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Polymer-interaction driven diffusionof eyeshadow in soft contact lenses☆

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ABSTRACT

Soft contact lenses used for the correction of ametropia are often made of hydrogel and silicone-hydrogel materials. Since they are placed directly on the surface of the eye and they are hydrated by tears, eye cosmetics can compromise the lens performance and, even worse, can be transported from an external environment to the ocular surface through the contact lens.

The diffusion of the dye component of a purple eyeshadow in soft contact lenses of different materials is here evaluated. Diffusivity is found to be typically higher in silicone-hydrogels than in hydrogels. In hydrogels, diffusivity is greater in the case of lower oxygen transmissibility. Despite differences between materials, absorbed mass of dye is much larger (10–100 times) than the expected mass by simple hydration and swelling of the contact lens. The most contaminated materials are also resistant to cleaning solutions. The results indicate that, notwithstanding the complexity of contact lens networks, diffusion of dye is found to follow Fick's law and it is driven by polymer-dye interaction, which governs lens hydration and swelling.

1. Introduction

Eye cosmetics typically contain pigments, waxes, oils, silicone components, and preservatives. Commercial cosmetics undergo safety testing for human use, but specific ocular changes associated with eye cosmetic are reported in the literature. For example, a very recent review summarizes current knowledge regarding the impact of cosmetic products on the eye, ocular surface, and tear film [1]. Stinging and burning, allergic conjunctivitis, allergic and irritant contact dermatitis, ocular infections, conjunctival pigmentation due to mascara and eyeliner, and eyeshadow mimicking orbital calcification were reported many years ago [2]. Conjunctival pigmentation secondary to eyelid cosmetics was also studied by light and electron microscopy [3]. The deposited materials were found to be ferritin particles and metal oxides [3]. Adverse reactions of cosmetics within the ocular surface were mainly attributed to the preservative benzalkonium chloride [4]. Extreme cases are those of ulcers associated with the use of mascara contaminated with *Pseudomonas aeruginosa* [5]. Makeup-human meibum interactions were recently studied in-vitro using infrared spectroscopy [6]. A makeup product was found to increase the lipid phase transition temperature when combined with human meibum causing an increase in the order of the meibum-lipid hydrocarbon chains, which could have adverse effects on tear film stability. In general, practitioners are familiar with observing cosmetic residuals in tear fluid when they observe the eye under slit-lamp biomicroscope.

The use of both eye cosmetics and contact lenses (CLs) is also very frequent and deserves to be investigated for possible adverse events. Indeed, the impact of CL contamination by eye make-up may compromise the performance and physical properties of the CL and, even worse, transport of make-up from an external environment to the ocular surface through the CL is of clinical relevance because it can anticipate adverse interactions occurring at the ocular surface. Contamination of CLs can occur through the contaminated tear fluid and through the contact with hands. Contamination in the conjunctival sac by cosmetic and cleaning products was reported [7]. Pencil eyeliner was found to migrate most readily and to maximally contaminate the tear film when applied posterior to the lash line with possible implications for CL wearers [8]. In addition to eye contamination, deformation and swelling of the CLs were also observed for silicone-hydrogel materials without plasma polymerization coating when applying cosmetics and cleansing oil together or cleansing oil alone. In another study, the cleaning efficacy was also investigated for some brands of daily cleaners

☆ Authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence this work.

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for silicone hydrogel CLs contaminated by pencil eyeliner and cosmetic cleansing products [9]. Both hydrogel and silicone-hydrogel CLs in wet and dry conditions were recently investigated [10]. Hydrogels were found to resist cosmetic cleansing oil, while silicone-hydrogels have different degrees of resistance depending on the lens material. Modifications of silicone-hydrogel CL shape (diameter, sagittal depth, base curve) and optical power after in-vitro CL coating with cosmetics were recently reported [11]. The same group [12] also reported modifications of silicone-hydrogel CL surface by analyzing microscope images and wettability data. In this framework, many aspects related to interaction between CL materials, cosmetics, and tear film need additional investigation.

The aim of this work is to quantify and compare absorption of the dye component of a purple eyeshadow in soft CLs of different materials, with special focus on the diffusion process underlying the mass transfer phenomenon. Through the short-time solution of Fick's second law, dye diffusion coefficients (diffusivity) are deduced. Different CL materials, both hydrogels and silicone-hydrogels, are compared in terms of diffusion coefficient and efficacy of a multipurpose solution (MPS) in removing the dye component of the cosmetic, thus obtaining information on the polymer-cosmetic interaction.

2. Materials and methods

Different CL materials (−3.00 D) were investigated, as reported in Table 1, where *t* is the central CL thickness (provided by manufacturers), Dk/t is the CL oxygen transmissibility (provided by manufacturers), EWC is its equilibrium water content defined as

$$EWC = \frac{W_{hydr} - W_{dry}}{W_{hydr}}, \quad (1)$$

W_{hydr} being the hydrated.CL weight and W_{dry} being the dehydrated-CL weight. EWC data reported in Table 1 are provided by manufacturers. Within an experimental error of 2%, the same values were deduced by measuring W_{hydr} and W_{dry} by a micro-balance Gibertini E42 (Italy) and applying Eq. (1).

The cosmetic is a purple highly concentrated loose powder eyeshadow (158, 40621, Kiko, Italy) made of talc, mica, paraffinum liquidum, magnesium stearate, lanolin oil, caprylic/capric triglyceride, phenoxyethanol, sodium dehydroacetate, diethyl-hexyl-syringylidenemalonate, and manganese violet dye (color index 77742), which are the typical components of eyeshadows (manganese dye is the typical colored component of purple ones).

The CLs were exposed to the cosmetic dissolved in 0.9% NaCl solution (Bausch & Lomb IOM saline solution) with cosmetic concentration equal to 1 mg/mL. Two procedures for evaluation of the relative mass of dye absorbed by a CL were applied. The first method is indirect because optical analyses are performed on solutions to obtain information on the absorbed mass in a CL. For the spectroscopic measurements of solutions, fused silica cuvettes were used with optical path of 1 mm. Absorbance measurements were performed between 900 and 220 nm by using a Jasco V-650 spectrophotometer (absorbance is defined as $-\log_{10}$(transmittance)). The method was applied after verifying the linear dependence of optical absorbance on eyeshadow concentration. This was preliminary performed by measuring the optical absorbance of the cosmetic in 0.9% NaCl solution (Bausch & Lomb IOM saline solution) in the range of eyeshadow concentrations from 1.0 to 8.8 mg/mL. Spectra measured on different solutions are reported in Fig. 1. The integrated absorbance from 540 to 610 nm was calculated and is reported in the inset as a function of cosmetic concentration. Linear regression of data (R = 0.999) shows the linear dependence of absorbance on eyeshadow concentration. Even if the fraction of dye is not known, a linear dependence can be inferred also as a function of dye concentration, the dye being the colored component and representing a fixed fraction. The method consists in (i) measuring the optical absorbance of the cosmetic solution before and after CL exposure to 5 mL of solution in a glass vial and (ii) calculating the variation of dye concentration in solution after CL exposure compared to the dye concentration before exposure based on the measured values of absorbance. Indeed, the ratio between the two values of absorbance is equal to the ratio between the two dye concentrations due to their linear relationship. Therefore, the variation of optical absorbance of the solution is an indicator of dye absorption in CLs ranging from 0% to 100% (when the solution becomes transparent after the CL exposure). The relative mass of absorbed dye is defined as M_τ/M_{tot}, where M_τ is the mass of dye absorbed in one CL and M_{tot} is the total amount of dye in a vial (the dye fraction in 5 mg of eyeshadow, i.e. the mass of dye available in the vial for one CL). Analyses were repeated at least three times for each material. Since glass vials were used, the decrease of dye concentration due to possible dye adhesion to walls was also preliminary investigated. Experiments were carried out by filling vials with 5 mL of solution without any CL. After 24 h, the loss of dye was found to be (5 ± 2)%.

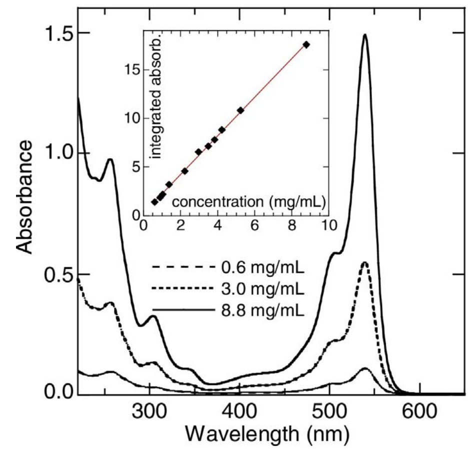

Fig. 1. Cosmetic absorbance spectra. Absorbance spectra of the cosmetic in 0.9% NaCl solutions with concentrations 0.6, 3.0, and 8.8 mg/mL. Inset: integrated absorbance from 540 to 610 nm as a function of cosmetic concentration in 0.9% NaCl solution. The line represents the result of linear regression of data (R = 0.999).

Table 1
Properties of the CLs investigated in this work.

MATERIAL	FDA group	Brand	t (mm)	EWC (%)	oxygen Dk/t (Fatt units)
hilafilcon B	Hydrogel: II	Bausch & Lomb Soflens Daily	0.090	59	22
nelfilcon A	Hydrogel: II	Alcon Dailies Aquacomfort Plus	0.100	69	26
omafilcon A	Hydrogel: II	CooperVision Proclear 1 day	0.090	59	33
etafilcon A	Hydrogel: IV	Johnson & Johnson 1-day Acuvue Moist	0.084	58	33.3
filcon IV	Hydrogel: IV	Safilens Fusion 1 day	0.050	58	40
narafilcon A	Silicone-hydrogel: I	Johnson & Joh 1-day Acuvue TruEye	0.085	48	118
enfilcon A	Silicone-hydrogel: I	CooperVision Avaira	0.080	46	125
comfilcon A	Silicone-hydrogel: I	CooperVision Biofinity	0.080	48	160
filcon V	Silicone-hydrogel: n.a.	Safilens Open30	0.090	45	65