Ex-vivo spectroscopic quantification of sunscreen efficacy: proposal of a universal sun protection factor

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Abstract. The sun protection factor (SPF) describes the protective behavior of sunscreens insufficiently, because this factor takes into account only the UVB spectral range, and strains the volunteers during its determination by invasively invoking an erythema. A new noninvasive method is proposed that is based on the UV spectroscopic measurement of tape strips taken from a sunscreen-treated skin area. The resulting sum transmission spectra of the tape strips reflect the *in-vivo* distribution of the absorber on the skin and quantify the protective efficacy of the applied sunscreens over the complete UV spectral range. The spectroscopic data provide a basis for the calculation of a universal sun protection factor (USPF). The comparison of the concrete values of USPF and SPF results in the following statements. 1. An unique functional correlation is not to be expected because a different UVB / UVA dependence exists. 2. The size of the differences between both values is influenced clearly by the intensity relation of the average sum transmission in the UVB in comparison to the UVA range. 3. The USPF values objectively assess the efficacy of sunscreens considering a protection against all irradiation injuries. [DOI: 10.1117/1.2753365]

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1 Introduction

Sun protection is of great importance, not only because the incidence rates of skin cancer[1–3] have increased, but also because other ultraviolet (UV)-induced damages, such as immunosuppression,[4,5] radical formation,[6] and skin aging[7,8] additionally endanger human health. Therefore, the availability of sunscreens to ensure a high efficacy against these effects with a defined protective ability is of importance.

One problem in this regard is the broad variation of the wavelength and intensity dependence of all these effects on the UV radiation of the sun, described by the action spectra. The situation is additionally complicated on account of the fact that the exact data are not quantitatively known in all cases.

Currently, the sun protection factor (SPF), determined by the formation of the erythema after UV irradiation,[9] quantifies the efficacy of sunscreens. This special biological response of the human skin after sun exposure depends mainly on the UVB intensity. In contrast, UV-induced injuries, including skin cancer, are not only induced by the UVB part of the sunlight, but also by the long wavelength UVA.[10]

These facts clearly demonstrate that the protective ability of sunscreens must be quantified, taking the complete UV wavelength range into account. As a result of this situation, a number of proposals exist to characterize sunscreens by measuring values, which consider the complete UV part of sunlight.

Zastrow et al.[6] investigated the formation of free radicals during UV radiation of skin biopsies by electron spin resonance spectroscopy. A direct correlation between the formation of free radicals and the SPF was found and, in addition, it was possible to determine the UVA protection. The concentration of the free radicals correlated with the persistent pigment darkening (PPD) values. However, this method presents a disadvantage in that it is based on biopsies obtained invasively, and the inhomogeneous distribution of sunscreens on the skin under *in-vivo* conditions is not accounted for.

For a realistic assessment of sun protection, the inhomogeneous distribution of sunscreens on the skin under *in-vivo* conditions is of utmost importance.[11] Therefore, several methods for the determination of the SPF have been described, which are based on spectroscopic measurements[12–16] using, e.g., deposits of sunscreens on carrier materials. However, these methods cannot reproduce a realistic distribution of sunscreens on living human skin. Herzog[17] proposed a method based on calculations of the SPF. In this case, an inhomogeneous distribution of the sunscreens on the skin is purported. This method is determined by varying the degree of the nonhomogeneity of the sunscreen distribution on the skin theoretically up to the moment when the calculated SPF is in agreement with the SPF values determined *in-vivo*. The method has the disadvantage that the degree of nonhomoge-

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neity determined for one formulation can differ, if other types of formulation are applied.

Spectroscopic measurements are the primary method to obtain wavelength-correlated information on the absorption properties of sunscreens. The direct determination of the absorption of sunscreens in optical cells results in misleading data, because the UV filters are distributed homogeneously in such measurements. Under *in-vivo* conditions, the active UV filter substances are distributed nonhomogeneously on the human skin. This characteristic distribution closely correlates with the skin profile and reduces the absorption efficacy of the applied UV filter to a large extent.[11,19]

An objective method to quantify sunscreen behavior must consider this skin-specific UV filter distribution. A convenient technique is the well-known method of tape stripping, which transfers the stratum corneum, together with the topically applied sunscreens, onto adhesive tapes layer by layer,[18] measuring the UV/VIS spectra of the removed tape strips afterward. This method is the basis for the development of a method for the spectroscopic determination of the efficacy of the UV filter substances, applied topically with sunscreens. In a first publication, the principal background and the prerequisites of this method, as well as the correlation of the spectroscopic data to the classical SPF, are described in Ref. 19. A clear trend line with a correlation coefficient of $R^2=0.99$ was found for the investigated sunscreens.

In the following, the average sum transmission values in the complete UV range were used to calculate a universal sun protection factor (USPF), which quantifies the efficacy of sunscreens under *in-vivo* conditions independently by a special biological response.

2 Materials and Methods

2.1 *Volunteers*

The tape stripping procedure was carried out in 82 independent measurements with 60 volunteers with skin types 2 and 3,[20] aged 20 to 50 years without any skin diseases. Approval of the Charité Ethics Committee had been obtained for these experiments.

2.2 *Application of Sunscreens*

The investigations were performed using commercial sunscreens from different cosmetic companies and European Cosmetic Toiletry and Perfumery Association (COLIPA) standard emulsions.

SPF 4.2: COLIPA P1 Low SPF Standard (DIN Std K17N) (BASF, Ludwigshafen, Germany), SPF 8 (earlier product), SPF 12, SPF 16, SPF 20 (earlier product), SPF 26 and SPF 50: Nivea Sun Feuchtigkeits-Sonnenmilch (Beiersdorf AG, Hamburg, Germany), SPF 8 (actual product), SPF 20 (actual product) Nivea Sun Pflegende Sonnenmilch (Beiersdorf AG, Hamburg, Germany), SPF 12.7: COLIPA P2 High SPF Standard (CTFA/JCIA Standard) (BASF, Ludwigshafen, Germany), SPF 15.5: COLIPA P3 High SPF Standard (BASF, Ludwigshafen, Germany), SPF 30: High Protection Body Cream (Lancaster A.N. Monaco, Paris), SPF 40: Anthèlios W Gel (La Roche-Posay, Laboratoire Pharmaceutique, France),

SPF 60: Créme Ecran Extrême (Eau Thermale Avéne, Paris, France).The term "earlier product" means an emulsion with a low absorption in the UVA range, and "actual product" means an emulsion with a high absorption in the UVA range.

These formulations contain the following UV filter substances.

UVB filter: ethylhexyl methoxycinnamate, ethylhexyl triazone, methoxyphenyl ethylhexyl methoxycinnamate, ethylhexyl salicylate, isoamyl p-methoxycinnamate, 4-methylbenzylidene camphor, octyl cyanophenylcinnamate, octyl triazone, octyl methoxycinnamat, phenyl benzimidazole sulfonic acid.

UVA filter: benzophenone-4, butyl methoxydibenzoylmethan, diethylamino hydroxybenzoyl hexyl benzoate.

UVA/UVB filter: benzophenone-3, bis-ethylhexyloxyphenol methoxyphenyl triazine, methylen bis-benzotriazolyltetramethylbutylphenol, terephtalydine dicamphor sulfonic acid, titanium dioxide, zinc oxide.

In agreement with the COLIPA standard, 2 mg/cm^2 sunscreen emulsion was applied onto a skin area of 10×8 cm^2 on the flexor forearm. Prior to the application of the sunscreen, the skin was gently washed with cold water and dried with soft tissues. The formulation was distributed homogeneously using a gloved finger saturated with the product. During the time between the application and the beginning of tape stripping, set at one hour, volunteers rested to avoid sweating and contact of the test areas with textiles. During this one hour, the sunscreens had completely penetrated into the upper layers of the skin; no surface residue was observed.

2.3 *Tape Stripping*

The method of tape stripping was performed as described previously.[18] The adhesive tapes (*tesa* film number 5529, Beiersdorf, Hamburg, Germany, width 19 mm, length approximately 6 cm) were pressed onto the area of the flexor forearm with a stamp (pressure: 14.5 kp/cm^2) for three seconds. The skin area from which the strips were taken was marked. Using forceps, the tape strips were removed with one swift movement, and fixed onto a rectangular sample holder. The strips were immediately measured in the spectrometer against an empty *tesa* film.

This procedure was repeated 10 to 20 times, so as to ensure the complete removal of the UV filter substances, but guaranteeing the noninvasive character of the protocol. Tape strips were additionally taken from untreated skin of the same forearm to correct the spectral influence of the corneocyte aggregates removed together with the UV filters from the treated skin region.

Usually, a series of tape strips was taken from one skin area for the analysis of each sunscreen from different volunteers.

To determine the variation of the measured values independently of the interindividual differences, tape strips were taken from three different parts of one treated skin area of the same volunteer in three cases.

All experiments were performed under standard ambient room conditions ($21\pm 1\,^{\circ}C$ room temperature, $50\pm 5\%$ relative humidity).

2.4 *Spectroscopic Measurements*

According to published results,[21] the characteristic distribution of the UV filter on the skin is transferred completely and

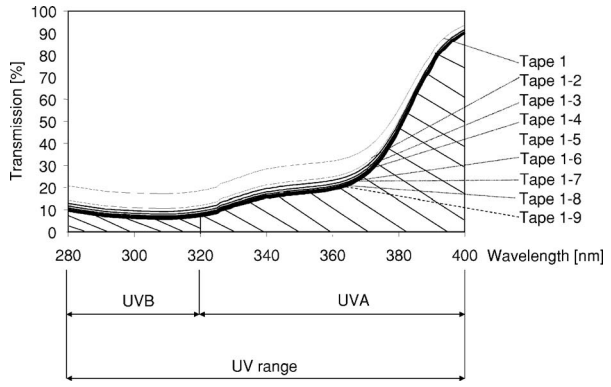

Fig. 1 Sum transmission curves measured for the first nine tape strips (dotted lines) of a series of tape strips removed from the same area of the skin treated with sunscreen and the sum transmission curve (full line) taken to calculate the hatched area under the curve. Nivea Sun Feuchtigkeits-Sonnenmilch SPF 8.

nearly undisturbed onto the tape strips. After removal of the tape strips from the skin, diffusion processes occur, which result in an increasingly homogeneous distribution, changing the absorbance values drastically. Therefore, the UV spectra of the removed tape strips were measured in the range between 280 and 400 nm within one minute, avoiding changes in the characteristic nonhomogeneous distribution of the UV filter. The spectra of the strips were registered using a modified spectrometer Lambda 5 (PerkinElmer, Frankfurt/Main, Germany), with an integrating sphere and a measuring area of 1 cm^2, to summarize the spectroscopic behavior of a larger area.

2.5 *Determination of the Average Sum Transmission*

The calculation of the average sum transmission in the three wavelength ranges: UVB, UVA, and in the complete UV was realized using the following protocol.

In a first step, the Software UV WinLab Version 2.70.01 (PerkinElmer, Frankfurt/Main, Germany) was used to correct the spectra in the absorbance scale of each tape strip removed from the same skin area. This was done by subtracting the absorbance spectra obtained from the untreated neighboring skin region as described previously.[22] This procedure results in corrected spectra, excluding the influence of the corneocytes removed together with the UV filter substances.

In a second step, the corrected spectra of one stripping procedure were added up cumulatively using the software UV WinLab Version 2.70.01 (PerkinElmer, Frankfurt/Main, Germany). This was done in the absorbance scale to have a linear correlation to the concentration of the absorbers and to obtain the sum spectra by simple addition. In this procedure, all tape strips with a recognizable UV filter content were taken into account.

In a third step, the UV sum spectra were converted from the absorbance scale to percent transmission using the software UV WinLab Version 2.70.01 (PerkinElmer, Frankfurt/Main, Germany). The result is given in Fig. 1.

In a fourth step, the size of the areas under the last sum transmission curve is determined and divided by the corresponding wavelength ranges 40 nm (UVB=280 to 320 nm), 80 nm (UVA=320 to 400 nm), or 120 nm (UV=280 to 400 nm), respectively. This calculation results in three average sum transmission values — UVA, UVB, and the complete UV — for each volunteer after application of the selected sunscreen.

In a last step, the average sum transmission values obtained for each sunscreen from the different volunteers (4 to 9) were summarized, and the corresponding mean value was determined. These data are the basis for calculating spectroscopic sun protection factors as described in the following chapter.

3 Results

The basis for the correct application of the described method are results obtained in experiments already published.

During tape stripping, the horny layer is transferred layer by layer to the adhesive tapes without disturbing the characteristic *in-vivo* UV filter distribution.[21] To avoid disturbances by diffusion processes, the spectroscopic measurements must be performed within 1 min after removal.[21]

In Ref. 23, penetration profiles of typical UV filter substances were determined. The UV filters were found in the uppermost part of the stratum corneum.

The correction of the original spectra to avoid disturbances by characteristic UV absorption bands of the corneocytes and substances found in the adhesive layer of the tapes are described in Ref. 24.

3.1 *Determination of the Average Spectroscopic Sum Transmission*

In agreement with the described protocol, the absorbance spectra of the individual tapes were added up cumulatively. After transformation to the transmission scale, the spectra shown in Fig. 1 were obtained for each removed tape strip.

The last sum transmission spectrum describes the influence of the UV filter on the incident radiation, taking into account the complete amount applied. In agreement with the protocol, the marked areas under the spectrum were the basis to calculate the average spectroscopic sum transmission in the three wavelength ranges, UVB, UVA, and the full UV range.

From the results given in Table 1, it is incidental that clear differences between the values obtained for the UVB and the UVA range exist.

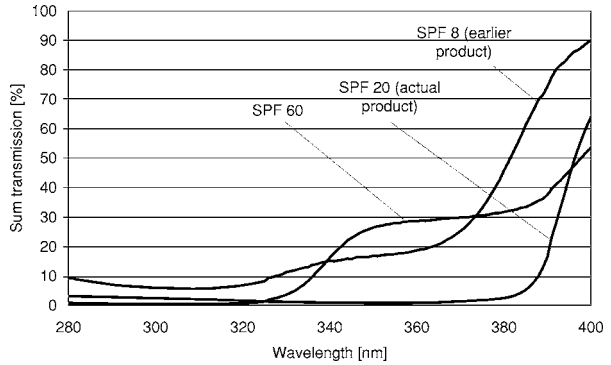

Fig. 2 Sum transmission spectra of three selected sunscreens: Nivea Sun Feuchtigkeits-Sonnenmilch, *earlier product* LF 8, Nivea Sun Pflegende Sonnenmilch, *actual product* LF 20, and Créme Ecran Extrême LF 60.

Table 1 Summary of the calculated average spectroscopic sum transmission values (area under the UVA, UVB, and UV transmission curve divided by the corresponding wavelength range), and the SPF values of all investigated sunscreens.

Product	Average spectroscopic sum transmission [% transmission]			Sun protection factor (SPF)
	UVB	UVA	Complete UV	
COLIPA P1	4.3	74	50.0	4.2
Nivea Sun Feuchtigkeits-Sonnenmilch *earlier product*	4.1	29	21	8
Nivea Sun Pflegende Sonnenmilch *actual product*	2.4	15	13	8
Nivea Sun Feuchtigkeits-Sonnenmilch	3.1	26	18	12
COLIPA P2	0.43	43	29	12.7
COLIPA P3	2.3	29	20	15.5
Nivea Sun Feuchtigkeits-Sonnenmilch	1.9	18	13	16
Nivea Sun Feuchtigkeits-Sonnenmilch *earlier product*	2.2	17.5	12	20
Nivea Sun Pflegende Sonnenmilch *actual product*	2.3	6.7	5.2	20
Nivea Sun Feuchtigkeits-Sonnenmilch	1.5	14	10	26
High Protection Body Cream	0.53	11	7.3	30
Anthèlios W Gel	1.3	5.8	3.6	40
Nivea Sun Feuchtigkeits-Sonnenmilch	0.6	9.3	6.4	50
Créme Ecran Extrême	0.4	25	17	60

Table 2 Calculated spectroscopic protection factors using the average sum transmission values given in Table 1.

Product	UVB Protection factor	UVA Protection factor	UV Protection factor =USPF	SPF
COLIPA P1	23	1.4	2.0	4.2
Nivea Sun Feuchtigkeits-Sonnenmilch, *earlier product*	24	3.4	4.8	8
Nivea Sun Pflegende Sonnenmilch *actual product*	42	6.7	7.7	8
Nivea Sun Feuchtigkeits-Sonnenmilch	32	3.8	5.6	12
COLIPA P2	233	2.3	3.4	12,7
COLIPA P3	44	3.4	5.0	15,5
Nivea Sun Feuchtigkeits-Sonnenmilch	53	5.6	7.7	16
Nivea Sun Feuchtigkeits-Sonnenmilch *earlier product*	46	5.7	8.3	20
Nivea Sun Pflegende Sonnenmilch *actual product*	44	15	19	20
Nivea Sun Feuchtigkeits-Sonnenmilch	67	7.1	10	26
High Protection Body Cream	189	9.1	14	30
Anthèlios W Gel,	77	17	28	40
Nivea Sun Feuchtigkeits-Sonnenmilch	167	11	16	50
Créme Ecran Extrême	250	4.0	5.9	60

An illustration of the wide differences found in Table 1 for three selected samples is given in Fig. 2.

3.2 *Determination of Spectroscopic Protection Factors*

The average spectroscopic sum transmission values are used to calculate spectroscopic protection factors. These factors describe the increased length of time possible to stay in the sun after sunscreen application, taking the reduced intensity of the incident radiation by the UV filter as the basic value. For example, if the average spectroscopic sum transmission is reduced to 10%, the time to stay in the sun is increased by a factor of 10, assuming that the intensity dependence of the injuring effect is constant over the wavelength range considered. This circumstance was the basis determining the corresponding protection factors for the three parts of the UV radiation given in Table 2 with the formula: spectroscopic protection factor = 100, divided by the remaining average spectroscopic sum transmission. The spectroscopic protection factor calculated for the complete UV range generally describes the sunscreen efficacy. This is the reason to propose

Table 3 Correlation between the factors calculated by the formula: average sum transmission in the UVB divided by average sum transmission in the UVA and the position of the corresponding values to the trend line.

Sunscreen	SPF	Factor Average sum transmission [% T] / average sum transmission in the UVA [% T]		
	SPF	Points on the trend line	Points beneath the trend line	Points above the trend line
COLIPA P1	4.2	0.06		
Nivea Sun Feuchtigkeits-Sonnenmilch, *earlier product*	8	0.14		
Nivea Sun Pflegende Sonnenmilch, *actual product*	8	0.16		
Nivea Sun Feuchtigkeits-Sonnenmilch	12	0.12		
COLIPA P2	12.7		0.01	
COLIPA P3	15.5	0.08		
Nivea Sun Feuchtigkeits-Sonnenmilch	16	0.11		
Nivea Sun Feuchtigkeits-Sonnenmilch, *earlier product*	20	0.13		
Nivea Sun Pflegende Sonnenmilch, *actual product*	20			0.34
Nivea Sun Feuchtigkeits-Sonnenmilch	26	0.11		
High Protection Body Cream	30	0.05		
Anthèlios W Gel	40			0.22
Nivea Sun Feuchtigkeits-Sonnenmilch	50	0.06		
Créme Ecran Extrême	60		0.02	

this value as a universal sun protection factor (USPF): universal sun protection factor (USPF)=100 / average spectroscopic sum transmission in the complete UV range (column 4 in Table 1).

3.3 *Variation of the Universal Sun Protection Factor Found for Three Skin Areas of the Same Volunteer*

The data obtained taking the tape strips from three different parts of one treated skin area of the same volunteer are given in Table 4. The individual values, the mean values of the universal sun protection factors, and the standard deviations are given, obtained for three volunteers measured after application of Nivea Sun Feuchtigkeitssonnenmilch SPF 8.

The mean standard deviation for the three values of the three volunteers is found at 5.7 %. A comparable investigation of the emulsion Nivea Sun Pflegende Sonnenmilch *actual product* SPF 20 yields a standard deviation of 6.3 %, resulting in a mean value of 6 %.

3.4 *Correlation of the Universal Sun Protection Factor with the Classical Sun Protection Factor*

Figure 3 describes the relation of the defined universal protection factor to the classical SPF. A clear correlation does not exist. As a prerequisite for discussion, a trend line is given and some deviating points are marked.

3.5 *Parameter Dependence of the Relation Universal Sun Protection Factor / Sun Protection Factor—Variation in the Ultraviolet A/Ultraviolet B Average Sum Transmission*

One characteristic difference comparing the investigated sunscreens is the variation in the UVB / UVA intensity relation,

Table 4 Determination of the variation of the USPF measured in three neighbored skin regions inside one application area of each of the three volunteers. The mean value is given in absolute values and in percentage transmission (Nivea Sun Feuchtigkeitssonnenmilch SPF 8).

	USPF		
	Volunteer 1	Volunteer 2	Volunteer 3
Area 1	7.7	8.0	7.1
Area 2	7.0	7.8	8.2
Area 3	6.4	8.5	7.8
Mean value	7.0	8.1	7.7
Standard deviation	0.5	0.3	0.5
Standard deviation in percent	7.5%	3.6%	6.0%
Mean value of the standard deviation		5.7 %	

demonstrated in Table 1 and Fig. 2. In Table 3, the factors: $F_{UVB/UVA}$ ($F_{UVB/UVA}$=average spectroscopic sum transmission in the UVB range / average spectroscopic sum transmission in the UVA range), were calculated based on the data given in Table 1. The data in Table 3, quantifying the differences between the transmissions in both wavelength ranges, are arranged in correlation to the position of the USPF values to the trend line.

3.6 *Parameter Dependence of the Universal Sun Protection Factor Values — Individual Skin Profiles*

The results published in Ref. 19 confirmed a large influence of the individual skin profile on the average UVB sum transmission. Table 5 summarizes the corresponding variation for the USPF together with the methodical error determined earlier at 6% (see Table 4).

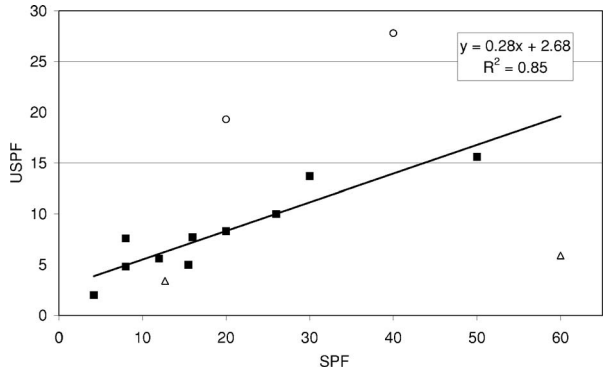

Fig. 3 Correlation of the universal sun protection factor and SPF.

4 Discussion

The calculation of sun protection factors based on spectroscopic measurements necessitates the development of a defined protocol as well as a discussion regarding the influencing parameters.

4.1 *Determination of the Average Spectroscopic Sum Transmission*

Figure 1 illustrates the procedure used to calculate the sum transmission spectra. The difference from one spectrum to the other is reduced continuously until an endpoint is reached, where the difference to the following spectrum is negligible. This needs the summation of 5 to 14 tape strips, depending on the spectral behavior of the investigated sunscreen.

This supports the result of penetration studies confirming that UV filter substances inclusive of particles are positioned in the uppermost part of the stratum corneum.[22,23]

The average UVA, UVB, and UV sum transmission values calculated in this study on the basis of the areas under the last transmission curve summarized in Table 1, as well as the spectra given in Fig. 2, describe large differences between the transmissions in both UV ranges.

The lowest transmission was measured for the UVB range, while the values found for the transmission in the UVA are clearly higher. This is correlated with the historical development of sunscreen products. The UVB-induced formation of erythema was the basis used to quantify the quality of sunscreens during the last years. The protection in this wavelength range was set high. Later on, the protection in the UVA range was increasingly taken into account, and the absorption in this range was enlarged.

4.2 *Determination of the Spectroscopic Protection Factors*

The available average spectroscopic sum transmission values, which describe the degree of attenuation of the UV radiation by sunscreens, are taken to calculate spectroscopic protection factors. These measured values given in Table 2 can be determined without provoking an erythema in volunteers with UV radiation, and reflect the characteristic *in-vivo* distribution of the sunscreen products on human skin. In agreement with the reasons already discussed, high spectroscopic protection factors exist for the UVB range, corresponding to a longer length of time in which it is possible to stay in the sun, while the values for the UVA and the UV ranges are much lower. In practice, this means that most of the investigated sunscreens possess a high protection efficacy against damages, induced by UVB radiation, but a relatively low one for the danger arising by exposure to UVA radiation. The spectroscopic protection factors allow a clear classification of sunscreens, taking into account the real protective ability in the different UV spectral ranges, including UVA.

4.3 *Definition of a Universal Sun Protection Factor*

The proposal of universal sun protection requires a value that ensures protection against all injuries correlated to sun radiation. Without the exact knowledge of the action spectra of the harmful effects, a mean protection must be based on the amount of photons entering the human skin in the complete UV spectral range. For this reason, the spectroscopic protec-

tion factor determined for the complete UV range was defined as the universal sun protection factor (USPF).

It is important to consider that the differences in the efficacy in the UVA and UVB range will be reduced more and more in modern sunscreens, when assessing the applicability of the USPF.

4.4 *Variation of the Universal Sun Protection Factor Found for Three Skin Areas of the Same Volunteer*

The obtained standard deviation given in Table 4 does not describe the measuring error of the spectroscopic method absolutely, as small differences in the skin profile exist also inside the investigated area of one volunteer, but this protocol excludes the large interindividual volunteer-specific variations in the skin profile. Independently of this restriction, the data are used to describe the standard deviation obtained for the values of the individual volunteers (see Table 4).

4.5 *Correlation of the Universal Sun Protection Factors to the Sun Protection Factor Values*

From Fig. 3, it is obvious that the USPF values are generally lower than the SPF. The comparison of the defined USPF and the classical SPF needs to take into consideration that both values depend on quite different parameters. Therefore, a unique correlation between the considered values, which describes different situations, is not to be expected. This is in agreement with the situation found in Fig. 3. To have a first orientation, a trend line is given.

The USPF depends on the remaining radiation intensity after sunscreen application in both parts of the UV range, UVB and UVA, while the SPF is determined by the formation of a special UV-induced injury, the erythema, depending mainly on the UVB intensity. Against this background, it is important to consider the influence of the different UVB/UVA transmission factors on the position of the points in the given graph.

4.6 *Parameter Dependence of the Relation Universal Sun Protection Factor / Sun Protection Factor — Variation in the Ultraviolet A / Ultraviolet B Intensity*

In Fig. 2, sum transmission spectra are shown for three selected emulsions. The sum spectra are taken to determine the maximum absorbance in the UVB maximum and to quantify differences in the absorption behavior in the UVB and UVA range (see Table 3).

The sum transmission spectra in Fig. 2 clearly give hints that the position of the points in the USPF / SPF relation (see Fig. 3) correlate with the transmission in the UVB and UVA range. The sunscreen Créme Ecran Extrême, SPF 60, has a small remaining transmission in the UVB and a relatively high one in the UVA. The corresponding point in the graph "Δ" is found beneath the given trend line. The corresponding UVB / UVA difference is reduced for the sunscreen Nivea Sun Feuchtigkeits-Sonnenmilch, *earlier produc*t, SPF 8. The appropriate point "■" is found on the trend line. A nearly identical remaining intensity in both spectral ranges exists for Nivea Sun Pflegende Sonnenmilch, actual product, SPF 20. The point "○" is positioned above the given line.

Table 5 Comparison of the influences of the measuring error and the interindividual differences—described by the standard deviation—on the dispersion of the USPF values, the relation of the UVB / UVA relation of the average sum transmission.

Sunscreen	Universal sun protection factor		
	Mean value	Standard deviation	Measuring error
COLIPA P1, 4.2	2.0	0.4	0.1
Nivea Sun Feuchtigkeits-Sonnenmilch, SPF 8	4.8	0.8	0.3
Nivea Sun Pflegende Sonnenmilch, SPF 8	7.7	0.7	0.5
Nivea Sun Feuchtigkeits-Sonnenmilch, SPF 12	5.6	1.1	0.3
COLIPA P2, SPF 12.7	3.4	0.1	0.2
COLIPA P3, SPF 15.5	5.0	0.5	0.3
Nivea Sun Feuchtigkeits-Sonnenmilch, SPF 16	7.7	1.6	0.5
Nivea Sun Feuchtigkeits-Sonnenmilch, SPF 20	8.8	1.5	0.5
Nivea Sun Pflegende Sonnenmilch, SPF 20	19	3.9	1.1
Nivea Sun Protection Factor Feuchtigkeits-Sonnenmilch, SPF 26	10	2.4	0.6
High Protection Body Cream, SPF 30	14	3.8	0.8
Anthèlios W Gel, SPF 40	28	3.8	1.7
Nivea Sun Feuchtigkeits-Sonnenmilch, SPF 50	16	1.9	1.0
Créme Ecran Extrême, SPF 60	5.9	0.5	0.4

The result obtained for the last sunscreen with a nearly optimal UVB and UVA protection is of principal importance. The absolute USPF value — USPF=19 — is nearly identical with the size of the traditional SPF. This substantiates that the spectroscopic protection factors obtained with the described method are reasonable.

Table 3 summarizes all the data of the UVB / UVA relation. The factor received for the examples positioned near the given line varies to a relatively large extent. This suggests that not only the discussed relation but also additional parameters must be considered. This is first the intensity-dependent formation of the erythema at a given dose,[25] and second the photoaugmentation.[26] A detailed discussion of these influences will be performed if the number of the investigated sunscreens is enlarged.

4.7 *Parameter Dependence of the Universal Sun Protection Factor Values — Individual Skin Profiles*

The data shown in Table 5 give the possibility to estimate the influence of the individual skin profile on the USPF. The standard deviation (column 3) was determined by the variation coming from differences in the individual skin profile of the volunteers and by the measuring error. With a methodical error of 6 %, as determined before (see Table 4), the data of column 5 were obtained. Comparing the values of both columns demonstrated that the influence of the individual skin profile was larger in nearly all cases. This confirms that the USPF is influenced by the interindividual difference in the skin structure.

5 Conclusion

In summary, the universal sun protection factor calculated on the basis of spectroscopic measurements after tape stripping describes the protective ability of sunscreens sensitively and independently on a biological response. Taking into account the UVB and UVA situation, the described values assess the efficacy of the investigated formulations against all types of injuries, taking into consideration the real distribution of the sunscreens on living human skin. Further investigations must enhance the number and variations of sunscreens, must investigate the correlation of the USPF to PPD values, and must compare results obtained in different laboratories.

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