF 4) and 3.5% (SPF 10), and isomerization was thus reduced more efficiently at a higher SPF ($p < 0.01$). The physical sunscreen reduced the formation of *cis*-UCA to 15%, and was significantly less effective than both the chemical SPF 10 sunscreen ($p < 0.01$) and the SPF 4 sunscreen ($p < 0.01$). The production of *cis*-urocanic acid in the area treated with the thin layer of the chemical SPF 10 sunscreen was 22%. The protection against the production of *cis*-urocanic acid was therefore reduced significantly ($p < 0.01$) when the sunscreen was applied in an amount lower than recommended.

Key words: UV radiation; immunosuppression; sunscreens; urocanic acid.

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Sunscreens provide protection against ultraviolet (UV)-induced erythema, but reports on the degree of protection against UV-induced immunosuppression offered by sunscreens are conflicting. Data indicate that the immunoprotective capacity is inferior to the protection against UV-induced erythema (1–3). Using a contact hypersensitivity model, some studies have found no protection against local (4) or systemic (5) immunosuppression; in another study sunscreens protected against both local and systemic suppression, but with decreasing protection at higher UV doses (1). Others have found, however, that the level of immune protection exceeded the labelled sun protection factor (SPF) (6), and the measured protective capacity seems to depend on the irradiation protocol, as well as on the nature and the concentration of the active ingredient (2).

Urocanic acid (UCA) is present in the stratum corneum as the *trans*-isomer (7). On UV exposure, *trans*-UCA undergoes a dose-dependent isomerization to *cis*-UCA until a photostationary state is reached when approximately equal quantities of the 2 isomers are present (8). A role for *cis*-UCA as an initiator of UV-induced immunosuppression has been proposed (9) and various experimental models have demonstrated, that *cis*-UCA can mediate some of the suppressive effects of UV irradiation on the immune system (10), including suppression of contact hypersensitivity (11), delayed hypersensitivity to herpes simplex virus infection (12) and prolongation of graft survival (13). Initiation and progressive growth of skin tumours in mice is facilitated when irradiation is combined with daily topical application of *trans*-UCA, suggesting a role for UCA in UV-induced carcinogenesis (14).

Sunscreens may provide protection from UV irradiation by absorbing the radiation superficially in the skin, or by reflecting radiation from the skin surface. The aim of the present study was to evaluate 2 chemical (absorbing) sunscreens containing organic filter substances, and 1 physical (particle-containing) sunscreen, with regard to their protection against the production of *cis*-UCA. The latter contains inorganic micronized pigments and can absorb light energy as well as scattering and reflecting the UV radiation entering the skin. As the amount of sunscreen applied in practice is typically less than that used to obtain the nominal sun protection factor (15–17), the effect of a thin layer of sunscreen on *cis*-UCA production was also evaluated.

MATERIAL AND METHODS

The study was approved by the local ethics committee (Municipalities of central Copenhagen and Frederiksberg). Seventeen healthy volunteers (8 females, 9 males, mean age 30.4 years, range 21–53 years) participated in the study after giving informed consent. The study was performed in January, and the volunteers had not been sun-exposed in the test areas for at least 3 months before the study. None of the participants were sun-bed users. Skin type was registered, according to the Fitzpatrick classification system, by interview regarding the tendency to burn and tan after sun exposure (18). One subject had skin type I, 6 type II, 6 type III and 4 type IV.

A total of 8 areas, each 16 cm^2 (4 × 4 cm) were marked on the back, and pigmentation was measured in each area by a reflectance technique (see below) before application of the test creams. After a 30 min rest period for absorption of the creams, 6 areas were irradiated with 3.6 standard erythema doses (SED) each. Two un-irradiated areas served as control. One SED = 10 mJ/cm^2 at 298 nm (19), is the dose producing just perceptible erythema in very sun-sensitive Caucasians. Samples for determination of UCA isomers were taken immediately after the irradiation. The irradiation dose (3.6 SED = 36 mJ/cm^2) was chosen from the UCA analysis of healthy subjects, skin types I–IV, exposed to different UV doses, in a study

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carried out previously (20). With the same filter and radiation source as in the present study, the production of *cis*-UCA at this dose was close to the maximum obtainable (51.7%). A dosage based on the individual minimal erythema dose was not used, as available data did not indicate a close correlation between skin type and isomerization of UCA (21, 22).

Measurement of pigmentation

Skin pigmentation was registered by reflectance equipment (UV-optimize, Matic, Copenhagen, Denmark) (23, 24). The instrument irradiates the skin surface with known intensities of green (555 nm) and red light with a maximum at 660 nm, and measures the reflection. Equations for calculation of the percentage pigmentation on a scale from 0% to 100% are integral parts of the instrument, and the mean value of 3 measurements is shown on the display. Zero percent pigmentation corresponds to white skin with no melanin pigmentation and 100% pigmentation to skin with no reflection at all, as in theoretically absolutely black skin (23).

Test creams

To evaluate the effect of a reflecting, particle-containing vs. a purely absorbing chemical sunscreen, a sunscreen containing a physical filter only (titanium dioxide, leaving the skin white after application) and a sunscreen containing chemical filters only (both UVB and UVA filter) were tested. Both creams had a SPF of 10. The impact of the SPF was evaluated by comparing 2 chemical sunscreens with SPF 10 and SPF 4, but otherwise of comparable formulation. Two mg/cm^2 of each cream was applied 30 min before irradiation in accordance with the FDA recommendations for sunscreen products (25). The effect of a thin layer of sunscreen was studied by comparing the chemical sunscreen SPF 10 at 2 mg/cm^2 with the same cream at 0.5 mg/cm^2.

Control areas.

Basal values for UCA isomers were obtained from untreated, un-irradiated skin. Preliminary tests indicated that the application of the physical, particle-containing cream interfered with the concentration of UCA isomers (lower total UCA, higher *cis*-UCA), whereas the chemical creams did not. To act as a control for the physical sunscreen, UCA measurement was also performed on un-irradiated skin 30 min after application of the physical sunscreen (15 subjects). Finally, a particle-containing barrier cream without sun-screening properties was applied (11 subjects), and UCA isomers were measured after irradiation.

Specification of test creams

Three sunscreen preparations from the same company were tested. The barrier cream (Kerodex 71) was kindly provided by ArSiMa, Copenhagen, Denmark. The composition of the sunscreens was as follows.

Chemical, SPF 4.

Buthylmethoxydibenzoylmethane (UVA filter), ethylhexyl-methoxy-cinnamate (UVB filter), cetyl stearyl alcohol, glycerol mono-stearate, carbomer, C12-15 alkyl benzoate, dimethicone, polymer, glycerol, sodium citrate, sodium edetate.

Chemical, SPF 10.

Buthylmethoxydibenzoylmethane (UVA filter), ethylhexyl-methoxy-cinnamate (UVB filter), Oxybenzone (UVA and UVB filter), cetyl stearyl alcohol, glycerol monostearate, carbomer, C12-15 alkyl benzoate, dimethicone, polymer, glycerol, sodium citrate, sodium edetate.

Physical, SPF 10.

Titanium dioxide, microcrystalline wax, aqua, isohexadecane, cyclo-methicone and PPG-15 stearyl ether, C12-15 alkyl benzoate, sorbeth-30, prunus dulcis, tocopherylacetate, sorbitan oleoate, polyglyceryl-3 ricinoleate, PEG-7 hydrogenated castor oil, panthenol, magnesium sulphate, candelilla wax, magnesium stearate, silica, propyleneglycol, diazolidinyl urea, methylparaben, propylparaben.

Barrier cream.

Zinc oxide, kaolin, paraffin products, sodium phosphate, methyl parahydroxybenzoate, cetanol, emulsifying cetyl stearyl alcohol.

Irradiation

The UV-source was a Philips TL12 broad-band UVB lamp combined with a 3 mm thick WG305 filter. The WG305 filter blocks out wavelengths below about 285–290 nm, making the source more comparable to the UVB spectrum of natural sunlight, as the stratospheric ozone blocks out these shorter wavelengths. The filtered irradiance from 270 nm to 400 nm was measured at a distance of 50 cm by use of an IL SED 400 detector with a WBS 320 filter and a quartz diffuser and recorded with an IL-1700 research radiometer (International Light, USA). The detector reading was 0.78 mW/cm^2. A correction was made for the spectral sensitivity of the detector by dividing the integral of the spectrum for the filtered TL12 lamp with the integral of the combined spectra for the filtered TL12 lamp and the detector, giving a detector correction factor of 33.45/24.65 = 1.36. Similarly, a CIE correction factor was derived by dividing the integral of the filtered TL12 lamp corrected for the CIE spectrum (26) with the integral for the filtered TL12 lamp, as 3.72/33.45 = 0.111. The corrected and CIE weighted irradiance was 0.78 mW/cm^2 × 1.36 × 0.111 = 0.117 mW/cm^2. The distance between the UV source and the subject's back was 50 cm, and the irradiation time to 1 SED was calculated by dividing 10 mJ/cm^2 with 0.117 mW/cm^2 = 85 s/SED.

Measurement of UCA isomers

Samples were taken according to the method described by Jansén et al. (27). At each test site 6 filter paper discs (diameter 7 mm) were applied for 60 min. The total UCA concentration and the percentage present as the *cis*-isomer were determined for each sample by high-performance liquid chromatography (28).

Calculation of the net yield of cis-UCA

As the study investigated the effect of irradiation of previously un-irradiated skin, the percentage of *cis*-UCA in the irradiated areas was corrected for *cis*-UCA in un-irradiated skin. The relative net yield (production) of *cis*-UCA was calculated from the formula (29):

% *cis*-UCA (net yield) = (% *cis*(irradiated) – % *cis*(control)) × 100/(100 – % *cis*(control))

where, % *cis*(irradiated) = relative amount of *cis*-UCA in irradiated skin and % *cis*(control) = relative amount of *cis*-UCA in non-irradiated skin.

For the physical sunscreen, the un-irradiated area with physical cream applied was the control, as application of the physical cream resulted in changes in the measured values of UCA isomers. For all other test areas the un-irradiated, untreated area was used as control.

100 – % *cis*(control) = relative amount of *trans*-UCA available for isomerization in non-irradiated skin.

Statistics

The Friedman and Wilcoxon non-parametric tests for paired samples were used to evaluate intra-individual differences in pigmentation, total UCA and *cis*-UCA. A p value below 0.05 was considered significant.

RESULTS

Pigmentation

As no significant differences was found between the 8 test areas ($p = 0.39$), any possible influence of pigmentation on isomerization could be ignored.

Total UCA

The concentration of total UCA in each site is shown in Table I. Total UCA was significantly lower in the 2 areas treated with the physical sunscreen both with ($p<0.01$) and without ($p<0.01$) irradiation, and in the area treated with the barrier cream ($p<0.01$) than in each of the other 5 areas, among which no significant differences were found ($p=0.41$).

Cis-UCA

The absolute concentration of *cis*-UCA (in nmol/cm^2) is shown in Table I. A reduction in *cis*-UCA was found in all sunscreen treated areas. As, however, the particle-containing cream layers reduced the penetration of UCA, the absolute *cis*-UCA values for these creams could not be ascribed to a sun-screening effect only. This was illustrated by the reduction in *cis*-UCA in the area treated with the barrier cream, which has no significant sun-screening property. The relative production of *cis*-UCA (Fig. 1) was therefore found more suitable for comparison of the test creams.

In un-irradiated skin the median percentage of *cis*-UCA was 3.6, range 1.8–6.6%. In un-irradiated skin treated with the physical sunscreen *cis*-UCA was higher, median 7.6% ($p<0.01$). The relative production of *cis*-UCA in each area is shown in Fig. 1. By definition, the calculated production of *cis*-UCA in the un-irradiated areas was 0. In irradiated unprotected skin, the production of *cis*-UCA was 52.4%.

For the chemical SPF 4 sunscreen the median production of *cis*-UCA was 7.4%, for the chemical SPF 10 3.5%, and for the physical SPF 10 14.6%. For the chemical SPF 10 sunscreen applied in a thin layer, the *cis*-UCA production was 21.6%. The chemical SPF 10 sunscreen gave significantly higher protection against isomerization of UCA than the chemical SPF 4 ($p<0.01$), and the physical sunscreen ($p<0.01$). The SPF 4 sunscreen also gave higher protection than the physical SPF 10 ($p<0.01$). For the chemical SPF 10 applied in a thin layer, protection was significantly lower than both the chemical SPF 10 ($p<0.01$), the chemical SPF 4 ($p<0.01$) and the physical sunscreen ($p=0.01$).

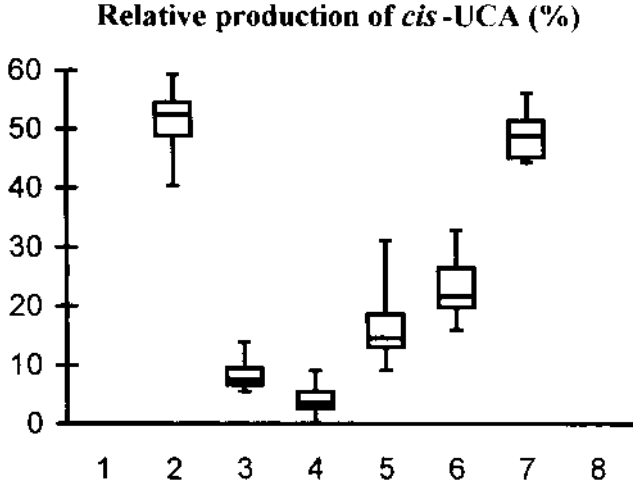

Fig. 1. Box and whisker plot showing the net production of *cis*-UCA (%) following a single dose of UV irradiation (3.6 SED) in 6 sites on the back of 17 healthy volunteers after application of different sunscreens and a barrier cream. The bars extend from the 25th to the 75th percentile, with a horizontal line at the median. Whiskers extend down to the smallest value and up to the largest. 1 = untreated, un-irradiated; 2 = untreated, irradiated; 3 = chemical sunscreen, SPF 4, irradiated; 4 = chemical sunscreen, SPF 10, irradiated; 5 = physical sunscreen, SPF10, irradiated; 6 = chemical sunscreen, SPF 10, 0.5 mg/cm^2, irradiated; 7 = barrier cream (Kerodex 71), irradiated; 8 = physical sunscreen, SPF10, un-irradiated.

Table I. *The concentration of total UCA and the concentration of the cis-isomer at 8 sites on the back of 17 subjects after application of different test creams. When not otherwise stated, creams were applied at 2 mg/cm^2*

	Total UCA (nmol/cm^2)	*Cis*-UCA (nmol/cm^2)
Untreated	12.3 (9.6–18.9)	0.5 (0.4–0.6)
Untreated[a]	13.7 (9.7–17.4)	6.7 (5.0–9.6)
SPF 4, chemical[a]	12.9 (9.9–17.9)	1.4 (1.1–1.8)
SPF 10, chemical[a]	11.6 (10.2–16.3)	1.1 (0.8–2.2)
SPF 10, physical[a]	4.7 (3.8–7.6)	0.8 (0.8–1.1)
SPF 10, chemical, 0.5 mg[a]	13.7 (9.7–17.6)	3.3 (2.6–4.2)
Barrier cream[a]	5.7 (3.7–12.3)	2.6 (2.1–5.8)
SPF 10 physical	5.1 (3.7–7.6)	0.5 (0.3–0.5)

[a] UV irradiation (3.6 SED).

DISCUSSION

Cis-UCA is one of the mediators of UV-induced immunomodulation, while other mechanisms may involve changes in DNA or cell membrane lipid peroxidation (30). In mice, UV exposure through both PABA and EHMC containing sunscreen preparations effectively inhibited the formation of *cis*-UCA (2), but only the EHMC containing sunscreen protected against impairment of CH. Similarly a lack of correlation between the level of *cis*-UCA and suppression of CH has been demonstrated by varying the proportion of UVA in the radiation source. Though the UVA-rich sources induced a relatively high level of *cis*-UCA, these sources did not result in suppression of CH (31). It has been suggested that UVA may block or modulate the *cis*-UCA induced signals for suppression of CH (32). Similar conclusions were reached by Reeve et al. (33) after showing that UVA was immunoprotective if administered before or after *cis*-UCA. Studies using a monoclonal antibody with specificity for *cis*-UCA have shown a dissociation of the *in vivo* effects of *cis*-UCA, as the antibody prevented UV-induced suppression of delayed hypersensitivity but not of CH responses (34, 35). Others have found however, that *cis*-UCA is involved in the suppression of both delayed and CH responses (36, 37), and it is still not clear how or where this molecule acts to modulate immunity.

Krien & Moyal (22) have investigated the effect of sunscreens with a low SPF on UV-induced formation of *cis*-UCA in human skin. Two sunscreens (SPF 3 and SPF 4.5) containing a UVB filter (EHMC) and 1 containing a UVA filter (Mexoryl SX) were evaluated. All 3 sunscreens protected efficiently against isomerization following a single UVB irradiation, with higher protection provided by the SPF 4.5 (EHMC-containing) than the SPF 3 (Mexoryl SX-containing) sunscreen. The impact of the SPF, however, is difficult to evaluate due to the difference in absorption spectra.

In the present study we wanted to evaluate the effect of

commercial sunscreens with a fairly large difference in nominal SPF, the exact SPF under the given conditions was considered less relevant. The SPFs of the creams used in the present study were specified by the manufacturer and products from only 1 company were used. The results confirm that sunscreens protect against *in vivo* isomerization of UCA in human skin, and show that protection increases with the labelled SPF. The amount of *cis*-UCA can determine the degree of immunosuppression, as demonstrated for the suppression of delayed hypersensitivity to herpes simplex virus (12, 38), and the survival of skin allografts (13). Though protective, in no case there was a complete elimination of isomerization, and the resulting levels of *cis*-UCA could possibly stimulate the immunosuppressive signals. The higher protection from the SPF 10 sunscreen when compared with SPF 4 may be related not only to a higher concentration of active ingredients but to the inclusion of oxybenzone in the SPF 10 cream.

When investigating the effects of sunscreens, irradiation with natural or simulated sunlight would be preferable. By use of the WG 305 filter, however, the source was made more comparable to the UVB spectrum of natural sunlight, as the ozone layer blocks out the shorter wavelengths in the UVB range.

Titanium dioxide and zinc oxide remains on the skin surface, while the ingredients in the chemical sunscreens are more or less absorbed in the stratum corneum and viable epidermis. It has been suggested that chemical sunscreens may accumulate below the stratum corneum, and therefore be unable to block the isomerization of UCA (5). We found, however, that the protection against isomerization offered by the physical sunscreen was considerably less than that of the chemical (EHMC-containing) sunscreen with the same or lower nominal SPF. Possibly the particle layer allows UV penetration between particles and scattering of radiation through the stratum corneum in amounts sufficient to isomerize *trans*-UCA. There is some indication that the sunscreen ingredient may interact chemically with UCA. Thus EHMC was more effective in preventing isomerization than para-amino-benzoic acid when the sunscreen ingredient was mixed with *trans*-UCA, but equally effective when the sunscreen ingredient was separated from the UCA solution (2). No similar studies have been performed with titanium dioxide. The conclusion that chemical sunscreens are superior to a sunscreen containing titanium dioxide in reducing isomerization is possibly valid only for EHMC-containing sunscreens. With regard to protection against local suppression of CH in mice, sunscreens with titanium dioxide have proved as effective as EHMC-containing sunscreens (3).

On sites treated with the physical sunscreen and the barrier cream, the total UCA was lower than in untreated skin. Thus particle-containing creams may form a barrier interfering with the penetration of small molecules. This is supported by the fact that application of the barrier cream, which protects the skin against penetration of aqueous solutions, also results in a diminished transepidermal water loss compared with untreated skin, or skin treated with a moisturizer (39). It is not clear why the percentage of *cis*-UCA for un-irradiated skin treated with the physical sunscreen was higher than for untreated un-irradiated skin. However, the net yield of *cis*-UCA in the area treated with the physical sunscreen was corrected for the higher *cis*-UCA in the corresponding un-irradiated area.

To obtain the nominal protection against erythema (SPF) indicated on a sunscreen container, it is important to apply the correct amount of cream (2 mg/cm^2 for creams tested according to the FDA recommendations), as a reduction in the amount applied reduces the SPF considerably (17, 40). In a study of beach visitors the average application of sunscreen was 0.5 mg/cm^2 (15). For a SPF 10 sunscreen applied in this concentration, a 5.5 times reduction in SPF could be calculated (17). The present results show that a SPF 10 sunscreen applied in a thickness of 0.5 mg/cm^2 has less effect on the formation of *cis*-UCA than a SPF 4 sunscreen at 2 mg/cm^2, further stressing the necessity for the correct application of sunscreens.

In conclusion, the tested sunscreens significantly reduced the production of *cis*-UCA, and hence presumably some of the harmful effects of UV radiation on the immune system. The degree of protection increased with the nominal SPF, and the sunscreens with chemical filters (EHMC) were superior to the 1 containing titanium dioxide in reducing isomerization. Application of an amount of sunscreen lower than recommended gave significantly less protection against *cis*-UCA production.

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