SKIN PENETRATION AND ANTIOXIDANT EFFECT OF COSMETO-TEXTILES WITH GALLIC ACID

C. Alonso[a,*], M. Martí[a], C. Barba[a], M. Lis[b], L. Rubio[a] and L. Coderch[a]

[a]Department of Chemical Technology,Advanced Chemical Institute of Catalonia, (IQAC-CSIC), Jordi Girona 18-26, 08034 Barcelona, Spain

[b]Terrassa School of Engineering (EET-UPC), Colom 1, 08222 Terrassa, Spain

*Corresponding author: E-mail address: cristina.alonso@iqac.csic.es

Abstract

In this work, the antioxidant gallic acid (GA) has been encapsulated in microspheres prepared with poly-ε-caprolactone (PCL) and incorporated into polyamide (PA) obtaining the cosmeto-textile. The topical application of the cosmeto-textile provides a reservoir effect in the skin delivery of GA. The close contact of the cosmeto-textile, containing microsphere-encapsulated GA (ME-GA), with the skin and their corresponding occlusion may be the main reasons that explain the crossing of active principle (GA) through the skin barrier, located in the stratum corneum, and its penetration into the different compartments of the skin, epidermis and dermis.

An *ex vivo* assessment was performed to evaluate the antioxidant effect of the ME-GA on the stratum corneum (SC) using the thiobarbituric acid reactive species (TBARS) test. The test is based on a non-invasive *ex vivo* methodology that evaluates lipid peroxides formed in the outermost layers of the SC from human volunteers after UV radiation to determine the effectiveness of an antioxidant. In this case, a ME-GA cosmeto-textile or ME-GA formulation were applied to the skin *in vivo* and lipid peroxidation (LPO) in the horny layer were determined after UV irradiation. This methodology may be used as a quality control tool to determine *ex vivo* the percentage of LPO inhibition on human SC for a variety of antioxidants that are topically applied, in this case GA.

Results show that LPO formation was inhibited in human SC when GA was applied directly or embedded in the cosmeto-textile, demonstrating the effectiveness of both applications. The percentage of LPO inhibition obtained after both topical applications was approximately 10% for the cosmeto-textile and 41% for the direct application of microspheres containing GA. This methodology could be used to determine the effectiveness of topically applied antioxidants encapsulated in cosmeto-textiles on human SC.

Keywords: gallic acid; microspheres; cosmeto-textiles; skin absorption; lipoperoxidation

1. INTRODUCTION

Biofunctional textiles are materials that exert a biological effect on human skin. Such textiles constitute the basis for the delivery system of cosmetic or pharmaceutical substances when the textiles come into contact with the skin[1]. Active substances are commonly incorporated into the vehicles, which may break when a garment rubs the skin, allowing for the release of the compounds directly to be absorbed by the skin. These cosmeto-textiles, with a slow released of the active compound into the skin, may help people with sensitive skin.

In fact, there are several textile products currently in the market that claim to have properties usually found in cosmetics[2], such as moisturizing, slimming, energizing, refreshing, relaxing or vitalizing properties, as well as UV protection[3-4] or simply fragrance. Thus, there is a real need to develop test methods to verify the effectiveness and durability of these claimed properties[5].

The specific case of UV protection, sunscreen lotions, clothing and shade structures provide protection from the deleterious effects of ultraviolet radiations (UV). The formation of reactive oxygen species (ROS) with UV exposure and their effect on lipids has also been extensively studied[6]. ROS have been implicated lipid oxidation [7], which can alter tissue structure via cross-linking, fragmentation, etc. ROS was part of the damage processes in SC. Some studies[8] demonstrated a marked decrease in intercellular delamination energy with increasing UV exposure indicating UV radiation causes a significant decrease in cellular cohesion and thus an alteration of intercellular lipid or corneodesmosome structure.

In case of cloths when UV hits the textile, different types of interactions occur depending upon the substrate and its conditions. The UV protection by textile materials is a function of the chemical characteristics, physico-chemical type of fibre, presence of UV absorbers, construction of fabric, thickness, porosity, extension of the fabric, moisture content of the fabrics, colour and the finishing given to the fabric. The UV transmitted through textile fabrics consists of the unchanged waves that pass through the interstices of the fabric as well as scattered waves that have interacted with the fabrics. Another part is absorbed when it penetrates the sample, and is converted into a different energy form. The portion of radiation that travels through the fabric and reaches the skin is referred to as the transmission component[9]. This portion of radiation could be one of the reasons to study the antioxidant protection effect of a biofunctional textile prepared with an antioxidant active.

Gallic acid (GA) is a polyhydroxyphenolic compound present in leafy vegetables, fruits, and nuts[10-12]. GA exhibits variety of biological activities including antioxidant[13-14], anti-tumor[11, 15-17], anti-inflammatory[18] and anti-bacterial[19-20]. Several line of evidence has shown that GA inhibits tumor cell growth, migration and invasion in vitro[21]. GA has recently been applied in cosmeto-textiles as an active component[22].

In this work, the GA was selected and incorporated into polyamide (PA) through microspheres prepared from poly-ε-caprolactone (PCL). PCL is an aliphatic polyester having good chemical resistance to solvents[23]. It is biodegradable and non-toxic to the human body[24]. And, it has the advantage of controlling the release of the active principle over a period of several days to several weeks in contrast to natural hydrophobic polymers, which have a shorter period of release[25]. Therefore PCL microspheres have been used as a vehicle for textile application to study the absorption and desorption properties thereof when incorporated into PA[22].

Polyamide (PA) was used as a textile fabric in this work to obtain biofunctional textiles because of their comfort when in contact with the skin. PA has been used for a number of industrial, apparel, and medical applications, such as wound sutures, artificial tendons, and medical packaging, due to its excellent wear resistance, strength, toughness, elastic recovery, low initial modulus, appearance retention, ease of coloration, and high resistance to rupture[26].

Using the *in vitro* methodology of percutaneous absorption, it is possible to detect the amount of the active principle that penetrates each skin layer from a given cosmeto-textile[27]. It is reasonable to assume that the reservoir capacity of a cosmeto-textile, close contact with the skin and the corresponding skin occlusion may be the main factors that determine how an active principle (e.g., GA) crosses the skin barrier, located in the stratum corneum, and penetrates the different compartments of the skin. The *in vitro* skin delivey of PA containing ME-GA has previously been explored the results obtained suggested that GA penetrates through the skin detecting at different skin layers (stratum corneum, epidermis and dermis)[22].

The aim of this work was to assess the antioxidant efficacy of a cosmeto-textile containing microsphere-encapsulated GA. Our study involves a topical antioxidant strategy to prevent damage to skin specially the lipid fraction. The antioxidant capacity was determined using human volunteers after topical cosmeto-textile application. An *ex vi*vo assessment was performed to evaluate the protection effect on the stratum corneum (SC) after cosmeto-textile application. The lipid peroxide formation was determined using the thiobarbituric acid reactive species test (TBARS). This test is a non-invasive *ex vivo* method that uses tape strips of the outermost layers of the SC from human volunteers to evaluate the effectiveness of an antioxidant[28].

2. MATERIALS AND METHODS

2.1 Materials

The textile bandages used were knitted fabrics (plain stitch) of polyamide 78/68/1 (DeFiber, S.A., Spain). Poly(vinyl alcohol) (PVA) (87–89% hydrolyzed, MW 31 000–50 000 Da) was used as a dispersant for microsphere preparation; poly-ε-caprolactone (PCL) (MW 45 000 Da) was used as the microsphere polymer. Both PVA and PCL were supplied by Sigma-Aldrich (Madrid, Spain). Gallic acid (GA), as the active ingredient, was supplied by Sigma-Aldrich (Madrid, Spain). All chemicals used were of analytical grade. Methanol (HPLC grade) and phosphoric acid were supplied by Merck (Darmstadt, Germany).

2.2 PCL-Microspheres

The solvent evaporation method was used to obtain microspheres by forming microemulsions ($w_1/o/w_2$ double emulsion)[22]. The preparation procedure was carried out twice to obtain a sufficient volume of microspheres for all textile bandage applications.

Briefly, 20 ml of a 2.91% (w/w) dispersion of GA in water was added to 20 ml of 2.91% (w/w) PCL in dichloromethane. A simple emulsion (w_1/o) was generated by mechanical agitation (ULTRA-TURRAX T25, IKA) for 25 min at 24 000 rpm. This simple emulsion was then added to a continuous phase consisting of 200 ml of an aqueous PVA solution (1.96% (w/w)) and was emulsified for 30 more minutes at 20 000 rpm, resulting in a double emulsion ($w_1/o/w_2$). The method used was carried out at 4 ºC [29]. The mixture was maintained under agitation at 400 rpm (20 h) at room temperature, leading to solvent evaporation and consequently microsphere formation. The percentage of GA in the formulation is 0.49 % (w/v) and its percentage related to microspheres without water was 11.60 %(w/w).

PCL microspheres of gallic acid (ME-GA) (mixture of both preparations) were applied to textiles (322 ± 1 cm^2 area) by bath exhaustion, with a bath ratio of 1/5 (1 g textile per 5 ml of treatment bath), at 50°C for 60 min with manual stirring performed every 10 min. To quantify the amount of product absorbed onto the fabrics, the dry samples were weighed before and after 24 h of application under standard ambient conditions (23±2°C and 55±5% relative humidity).

The GA present in the formulations and absorbed onto the fabrics was extracted with methanol during 15 minutes under ultrasounds and quantified using a Hitachi-Merck HPLC equipped with an L-6000 Intelligent Pump, AS-4000 Autosampler and L-4250 UV-Vis Detector. The column used was a LiChrocart 250-4/Lichrosorb RP-18 (5 mm) (Darmstadt, Germany). The mobile phase was 90% water (with 0.7% H_3PO_4)/10% methanol flowed at a rate of 1 ml/min. GA detection was conducted at 280 nm with a retention time of 6.9 min. The area below the peak in the chromatogram was used to calculate the concentration of GA using external standards that displayed linearity over a concentration range of 0.25 to 100 mg/ml. The equation yielding the regression line through the experimental values was (ABS= 15967·[GA]+4417.1, r^2= 0.9999). This analytical methodology was fully validated.

2.3 Size of PCL microspheres

The size distribution and polydispersity of the PCL microspheres were measured by dynamic light scattering (DLS) (Zetasizer Nano ZS ZEN3600; Malvern Instruments Ltd., Malvern, Worcestershire, UK). The non-invasive backscattering technology was used to minimize multiple scattering effects without the need for sample dilution. The size distribution and polydispersity measurements were performed at room temperature with polystyrol/polystyrene cells (Ref 67.754 Sarstedt). The scattered light was detected at an angle of 173º. Each sample was measured in triplicate. The data were interpreted by considering the size distribution by intensity. All data were collected and analyzed using the program DTS (dispersion technology software) provided by Malvern Instruments Ltd.

2.4 Volunteers

The experimental protocol was conducted with 8 healthy Caucasian volunteers (all women) with phototypes II, III and IV [30]. The mean age of the volunteers was 36.8 ± 13.6 years (range years) (Table 1). The volunteers refrained from using cosmetics, body oils, sunscreens or moisturizers on their arms 4 days prior to the study and during the study except for the 2 formulations selected. The participants were given a detailed description of the study, and the corresponding written consent forms were obtained. The study design was approved by the local ethics committee (IQAC-CSIC, Barcelona, Spain).

Table1. Age and phototype of volunteers.

Volunteer	1	2	3	4	5	6	7	8	Mean ± SD
Age	24	24	28	60	34	36	33	55	36.8 ± 13.6
Phototype	II	III	IV	II	IV	IV	IV	III	

2.5 In vivo cosmeto-textile and formulation application

The cosmeto-textiles (polyamide containing ME-GA) and control textiles (polyamide without antioxidant) were applied on subjects' arms, maintaining close contact with the skin over a period of 4 days as a bandage application.

Moreover, the formulation containing PCL microspheres of GA (ME-GA) was directly applied to the skin of each volunteer. A skin area of 18 x 5 cm^2 was marked on the volunteers' forearms. Formulations were applied by each volunteer twice a day over a period of 4 days on one forearm with a final total amount of 6 mL of ME-GA applied (327 µg/cm^2 of GA). The other forearm was used as a control without antioxidant application.

2.6 Tape stripping and lipid extraction

The tape stripping of the SC of each forearm and arm was carried out on the 4^{th} day in a conditioned room at 25 ±1ºC and 50 ± 2% relative humidity using D-Squame™ tape (ϕ= 22 mm, CuDerm, Dallas, USA) previously pressed onto the skin with a roller and stripped in one quick move.

The weight of each tape was determined directly (Mettler Toledo Excellence XA105, Greifensee, Switzerland) before and after stripping, and the weight of the SC removed was then determined. Then, half of the strips were fixed in a glass plate and irradiated using a light source simulating UV solar radiation (3.045 J/min cm^2, Suntest CPS, Atlas, USA). This radiation is double the maximum radiation input in one day in June in Catalonia (1.50-1.84 J/min cm^2 equivalent to 21-26.5 MJ/m^2 per day [31]). The UV exposure time was 60 min, yielding a UV irradiation intensity of 182.7 J/cm^2.

The SC lipids from a group of 3 strips were extracted with methanol (Merck, Darmstadt, Germany) with sonicated in a Labsonic 1510 device (B. Braun, Melsungen, Germany) for 15 min.

2.7 Determination of lipoperoxidation (LPO)

Lipid peroxides (LPO species) were measured by the thiobarbituric acid (TBA) assay [28]. The thiobarbituric acid-reactive species (TBARS) were quantified by spectrophotometry at 534 nm (Cary 300 Bio UV-Visible Spectrophotometer, Varian, USA). At low pH and elevated temperature, MDA readily participates in a nucleophilic addition reaction with TBA, generating a red, fluorescent 1:2 MDA:TBA adduct.

The results obtained were expressed as malonaldehyde bis(dimethyl acetal) equivalents (µM MDA) using a standard curve for pure MDA-TBA complexes. The calibration curve was obtained by using MDA (Sigma, St Louis, MO, USA) in different concentrations (0-40 µM). Additionally, negative and positive controls were quantified using 0 and 100 µM MDA. The calibration curve was prepared on each day of the experimental study. The general regression equation obtained from the experimental analysis was ABS= -0.0006 $[MDA]^2$+0.0751[MDA]-0.0137 (correlation coefficient, r^2= 0.999). The repeatability and reproducibility of the analytical method was confirmed by the absorbance of the MDA positive control (100 µM MDA). The mean value obtained for this MDA control (100 µM) was 2.3314± 0.0206. The results for each experimental analysis indicated good repeatability and intra-day precision with an acceptable R.S.D. (<0.50%).

Briefly, a 0.5 ml volume of SC lipid extracts and standard MDA solutions was added to aliquots (1 ml) of a solution made up with 0.4% TBA (Sigma, St Louis, MO, USA) and 15% trichloroacetic acid (TCA) (Merck, Darmstadt, Germany) in 100 ml of HCl solution (0.25 M). The mixture was incubated for 1 h in a boiling water bath. Fresh TBA /TCA stock solution was prepared on each day of analysis.

Following the experimental procedure[28], the amount of LPO formed from unprotected skin (placebo) and the amount of LPO formed from protected skin (antioxidant application) were calculated based on the absorbance values obtained for the SC extraction samples by MDA determination. Therefore, the percentage of LPO inhibition (% LPO inhib.) was determined from the difference in the amount of LPO formed between the SC placebos and SC antioxidant samples.

2.8 Statistics

Global results were calculated as medians with their 0.25 and 0.75 percentiles (0.25; 0.75). The Mann-Whitney test was applied for group comparisons. The software used was STATGRAPHICS plus 5. Significant differences in the mean values were evaluated by an F-test. A *p* value below 0.05 was considered significant.

3. RESULTS AND DISCUSSION

Formulations containing PCL microspheres were prepared using a double emulsion method, as described in the Materials and Methods section. The diameter of the particles in the ME-GA mixture was measured with Dynamic Light Scattering (DLS) and results indicated the presence of microspheres with a homogeneous size distribution of 2692 nm with a polydispersity index of 0.437. Moreover, the amount of GA present in the PCL microsphere formulation was determined by HPLC using an external calibration curve. The amount of GA in the ME-GA formulation was 0.49 ± 0.01% (w/v).

The performance of biofunctional textiles with release properties could be affected by a number of factors, such as biocompatibility, biostability, biodegradability, drug delivery efficiency, drug quantity, system design and control in terms of dose, rate and time of development[32]. Thus, it is very important to establish the precise amount of active agents present in a textile before its use as a textile drug delivery system. In this study, PCL microspheres were applied by bath exhaustion, as discussed in the 'Materials and Methods' section. Textiles were submitted to a bath impregnation formulation that contained ME-GA. Table 2 shows the weights of the PA bandages before and after application. The final percentages of dry product incorporated into the fabrics were calculated based on the weight difference between the initial dry fabrics and the dry fabrics after the bath exhaustion process. The median amount of dry product applied was 11.59±0.65% over weight of fiber (owf). Taking into account the percentage of GA in PCL microspheres without water (11.60% (w/w)), the mean of the treated area of fabric (322 cm^2) and the mass increase of the fabric (0.9124 g), the mean amount of GA/cm^2 in the textile calculated accounts for 350 ± 17 µg GA/cm^2.

Table 2. Weights of PA bandage before and after ME-GA application by bath exhaustion and the total dry product on the textile after water evaporation

Volunteer	PA WEIGHT after 24h at 23ºC and 55%Hr			Dry Product
	Bandage before ME-GA application (g)	Bandage after ME-GA application (g)	Mass Increased (g)	% owf of ME-GA
1	8.3385	9.2989	0.9604	11.52
2	5.6969	6.3860	0.6891	12.09
3	8.3429	9.3572	1.0143	12.06
4	8.4450	9.4432	0.9982	11.82
5	8.2804	9.2498	0.9694	11.71
6	8.1517	8.9948	0.8431	10.34
Mean	*7.8759*	*8.7883*	*0.9124*	*11.59*

In addition, a piece of treated textile was used to extract GA with methanol using an ultrasound bath to quantify GA by HPLC. The amount of GA incorporated into the textiles was determined to be 376.63 ± 19.93 µg GA/cm² fabric. The theoretical value of approximately 350 µg GA/cm² on PA obtained from mass increase of fabric confirms the equivalence of the two methodologies in determining the amount of GA in the textiles. In addition, this result indicated that it was substantively between the textile and active agent, which could play an important role during the application process.

After analytical determination, microspheres of GA were applied in vivo. Cosmeto-textiles containing ME-GA were fixed on one arm of 6 volunteers, and the ME-GA formulation (concentration of 0.49% w/v) was directly applied on one forearm of 6 volunteers; both applications were maintained for 4 days. The GA applied in skin was of 377 µg/cm² for cosmeto-textile and 327 µg/cm² for formulation. The outermost layers of SC were then obtained using tape as described in the Materials and Methods. The results obtained for the mean weight of SC for both applications were similar. The mean weights of the SC obtained were 0.83 ±0.11 and 0.76 ± 0.17 mg/3 tape strips for the cosmeto-textile and direct application modes, respectively.

Half of the SC layers in the strips (from unprotected and protected skin) obtained by each application mode were irradiated with an intensity of 182.7 J/cm². LPO compounds were then extracted from a group of 3 strips. The LPO values and the percentage of LPO inhibition due to the application of the cosmeto-textiles and the formulation were determined for all volunteers.

The LPO results obtained in µM from unprotected and protected skin are shown in Table 3, as well as the percentages of LPO inhibition (%). Figure 1 presents the medians of the results obtained from unprotected and protected skin when ME-GA was applied via a cosmeto-textile or directly.

Table 3. LPO values obtained from unprotected and protected skin with ME-GA for each volunteer when cosmeto-textiles and formulation were applied.

Application	Volunteer	LPO (µM) Unprotected skin	LPO (µM) Protected skin	% LPO inhib.	% LPO median (percentil 0.25; 0.75)
ME-GA Cosmeto-Textiles	1	0.7899	0.7245	8.28	10.12 (8.68; 15.73)
	2	0.5891	0.4860	17.51	
	3	0.9059	0.8120	10.37	
	4	0.1820	0.1640	9.87	
	5	0.2967	0.1904	35.81	
	6	0.5205	0.4939	5.11	
ME-GA formulation	3	0.8223	0.3310	59.75	41.45 (34.43; 52.97)
	4	0.0470	0.0304	35.19	
	5	0.2517	0.1140	54.72	
	6	0.3155	0.2077	34.17	
	7	0.3803	0.1989	47.71	
	8	0.0963	0.0956	0.77	

As shown, the amounts of LPO obtained from unprotected skin were higher than those obtained from protected skin using ME-GA via each application mode (Figure 1). These results demonstrate a lower extent of formation of lipid peroxides in the SC of skin protected after UV irradiation when the antioxidant was used. The amounts of LPO obtained for each volunteer were highly variable due to the effects of several variables such as the amount of GA delivered into skin, the different skin types of the volunteers, and the amount of SC present in the samples. Therefore, even the results are not statistically significant for any of the applications there is an appreciable difference in the amounts of LPO obtained from unprotected and protected skin.

Despite the variation in the percentage of LPO inhibition, the results indicate a clear inhibition of LPO for both ME-GA applications. It appears that the ME-GA used has a protective effect on human SC against lipid peroxidation, with the percentage of LPO inhibition reaching 10.12% LPO (8.68; 15.73) for the cosmeto-textile application and 41.45% LPO (34.43; 52.97) for the direct application of the ME-GA formulation.

Similar amounts of SC were retrieved on the 3 strips: 0.79 ± 0.15 mg/3 tape strips. The percentage of LPO inhibition was calculated based on the total amount of lipid peroxides on SC treated or not treated with antioxidant. The results of LPO inhibition (%/mg of SC) obtained were 11.28%/mg (8.09; 35.58) for the ME-GA cosmeto-textiles and 43.65%/mg (14.37; 53.38) for the ME-GA formulation.

TBARS assay is a convenient and simple method which has been frequently used as a standard biomarker of LPO in vivo with human plasma and urine. LPO is the major reaction taking place under oxidative stress and assumed to play an important role in the pathogenesis and progression of many diseases[33]. This paper reports a non-invasive ex vivo method to detect LPO in human skin using tape

strips of the outmost layers of SC from human volunteers. This strategy permits evaluate the effectiveness of topical treatment with antioxidant against oxidative stress caused by UV exposure.

In a previous study[22], a specific *in vitro* percutaneous absorption methodology was designed to demonstrate the delivery of an encapsulated component from a textile to the different skin layers (stratum corneum, epidermis or dermis). The percutaneous absorption results obtained are shown in Figure 2.

The percutaneous absorption results indicate that the skin penetration of GA released from PCL microspheres that were applied directly to the skin was higher than that observed when GA was embedded within the cosmeto-textiles. In all cases, the highest amount of GA that penetrated the skin was observed in the superficial layer (SC, stratum corneum), where the amount was 5 to 10 times higher than that in the epidermis or the dermis. In conclusion, an interesting reservoir effect may have been promoted when biofunctional textiles were used.

Results concerning skin delivery to the different skin layers (stratum corneum, epidermis and dermis) showed that ME-GA incorporated into the cosmeto-textiles displayed high GA retention. This retention capacity of cosmeto-textiles was deduced by the lower amount of antioxidant found in the inner skin layers compared to that measured after the direct application of ME-GA. This suggests a slower but continuous release of antioxidant to the skin when ME-GA cosmeto-textile is applied. The high amount of GA in the SC layer for both applications can be related to the extensive LPO inhibition observed after UV irradiation of the tape strips containing SC. In addition, a stronger protective effect of the ME-GA formulation was observed compared to the ME-GA cosmeto-textiles. It may also be due to the different amounts of GA found in the SC for the two different types of applications. The cosmeto-texile presents two diffusion phases, first this active compound must diffuse from the fabric to the skin surface when the cosmeto-textile is topically applied. The second phase is the penetration of the compound at the different skin layers. The low release of GA from the cosmeto-textiles may suggest a slow but continuous release of the antioxidant to the skin.

Although the content of antioxidant present in the skin was lower for the cosmeto-textile mode of application than for the direct mode of application, it is important to note that the amount released demonstrated sufficient capacity to combat lipid peroxidation in human SC. The use of cosmeto-textiles allowed for a reservoir effect with a prolonged and controlled dose of the antioxidant such that the corresponding UV protection was also prolonged.

4. CONCLUSIONS

This study explored the antioxidant efficacy of a cosmeto-textile containing ME-GA and a formulation containing gallic acid in microspheres. The effectiveness of the antioxidant via the ME-GA cosmeto-textile and direct application routes was determined by a non-invasive *ex vivo* method with tape strips of the outermost layers of the SC of human volunteers. The antioxidant was applied to prevent lipid peroxidation in the horny layer after UV irradiation.

The results indicate that LPO was inhibited in human SC when GA was applied, demonstrating the effectiveness of both applications. The capacity of each application route to reduce LPO in the outermost

layers of the skin was confirmed. The percentage of LPO inhibition obtained after each topical application was approximately 10% for the cosmeto-textile route and 41% for the direct route.

This finding is in accord with the results obtained from a percutaneous absorption study in which PCL microspheres containing GA and the textiles were impregnated with the same formulation. Percutaneous absorption data indicate a high level of skin penetration for GA that was directly applied within PCL microspheres. The high extent of LPO inhibition measured is proportional to the amount of GA measured in the outermost layers of the skin.

The LPO methodology could be used to verify the antioxidant capacity of encapsulated substances transferred into human skin by cosmeto-textiles that can deliver specific doses of active ingredients. The incorporation of antioxidants into cosmeto-textiles allows for the natural photoprotection capacity of the skin to be enhanced when such textiles are used for prolonged application periods.

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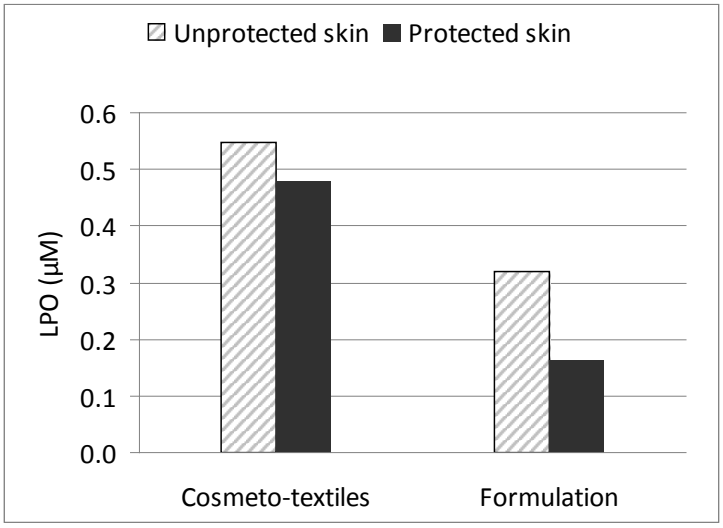

Figure 1. LPO values obtained from unprotected and protected skin with ME-GA cosmeto-textiles and ME-GA formulation ($p>0.05$).

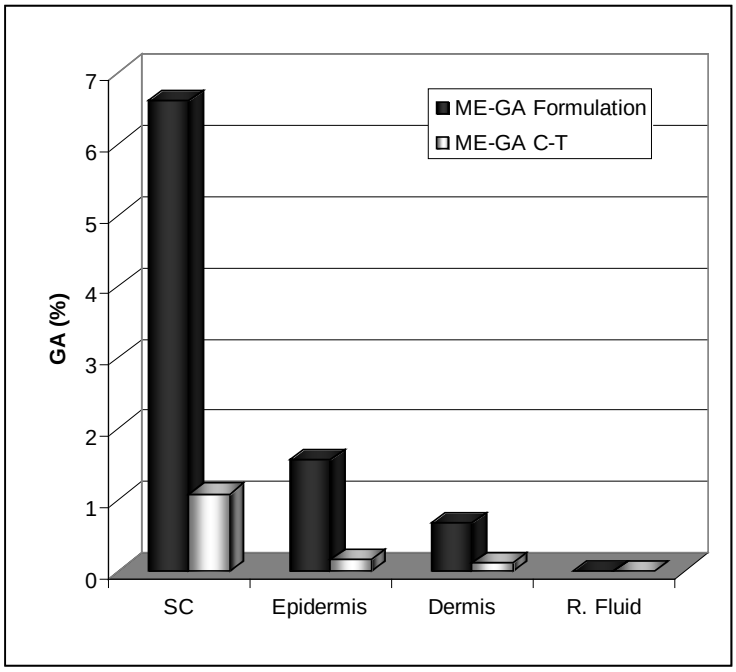

Figure 2. *In vitro* percutaneous absorption of GA from PCL-microspheres and from biofunctional textiles (PA). (SC: stratum corneum; E: epidermis; D: dermis; R. Fluid: receptor fluid)