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Effect of Ultraviolet B Radiation on the Absorption Characteristics of Various Intraocular Lenses

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Key Words
Intraocular lens opacification · Intraocular lens · Ultraviolet B · Ultraviolet filter

Abstract

Background: The aim of this study was to determine the effect of ultraviolet B (UVB) exposure on UV filters of various intraocular lenses (IOLs). ***Methods:*** Eight samples each of the hydrophobic acrylic, hydrophilic acrylic and silicone IOLs were used. Four IOLs of each type was selected randomly as the control group while the remaining four IOLs of each type were exposed to a UVB dose of 1.4 J/cm^2 (2.40 mW/cm^2) for 9.45 min, two times with a 4-week interval. IOLs were evaluated for any sign of opacification under microscope weekly. After a follow-up period of 16 weeks, spectrometry for UV filter absorption rates, scanning electron microscopy for deposit formation and energy dispersive X-ray analysis for elemental composition were performed for all IOLs, and findings of the control group IOLs were compared with those of the UVB-exposed IOLs. All these procedures were done at the Department of Ophthalmology, Faculty of Medicine, Dokuz Eylul University. ***Results:*** All the IOLs were free of any opacification during the follow-up period. Spectrometric analysis of their UV filters revealed a change in absorption rates in the hydrophilic acrylic and silicone IOLs compared to the control IOLs of the same type. Only the hydrophobic acrylic IOLs preserved the same UV absorption curve after UVB exposure. ***Conclusion:*** The pathogenesis of IOL opacification is still undetermined. Some reports claimed that the UV light was the responsible factor. Our experimental study revealed that high doses of UVB did not cause any opacification though they impaired the function of UV filters of the hydrophilic acrylic and silicone IOLs.

Introduction

Ultraviolet B (UVB) radiation has been considered as a cataractogenic factor in several epidemiologic and animal studies [1, 2]. It damages the lens by inducing photooxidation and forming free radicals [3, 4]. In a study by Hightower and McCready [5] on cultured rabbit lens, UVB (295–330 nm) was found more harmful than higher doses of UVA in terms of morphological changes and opacification [5]. The UV wavelengths of sunlight that reach the Earth range from 295 to 400 nm [6]. However,

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Table 1. Characteristics of the IOLs

	Silicone IOL	Hydrophilic IOL	Hydrophobic IOL
Design	3-piece silicone IOL	single-piece acrylic IOL	3-piece acrylic IOL
Optic material	silicone elastomer	hydrophilic acrylic copolymer	hydrophobic acrylic copolymer
Haptic material	PMMA	acrylic	PMMA
Water content	<0.5%	25%	<0.5%
Refractive index	1.43	1.46	1.55

the phakic human eye is protected from these effects as wavelengths under 320 nm are absorbed by the cornea, while wavelengths between 320 and 400 nm are absorbed almost completely by the lens [7].

Recent developments in technology enabled to incorporate various UV-blocking agents in the intraocular lenses (IOLs) to protect the eye from UVA, UVB and UVC radiation after removal of the crystalline lens. Commonly used UV blockers are derivatives of benzotriazoles or benzophenones [8]. All these materials are incorporated into the polymer matrix during polymerization and to avoid gradual bleaching and loss of effectiveness over time.

The aim of our study was to determine the effect of UVB exposure on UV filters of IOLs manufactured from different optic materials.

Materials and Methods

Hydrophobic acrylic (Acrysof SA30AL, Alcon Laboratories, Tex., USA), hydrophilic acrylic (EuroCrystal, Toulouse, France) and silicone (Intraocular Optical International-IOI, Calif., USA) IOLs were included in the study. Table 1 summarizes the characteristics of these IOLs. Eight brand new samples of each type with the same power of diopters were provided for the study. The lot number of the lenses was ignored in order to make a randomized selection.

Four IOLs from each type were placed in a vial containing BSS solution and exposed to 1.4 J/cm^2 (2.40 mW/cm^2) UVB for 9.45 min. This procedure was repeated one more time after an interval of 4 weeks. The UVB dosage was based on the studies of Bardak et al. [9] and Michael et al. [10]. Waldmann 8001 K (Waldmann Lichttechnik GmbH, Schwenningen, Germany) was preferred as radiation source as it included broadband UVB wavelength. The wavelength of Waldmann 8001 K was 285–315 nm.

The remaining four IOLs from each of the three IOL types were selected as the control group. Both the UVB-exposed IOLs and the control group IOLs were placed in a closed cabinet in order to prevent exposure to additional sunlight during follow-up.

All IOLs were evaluated weekly for opacification and 16 weeks later for the presence of any calcium deposits and UV filter absorption rate using the double-blind method.

Gross and microscopic evaluations of the IOL for opacification were performed weekly by the same researcher (N.K.) and photographed under a light microscope (Zeiss Opmi Visu 200) for further comparison.

To analyze the absorption rates of UV filters, all IOLs were examined with a Varian spectrometer (Model Cary 50, instrument version 1.00, scan software 02.00, UV-Vis scan rate 24,000 nm/min, 5-nm data interval, UV-Vis average time 0.0125 s, dual beam mode with baseline correction; UV-Vis Varian Inc., Palo Alto, Calif., USA) at the end of 16 weeks.

All IOLs were air dried at room temperature in a dark room for 7 days preceding the cut sections, one of which was covered with gold-palladium for examination under scanning electron microscope (Philips XL 30 SFEG) and energy dispersive X-ray (EDX) microanalysis for elemental composition with EDX detector. The remaining sections were dehydrated and embedded in paraffin to obtain sagittal sections for staining by the von Kossa method to detect calcium.

Results

At the end of the study, both the UVB-exposed and control group IOLs were free from any opacification grossly and microscopically.

The UV filter analysis by spectrometer demonstrated different results for each IOL type. The hydrophobic IOLs in the UVB-exposed study group and control group had a similar absorption curve fitting nearly 300–350% absorption of UV light between 200–400 nm while showing a sharp decrease to less than 50% above 400-nm wavelengths (fig. 1a). The UVB-exposed hydrophilic acrylic IOLs presented a descending UV light absorption curve starting from 280% between 200–350 nm and becoming stable near 200% above 350 nm. In contrast, the absorption curve of the control hydrophilic acrylic IOLs demonstrated a nearly steady absorption curve around 350% between 200–350 nm; however, it decreased sharply to 100% after 400 nm, as with the hydrophobic IOLs (fig. 1b). As shown in figure 1c, the spectral analysis of the control silicone IOLs was also similar except for the sharp but longer decrease interval than the acrylic IOLs. However,

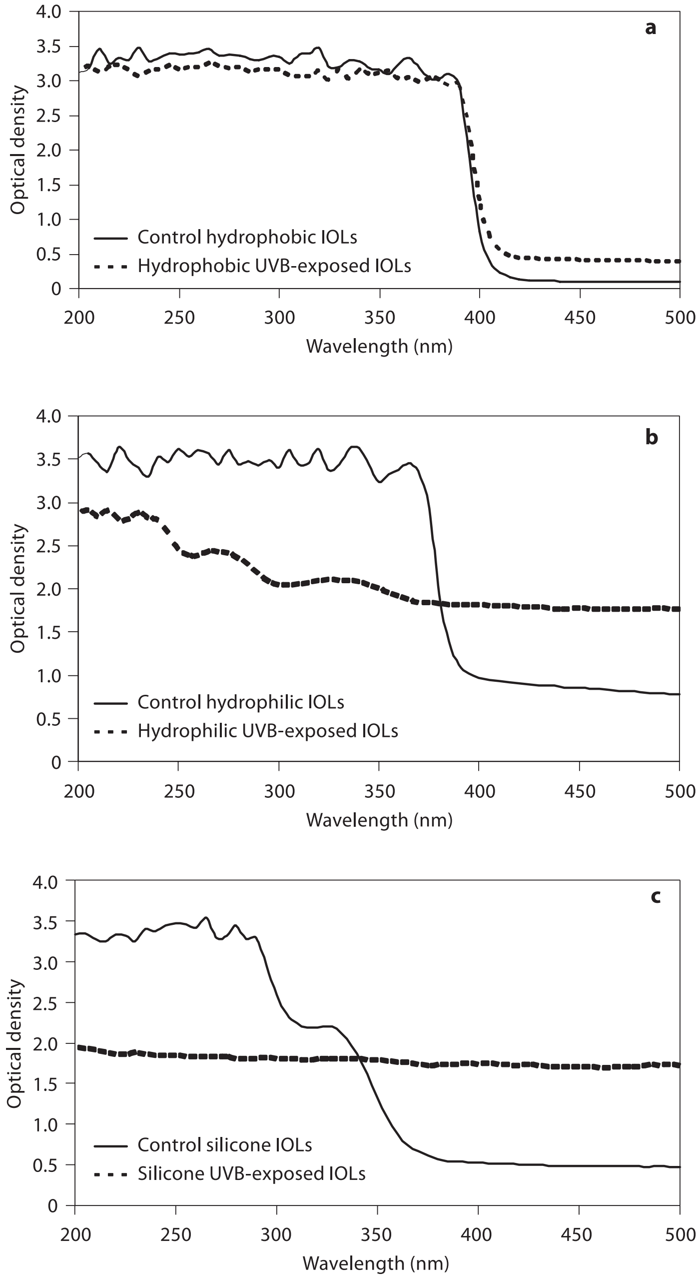


Fig. 1. Spectral analysis of the IOLs (the optical density of 1 means 100% absorption). **a** Hydrophobic IOLs. **b** Hydrophilic IOLs. **c** Silicone IOLs.

the UVB-exposed silicone IOLs had a fixed absorption percentage of 200% along the whole UV spectrum. These findings indicate that only hydrophobic acrylic IOL preserves its absorption curve after UVB exposure.

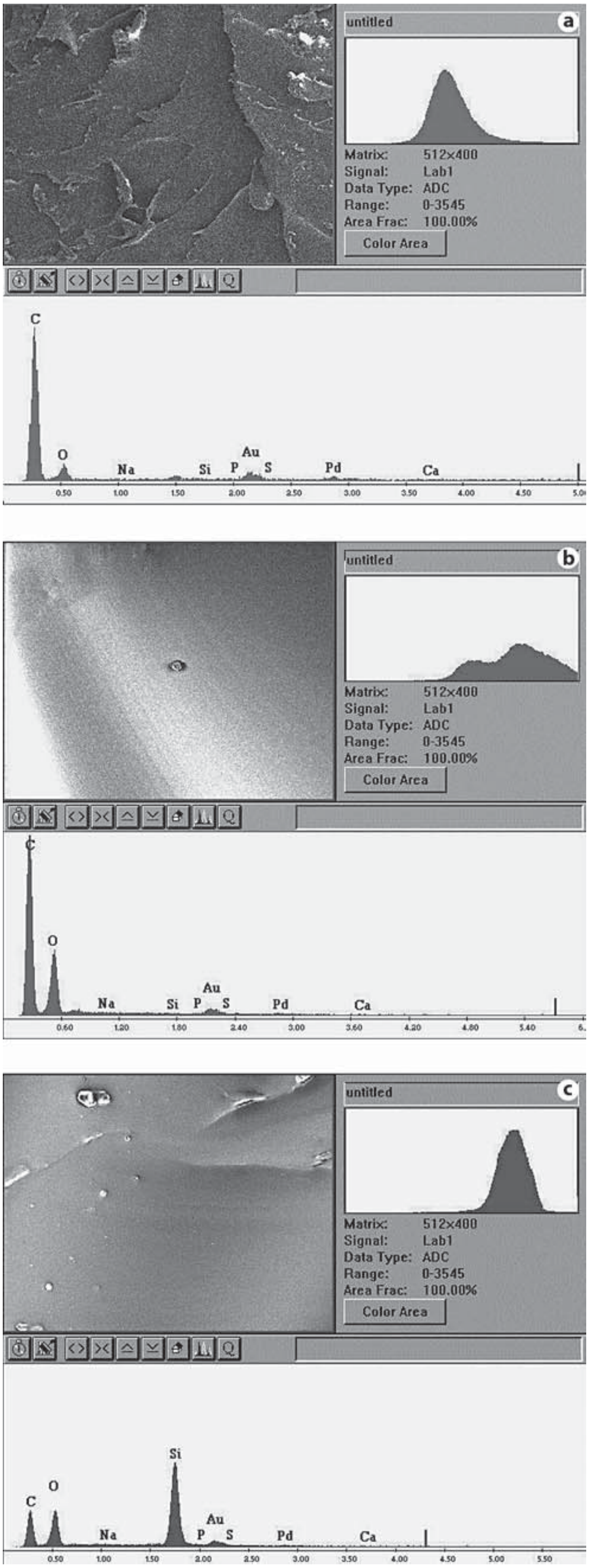
Scanning electron microscopy analysis of the cut sections (sagittal view) of the IOLs' optics confirmed that the whole optic area was free of deposits. EDX performed precisely on the same sections for all IOLs revealed the carbon and oxygen content of the hydrophilic and hydrophobic acrylic IOLs, and the carbon, oxygen and silicone content of the silicone IOLs. All lenses were covered with gold-palladium. Therefore, gold and palladium peaks were noted in all IOLs. The calcium and phosphate peaks were absent in all IOLs. The detailed data of the analysis are presented in figure 2a–c. Furthermore the von Kossa method did not detect a positive staining for calcium.

Discussion

Reports on optic vacuoles or opacification of different IOL designs have been published [11, 12]. These are: (1) glistening on hydrophobic acrylic lenses, (2) calcification within the optics and optical surfaces of hydrophilic acrylic lenses, (3) discoloration of the silicone lenses.

Clinically insignificant glistening of hydrophobic acrylic IOLs (Acrysof®) has been reported following surgery [13] and was thought to be caused by microvacuole formation within the lens polymer as the temperature exceeded the glass transition temperature. As water from the anterior chamber entered these vacuoles, the patient noted the glistening. These vacuoles disappeared when the IOL was dehydrated or dried [13, 14]. McKibbin et al. [15] reported transient fogging of hydrophobic acrylic IOL (Acrysof) caused by excessive heating prior to implantation and, when explanted, it became clear again.

Although the mechanism of intralenticular calcium precipitation of hydrophilic acrylic IOLs is not fully understood, Dorey et al. [16] noted that the opacification of Hydroview® hydrogel IOLs is associated with silicone, which was presumably derived from the Surefold packaging system. Silicone may act as a nidus for calcium deposits within these lenses, which is consistent with their results. Furthermore, Bausch and Lomb replaced the Surefold system in March 2001 with a newer system that does not utilize a silicone gasket, and received no reports of opacification [17–19]. Recently, Ghosh and Goodall [20] reported 5 cases with significant visual deterioration due to total opacification (optic and haptic) of a single-piece



Matrix: 512×400
Signal: Lab1
Data Type: ADC
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Fig. 2. a Scanning electron photomicrographs of the cut section of the hydrophobic acrylic IOL and EDX spectra of the lens optic coated with gold-palladium. **b** Scanning electron photomicrographs of the cut section of the hydrophilic acrylic IOL and EDX spectra of the lens optic coated with gold-palladium. **c** Scanning electron photomicrographs of the cut section of the silicone IOL and EDX spectra of the lens optic coated with gold-palladium.

hydrophilic acrylic IOL (Aquasense, Ophthalmic Innovations, Inc.) more than a year after uneventful phacoemulsification surgery. The whole lens had diffused opacification within its substance and was uniformly distributed in all cases. They found no apparent cause for the opacification. However, the majority of the patients with IOL opacification had an associated systemic disease; therefore, the possibility of a patient-related factor, such as metabolic imbalance in diabetes cannot be underestimated [21–24].

Pseudophakic eyes with brownish discoloration and central haze of silicone lenses have been reported as well [24–26]. This complication has been generally observed in the early postoperative period. Fortunately, they were clinically insignificant and IOL explantation has rarely been performed. These studies have suggested that the brown haze was due to the light scattered from water vapor that may have diffused into the silicone when immersed in an aqueous medium [25–27]. Tanaka et al. [28] reported a case of brown haze in a patient with SI-40NB® silicone IOL. They explanted the IOL upon the patient's request after the 15th postoperative day. Abnormal brown haze in silicone IOLs manufactured by Allergan has also been reported [28]. Chemical composition of the Allergan silicone IOLs and the sterilization method used were the causes of the haze formation [28, 29]. Wackernagel et al. [30] described opacification of a plate-haptic silicone IOL (Chiron Vision C10UB plate-haptic silicone lens) caused by calcification in a diabetic patient with asteroid hyalosis after Nd:YAG laser capsulotomy. Analysis of the lens surface showed calcium, phosphate, and oxygen on corresponding locations within a larger agglomeration of deposits. They reported that the pathogenesis of calcification and its precipitating factors remained unclear. Foot et al. [31] described an analysis performed on three silicone-plate IOLs (model AA4203, Staar Surgical, Monrovia, Calif., USA), which were explanted because of the presence of calcified deposits on their posterior surfaces observed at least 2 years after IOL implantation and after Nd:YAG laser capsulotomy. All of the patients had clinically observable asteroid hyalosis. X-ray spectroscopy analysis demonstrated the composition of the deposits to be similar to hydroxyapatite. They noted that the deposits were observed only on the posterior surface of the lenses. The material affecting the IOLs was probably derived from the asteroid bodies or from a similar process that resulted from this vitreous condition, because its composition was found to be similar to that of hydroxyapatite (calcium and phosphate). It appears that direct contact between the posterior IOL surface and the vitreous, promoted by the laser capsulotomies, accelerated the process of calcium precipitation in each case.

The other cause of the opacification of the IOLs is the degeneration of UV filtration material as reported by Frohn et al. [8] and Mattova et al. [32]. The UV radiation starting at 200 nm and up to 400 nm is harmful to the retina. To protect the retina of the human healthy eye, UVC radiation (200–290 nm) is absorbed by the cornea, UVB radiation (290–320 nm) is absorbed by the lens capsule, and UVA radiation (320–400 nm) is absorbed by the stroma of the lens [33]. After cataract surgery, a significant part of the natural UV filter function is lost. For this reason, a UV-blocking agent is incorporated routinely while manufacturing the IOLs. Mattova et al. [32] reported a histopathological and spectrophotometer analysis of two explanted opacified hydrophilic acrylic IOLs (MemoryLens U940A, Mentor Ophthalmics, Inc.) out of 205 eyes that underwent implantation of the same IOL. They also evaluated an unused IOL (MemoryLens U940A) as reference. Spectrophotometry showed the presence of the UV absorber on the benzophenone base in the reference lens but not in the opacified IOLs. In contrast, an increased concentration of low-molecular-weight components generated during the degradation of the polymer was present in the opacified lenses. The results of this study indicated opacification of the hydrophilic acrylic IOL was caused by premature consumption of the UV absorber in the polymer component of the IOL's optic, with a subsequent degradation of the polymer. Frohn et al. [8] analyzed six opacified IOLs (SC60B-OUV®) and one brand new IOL (SC60B-OUV) with a Varian spectrometer, model Cary 50. All opacified IOLs showed a high absorption rate in the UV spectrum, ranging from 200 nm to more than 370 nm, whereas the brand new IOL had a smooth absorption curve fitting with nearly 300% absorption of UV light. All explanted IOLs had sharp absorption peaks within the UV spectrum. They explained these spectroscopic findings as premature aging of the UV blocking agent incorporated in the lens biomaterial.

Parisi et al. [34] have shown that the percentage diffuse UV at each time varied with season. In full sun, the UVB averages were 39, 29 and 49% for the morning, noon and afternoon periods, and 26, 19 and 30% for UVA, respectively. Furthermore, in the study of Frohn et al. [8] all opacified IOLs showed a high absorption in the UV spectrum, ranging from 200 nm to more than 370 nm. This wavelength is close to UVB. Therefore, instead of a combination of UVA and UVB, we set this in vitro study in order to determine the effect of UVB exposure on UV filters of IOLs.

In this experimental study, the UV filter absorption rates analyzed by spectrometer showed different results for various IOLs. All the control IOLs and the UVB-exposed hydrophobic acrylic IOLs had a similar absorption curve fitting with nearly 300–350% absorption of UV light between 200 and 400 nm and showed a sharp decrease in absorption to nearly 100–50% after 400 nm.

However the UVB-exposed hydrophilic acrylic IOLs presented a descending absorption curve fitting with nearly 280–200% absorption of UV light between 200 and 400 nm. The UVB-exposed silicone IOLs also had a smooth absorption curve fitting with nearly 200% absorption of UV light between 200 and 400 nm. These two types of IOLs continued to have an absorption curve fitting with nearly 200% absorption of light after 400 nm.

In conclusion, we might say that high doses of UVB change the characteristics of the UV filters in the hydrophilic acrylic and silicone IOLs. They had less absorption of UV light than the control IOLs between 200 and 400 nm, and had more absorption of light than the control IOLs after 400 nm. Interestingly, high doses of UVB did not impair the spectroscopic findings of the hydrophobic acrylic IOLs and even the UVB-exposed hydrophobic acrylic IOLs showed similar absorption percentage of UV light as the control samples between 200 and 400 nm and also after 400 nm.

The spectroscopic changes observed in the UVB-exposed silicone and hydrophilic acrylic IOLs may cause some deterioration in the quality of vision in human eyes. But none of them showed opacification. As UVB doses from sunlight do not reach the doses used in this experimental study, these spectroscopic changes are not possible to occur clinically.

Additionally, based on the results of this study it is not possible to say that IOL opacification is related to premature aging of the UV blocking agent incorporated in the lens biomaterial.

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