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Effect of the product type, of the amount of applied sunscreen product and the level of protection in the UVB range on the level of protection achieved in the UVA range

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ABSTRACT

Using a topical product is part of the overall strategy for skin cancer prevention. The level of protection attainable when using commercial products is indicated by the Sun Protection Factor (SPF) value, in use everywhere. This value reflects the level of protection primarily in the UVB range. However, UVA radiation also has deleterious effects on the skin, and it is essential to prevent it, which is why products must offer a wide spectrum of protection. Tests conducted *in vivo*, before any marketing, are done by applying the studied product at a rate of 2.0 mg cm^{-2}, while users, in practice, only use 1.0–1.5 mg cm^{-2}. We now know that this reduction in the amount of applied product greatly affects the SPF. To complete the state of knowledge in this area, we sought to evaluate the effect of a decrease in the amount of applied sunscreen product by studying sunscreen creams and oils on the level of protection attainable in the UVA range. We have shown that the PF-UVA is divided by a factor of 2.2, on average, when the amount of applied product is reduced by half, with differences depending on the product type under consideration (cream or oil) and depending on the SPF of the preparation.

1. Introduction

The first external sun protection products, formulated in the 1930s, contained very few filters, often only one (benzyl salicylate, for example) and only protected their users in the UVB range (Urbach, 2001; Wolf et al., 2001). This was due to the fact that for a long time, only UVB radiation was identified as responsible for skin sun damage (Epstein, 1983). It was not until the 1980s that there was growing awareness of the deleterious effects caused by UVA radiation as well (Staberg et al., 1983; Césarini et al., 1998). Product formulas then changed. Subsequently, both UVB filters (salicylates and cinnamates) and UVA filters (butyl methoxydibenzoylmethane) are incorporated, often combined with broad spectrum filters (benzophenones and triazine derivatives). Since 2006, European guidelines specify the requirements to be met by commercial sunscreen products; i.e., the ratio between protection in the UVB range and the UVA range, less than or equal to 3, and the critical wavelength (λ_c) greater than or equal to 370 nm (Anon., 2006), in order to provide the user with a sufficiently broad protection. In this context, the foundation is laid for a level of protection across the entire spectrum that can certainly be improved, but which constitutes a significant advance compared to products placed on the market in the 20th century. A major ongoing problem concerns the amount of applied product by sunscreen product users. While tests carried out before the marketing of sunscreen products applied doses to volunteers of 2.0 mg.cm^{-2} (Schulze, 1956) according to the Standard EN ISO 24442:2011, studies done in the field showed that end users actually use only 0.5–1.0 mg cm^{-2} of the product (Diffey, 2001). It is known that the level of protection achieved in the UVB range is dependent on the amount of applied product (Couteau et al., 2012; Liu et al., 2012). However, there is no data available on the effect of the amount of applied sunscreen product on the level of protection in the UVA range. In this work, we evaluated the possible consequences of the decrease in the amount of applied sunscreen creams and oils on the PF-UVA.

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Table 1
Sunscreens with low protection tested.

Trade name	Product type	UV-filters
Ambre solaire Garnier SPF 6	Oil	Ethylhexyl methoxycinnamate
Inell sun IP 6	Oil	Octocrylene, Butylmethoxydibenzoylmethane, Diethylamino hydroxybenzoyl hexyl benzoate
Lancaster Soin de beauté solaire SPF 10	Emulsion	Isoamyl-*p*-methoxycinnamate, butyl methoxydibenzoylmethane, bis-ethylhexyloxyphenol methoxyphenyl triazine, methylene bis-benzotriazolyl tetramethylbutylphenol
Lancôme Génifique Sôleil huile protectrice SPF 10	Oil	Octocrylene, Ethylhexylsalicylate, Butylmethoxydibenzoylmethane, Ethylhexyltriazone, Drometrizole trisiloxane
Nivea sun bronzage intense SPF 6	Oil	Ethylhexyl methoxycinnamate, Butylmethoxydibenzoylmethane
Polysianes SPF 6	Oil	Ethylhexyl methoxycinnamate, Octocrylene, Bis-Ethylhexyloxyphenol methoxyphenyl triazine
Soleil noir spray huile sèche SPF 10	Oil	Octocrylene, Ethylhexyl methoxycinnamate, Butylmethoxydibenzoylmethane, Ethylhexylsalicylate

2. Experimental design

2.1. Materials

The various marketed products tested (15 sun oils and 16 emulsions) are presented in Tables 1–3 , according to whether these are low protection, medium protection or high or very high protection products. It should be remembered that this classification is established based on the level of protection offered in the UVB range. 50 mg of product exactly weighed were spread on PMMA plates over the whole surface (25 cm^2) using a finger cot in order to provide homogenous layer over the entire plate. The polymethylmethacrylate (PMMA) plates were purchased from Europlast (Aubervilliers, France). Different residual masses were tested: 5.0, 7.5, 10.0, 12.5 and 15.0 mg. The PF-UVA of the products was measured *in vitro*. Three plates were prepared for each product to be tested; after the application, the plates are placed for 15 min in the dark at ambient temperature. Nine measures were performed on each plate (Couteau et al., 2008). Transmission measurements between 320 and 400 nm were carried out using a spectrophotometer equipped with an integrating sphere (UV Transmittance Analyzer UV1000S, Labsphere, North Sutton, US). The calculations for either term use the same relationship:

$$\mathrm{PF-UVA} = \frac{\sum_{320}^{400} E_\lambda S_\lambda d_\lambda}{\sum_{320}^{400} E_\lambda S_\lambda T_\lambda d_\lambda}$$

where E_λ is CIE erythemal spectral effectiveness, S_λ is solar spectral irradiance and T_λ is spectral transmittance of the sample at wavelength λ and d_λ is the wavelength increment (1 nm) (Diffey and Robson, 1989; Couteau et al., 2008).

2.2. Statistical analysis

Results are expressed as the mean ± SD. Statistical analysis for calculated parameters was performed using the Wilcoxon test and differences were considered significant at $p < 0.05$.

3. Results and discussion

The results obtained when the quantity of applied product is 2.0 $mg.cm^{-2}$ are presented in Table 4. The mass of applied product affects the level of protection achieved in the UVA range. There are differences of performance depending on the product type on the one hand, and on the level of protection announced in the UVB range. To model the effect of the amount of applied product on the PF-UVA value, we used several mathematical functions. In fact, in some cases, the PF-UVA increases continuously and linearly with the applied mass. The progression is linear and unlimited. The increase in PF-UVA is neither slowed nor accelerated when the mass varies. In other cases, we chose a polynomial with a negative leading monomial coefficient to describe the phenomenon observed experimentally, because the PF-UVA increases with the mass, but this increase is slowed and tends towards a maximum value when the mass increases, with a threshold effect. A polynomial with a positive leading monomial coefficient was selected when the PF-UVA increases with the mass applied, with an increase which accelerates when the values of the mass increase. Finally, an exponential function was chosen in situations where, for low mass values, the increase occurs normally, while

Table 2
Sunscreens with medium protection tested.

Trade name	Product type	UV-filters
Anthelios SPF 20	Emulsion	Ethylhexyl salicylate, Titanium dioxide, Bis-ethylhexyloxyphenol methoxyphenyl triazine, Drometrizole trisiloxane, Octocrylene, Butylmethoxydibenzoylmethane, Ethylhexyl triazone, Terephtalidene dicamphor sulfonic acid
Bergasol huile sèche SPF 20	Oil	Octocrylene, Homosalate, Ethylhexylsalicylate, Butylmethoxydibenzoylmethane, Diethylhexyl butamido triazone, Bis-Ethylhexyloxyphenol methoxyphenyl triazine
Biotherm sun anti-rides solaire SPF 15	Emulsion	Octocrylene, Ethylhexyl salicylate, Butylmethoxydibenzoylmethane, Titanium dioxide, Drometrizole trisiloxane, Terephtalidene dicamphor sulfonic acid
Galenic huile sèche à l'Uncaria d'Amazonie SPF 15	Oil	Ethylhexyl methoxycinnamate, Octocrylene, Bis-Ethylhexyloxyphenol methoxyphenyl triazine
Hawaiian tropic huile sèche SPF 20	Oil	Homosalate, Benzophenone-3, Butylmethoxydibenzoylmethane, Octocrylene
Polysianes huile sèche SPF 15	Oil	Octocrylene, Ethylhexyl methoxycinnamate, Bis-Ethylhexyloxyphenol methoxyphenyl triazine
Solar expertise huile prévention âge SPF 20	Oil	Octocrylene, Ethylhexylsalicylate, Diethylhexyl butamido triazone, Butylmethoxydibenzoylmethane, Ethyl hexyl triazone, Drometrizole trisiloxane
Solei boots SPF 15	Emulsion	Octocrylene, Butylmethoxydibenzoylmethane, Diethylhexylbutamidotriazone, Bis-Ethylhexyloxyphenol methoxyphenyl triazine, titanium dioxide
Vichy capital soleil SPF 20	Oil	Octocrylene, Ethylhexylsalicylate, Butylmethoxydibenzoylmethane, Diethylhexyl butamido triazone, Ethylhexyl triazone, Drometrizole trisiloxane