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Comparison of in vitro and in vivo ultraviolet protective properties of PET textile samples

Raša Urbas[1], Franci Sluga[1], Jovan Miljković[2] ✉, Igor Bartenjev[3]

Abstract

Background: Many studies have been devoted to the problem of harmful effects of UV radiation on human skin. The incidence rate for all forms of skin cancer is rising quickly. Considering this fact, there is currently a need for diligent preventive work, not only from dermatologists but also from other doctors and scientists. Textiles represent simple and effective protection against UV radiation. Good protective clothing can reduce UV radiation on the surface of skin by at least 95%. Even though numerous studies present the effects of various textile parameters on UV protection, not many have been conducted for determining the degree of agreement between in vivo and in vitro measurements of UPF.
Methods: This study presents the effect of various constructional parameters on UPF values (determined using spectrophotometry). The phenomenon of minimal erythema doses on the skin of test subjects was tested based on in vitro calculated UPF values.
Results: Despite some differences in values, the study nevertheless showed a good correlation between both methods and confirms the congruity of in vivo and in vitro UPF values.
Conclusions: It is clear that both methods are needed for a more precise look at the UV protection offered by textiles.

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Introduction

The connection between the harmful nature of ultraviolet (UV) radiation and skin cancer is indisputable (1). The incidence rate for all forms of skin cancer is rising faster than the incidence rate of any other malignant neoplasms, not only in regions near the equator, but in Europe as well (2-4).

Considering this fact, there is currently a need for diligent preventative work, meaning protecting and reducing skin exposure to UV radiation, especially among children and adolescents (primary prevention) (5), as well as earlier detection and treatment for malignant tumors of the skin while they are still treatable and curable (secondary prevention).

The natural protective mechanisms of human skin do not offer the most basic protection. Necessary and optimal protection against UV radiation is thus offered by a combination of avoiding the sun's rays while they are most intense, using UV protective clothing, coverings, and sunglasses, regularly applying wide-spectrum (UVA and UVB) products with a UV protection factor of at least 15, and avoiding the use of medication that induces photosensitivity.

Textiles represent simple and effective wide-spectrum protection against UV radiation (6). The advantage of textile products, in comparison with protective physical-chemical products (e.g., creams, lotions, ointments, tonics, etc.), is that with the use of textiles one can very easily differentiate the protected area of the body from the unprotected area. For this reason there are no side effects in the form of irritation or the development of skin allergies. With loose clothing made from light fabrics there is also the added benefit of air convection, which makes the skin cooler than if it were directly exposed to the sun without protective clothing (7).

Just like physical-chemical products, textiles are rated on the ultraviolet protective factor (UPF) scale. Table 1 represents the UPF values of Australian / New Zealand and European standards.

Clothing's level of UV protection is basically determined by the structural characteristics (cover factor), fiber type (the chemical and morphological qualities of fibers), color (of the fabrics as well as material color), effects of water or moisture (water binding to fabrics), regular use and care, finishing treatments, and the presence of UV absorbers and reflective materials (8, 9).

The final UPF value is therefore influenced by all these parameters. Due to the complexity of the mutual influence of these parameters, the UPF value of clothing cannot be determined by any universal mathematical model, but must instead be determined for each individual fabric, similar to current practice for chemical UV protective products (8, 10).

Table 1 | **Comparison of Australian / New Zealand (AS/NZS 4399:1996) and European (EN 13758-1:2002 and EN 13758-2:2003) standards.**

Regions of UV Radiation	UPF rating on clothing	Protection level	UV radiation transmission (%)
Australian / New Zealand standard			
UVB 280-315 nm UVA 315-400 nm	15, 20 25, 30, 35 40, 45, 50, 50+	Good Very good Excellent	6.7-4.2 4.1-2.6 ‹ 2.5
European standard			
UVB 290-315 nm UVA 315-400 nm	40+	Excellent	‹ 2.5

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Snežniška 5, SI-1000 Ljubljana, Slovenia. [2]University of Maribor, Faculty of Medicine, Department of Dermatovenerology, Slomškova cesta 15, SI-2000 Maribor, Slovenia. [3]University of Ljubljana, Faculty of Medicine, Department of Dermatovenerology, Vrazov trg 2, SI-1000 Ljubljana, Slovenia. ✉ **Corresponding author: jovan.milkovic@siol.net**

Methods

The purpose of this study was to determine the degree of agreement between in vitro and in vivo measurements of UPF ratings for selected textile samples. Although several studies dealing with these issues have already been conducted, the majority of them were carried out on samples of knitted and various woven fabrics with very different basic characteristics (i.e., the commercially most accessible summer textile products). As mentioned above, the characteristics, including the level of UV protection, of knitted and woven fabrics differ greatly from one another (8, 11-16). We are currently unaware of any precise studies of the same fabrics, but with different constructive parameters, and the influence such differences have on a UPF rating.

Therefore, high-module polyethylene terephthalate (PET) monofilament fabrics (nine different samples) distinguished by high dimensional stability were chosen for this study. Samples differed in the yarn diameter, fabric density, open-area portion, and fabric thickness, mass, and weave.

In vitro measurements

Measurements of basic properties (fabric density, yarn diameter, and open-area portion) were determined with photo analysis (Figure 1). Microscopic photos were taken with a JEOL Scanning Electron Microscope JSM-6060LV at different magnifications (100× and 400×). Over 20 measurements were made for each sample and the average values of the measured parameters were then calculated. The results are presented in Table 2.

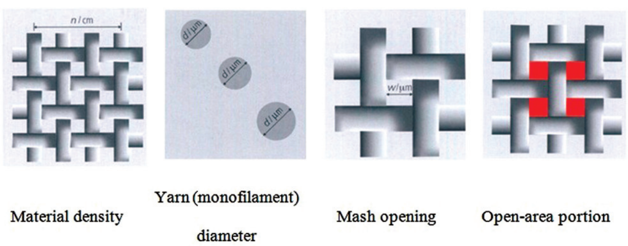

Figure 1 | Measurements of basic fabric properties.

The values of UV transmission were measured in line with European standards (EN 13758-1:2002 and EN 13758-2:2003) using a Lambda 800 UV/VIS Spectrophotometer (PELA-1000) (PerkinElmer, Inc). The transmission values obtained (Equation 1) were used to calculate the in vitro UPF (Equation 2). The results are presented in Table 4.

$$UV_i = \frac{1}{n}\sum_{290}^{400} T_i(\lambda) \qquad \text{(Eq. 1)}$$

$$UPF = \frac{\sum_{290}^{400} E(\lambda)\cdot\varepsilon(\lambda)\cdot\Delta\lambda}{\sum_{290}^{400} E(\lambda)\cdot\varepsilon(\lambda)\cdot T(\lambda)\cdot\Delta\lambda} \qquad \text{(Eq. 2)}$$

In vivo measurements

On the basis of calculated in vitro UPF values, and in line with the CIE erythemal action spectrum, the phenomenon of minimal erythema doses on the skin of test subjects was tested and the subsequent in vivo UPF values were calculated. Several healthy persons (75 male and female) participated in the study; they ranged from 18 to 45 years of age and represented skin types I to IV. The Slovenian Medical Ethics Committee approved the study and all participants signed a written informed consent.

Testing was carried out during the winter, in a test region of skin (the upper section of the back under the shoulders) that had not been exposed to natural or artificial sources of radiation for at least 45 days.

In vivo measurements were carried out with a Saalmann-multitester SBB LT 400 solar radiation simulator. First, the minimal erythema dose for unprotected skin (MEDunprotected) was determined. The test subjects' skin was simultaneously irradiated with five different field doses for different durations of irradiation, which were determined on the basis of skin type (Table 3). Selected durations were chosen for the irradiation of unprotected skin.

Table 3 | **Strength of doses for determined duration of UV ray irradiation.**

Duration of irradiation (s)	Skin type	Field 5	4	3	2	1
		Dose (J/cm²)				
7	I	0.042	0.035	0.028	0.020	0.014
10	II	0.060	0.050	0.040	0.030	0.020
15	III	0.090	0.075	0.060	0.045	0.030
20	IV	0.120	0.100	0.080	0.060	0.040

The MED was read 24 hours after irradiation with UV radiation, which is in accordance with literature recommendations (17-19). Figure 2 presents the formation of erythema on the skin of one participant.

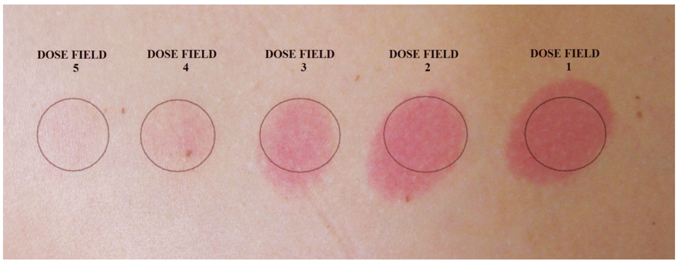

Figure 2 | Formation of erythema on skin of participant.

Table 2 | **Physical and constructional properties of selected samples.**

No.	Sample denotation	Weave	Fabric density (no. yarns/cm)	Yarn diameter (μm)	Fabric thickness (μm)	Open-area portion (%)	Fabric mass (g/m²)
1	PET 120-31	plain	120 ± 3.0	31	49 ± 3	35.0	26
2	PET 120-34	plain	120 ± 3.0	34	55 ± 3	29.6	34
3	PET 120-40	plain	120 ± 3.0	40	65 ± 3	20.1	44
4	PET 140-31	plain	140 ± 3.5	31	48 ± 2	26.0	30
5	PET 140-34	plain	140 ± 3.5	34	55 ± 3	19.4	39
6	PET 150-31	plain	150 ± 4.0	31	47 ± 2	23.3	32
7	PET 165-31	plain	165 ± 4.0	31	48 ± 2	14.5	36
8	PET 180-31	twill	180 ± 4.5	31	55 ± 3	16.6	39
9	PET 190-31	twill	190 ± 5.0	31	55 ± 3	9.0	41

After the determination of MEDunprotected, which represents detectable erythema on the skin of all participants, measurements were repeated with a previously selected textile sample and minimal erythema doses for protected skin (MEDprotected) were ascertained. The time of exposure to radiation was extended in line with calculated in vitro protection factors for individual textiles, meaning that the duration time of irradiation for an individual skin type was multiplied by the UPF value of the textile, which was determined from in vitro measurements (Table 4).

Final UPF values of textile materials (UPFtex) were calculated according to the ratio between MEDprotected and MEDunprotected (Equation 3).

$$UZF_{tex} = {MED_{protected}} / {MED_{unprotected}} \qquad \text{(Eq. 3)}$$

Table 4 | Irradiation durations for individual selected samples of fabric according to skin type.

No.	Sample denotation	UPF	Duration of irradiation (s)			
			Skin type			
			I	II	III	IV
0	Unprotected skin	/	7	10	15	20
1	PET 120-31	5.60	39	56	84	112
2	PET 120-34	8.48	59	85	127	170
3	PET 120-40	14.83	104	148	222	297
4	PET 140-31	9.57	70	95	144	191
5	PET 140-34	17.27	121	173	259	345
6	PET 150-31	13.57	95	136	204	271
7	PET 165-31	19.67	138	197	295	393
8	PET 180-31	18.73	131	187	281	375
9	PET 190-31	24.13	169	241	362	483

During testing each fabric was laid directly on the skin surface (e.g., on-skin measurements). Previous studies (20-22) showed that skin reactions in on-skin measurements are a bit higher than in off-skin measurements in which the textile material is about 2 mm away from the skin surface. Due to this fact, the measured on-skin UPF values of textiles are lower than off-skin ones. All other potential factors (e.g., skin surface properties, menstrual period, physical and mental activities, intra- and inter-individual activities, smoking, coffee drinking, medications, etc.) that could influence the intensity of erythemal reaction were disregarded.

For test subjects with skin type IV, due to very high UPF values and extended durations of irradiation, in vivo measurements were not completely performed. To prevent the formation of burns (caused by overheating the solar radiation simulator), measurements were carried out only partially (Gamblichler reported on similar problems; 20-22).

Results

All calculated in vivo UPF values according to individual skin type, and also as an average for all skin types, are presented in Table 5. The calculated in vitro and in vivo results of UPF values are presented graphically in Figure 3.

Discussion

Our results show that UPF values for the two methods slightly differed from each other. The observed divergence between in vitro and in vivo UPF measurements and the divergence among in vivo measurements could probably be ascribed to the optical-geometric properties of the textiles and the amount of direct and dispersed radiation that passes through the pores between fibers. Sunlight is in actual fact composed of a significant amount of diffused radiation, which textiles further disperse and absorb as direct parallel beams of radiation. For this reason the UPF values determined in real conditions are usually higher than those determined with conventional in vitro and in vivo testing in which a source of UV radiation with parallel radiation beams are used (21, 22). Finally, the differences between the data gathered can be attributed to differences in the methodologies used. Studies describe the differences in measurements on-skin and off-skin, in which case the UPF would be higher if the textile had been placed 2 mm away from the skin, which is an off-skin measurement, as opposed to an on-skin one (20).

Despite the existing small differences in values, the study nevertheless showed that a very good correlation exists between the two methods (0.985; Table 6 and Figure 3).

Table 5 | Comparison of UPF values ascertained from in vitro and in vivo methods.

No.	Sample denotation	UPF					
			In vivo				
			Skin type				Average for
			I	II	III	IV	skin types I-IV
0	Unprotected skin	/	0	0	0	0	0
1	PET 120-31	5.60	6.50	6.22	4.35	5.60	5.67
2	PET 120-34	8.48	10.20	9.21	6.58	9.21	8.80
3	PET 120-40	14.83	14.84	14.80	13.16	14.85	14.42
4	PET 140-31	9.57	10.00	7.65	7.47	6.61	7.94
5	PET 140-34	17.27	15.36	18.74	13.43	17.25	16.20
6	PET 150-31	13.57	14.33	15.11	11.33	16.47	14.31
7	PET 165-31	19.67	19.71	25.45	17.48	/	20.88
8	PET 180-31	18.73	21.83	22.33	14.57	/	19.58
9	PET 190-31	24.13	28.84	31.13	24.13	/	28.03

Table 6 | Correlation matrix for in vitro and in vivo UPF values.

			Skin type				
		In vitro	I	II	III	IV	In vivo
	In vitro	1.000					
Skin type	I	0.965	1.000				
	II	0.981	0.971	1.000			
	III	0.978	0.970	0.976	1.000		
	IV	0.935	0.956	0.981	0.936	1.000	
	In vivo	0.985	0.986	0.994	0.989	0.987	1.000

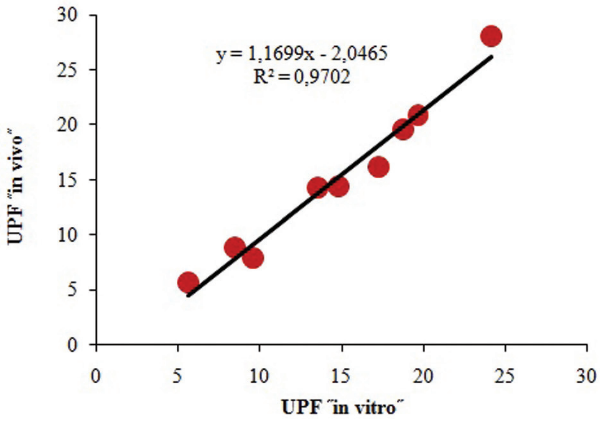

Figure 3 | Comparison of in vitro and in vivo UPF values.

It can therefore be concluded that the results obtained confirm the congruity of in vitro and in vivo UPF values. For this reason, we assert that as far as the need to determine UPF values for woven textile samples in practice is concerned, the in vitro method is sufficient because it enables a simple, expedient, inexpensive, and favorable way to achieve results. For a more precise look into the actual protection offered, however, we must not overlook in vivo measurements.

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