VOLUME 6 | ISSUE 3

ORIGINAL ARTICLE Medical Physics

X-ray radiation affects the protection filter of yellow-tinted acrylic hydrophobic intraocular lenses against harmful UV-A and blue light

Ellas Spyratou[1], Ioannis Antonakos[1], Georgios Kareliotis[2], Constantinos Bacharis[2] and Efstathios Efstathopoulos[1]

[1]*2nd Department of Radiology, Medical School, National and Kapodistrian University of Athens, 12462, Athens, Greece.*
[2]*Physics Department, School of Applied Mathematical and Physical Sciences, National Technical University of Athens, Zografou Campus, 15780 Athens, Greece*

SUBMISSION: 17/02/2021 - ACCEPTANCE: 16/06/2021

ABSTRACT

Purpose: This study aims to investigate whether x-ray irradiation at doses delivered to the eye in plain radiography, CT and fluoroscopically guided procedures can affect the optical properties of yellow-tinted intraocular lenses (IOLs) implants in the near-Ultraviolet (UV-A) and visible (VIS) region.
Material and Methods: 5 yellow azodye doped IOL of different models and diopters were irradiated with x-rays ranging from 1.1 to 22.6 mGy. The transmission spectra of each IOL were recorded pre-irradiation and post-irradiation by using a light source for IOL illumination, a spectraflect-coated integration sphere for the spectrum collection and a UV/VIS spectrometer for the spectrum record.
Results: According to the recorded spectra, the transmittance of all the yellow-tinted IOLs increases systematically in the UV-A and blue light region as the irradiation dose increases. A linear dependence is recorded between the percentage increase of the transmittance and the increase in the irradiation dose at 380 nm.
Conclusions: Our findings determine that x-ray radiation affects significantly the filter of yellow-tinted IOLs for retina protection towards the natural exposure to the UV-A and short wavelength blue light.

CORRESPONDING AUTHOR, GUARANTOR

Efstathios Efstathopoulos
2nd Department of Radiology, General University Hospital "Attikon", Medical School, National and Kapodistrian University of Athens, 1 Rimini Str., Chaidari 12462, Athens, Greece. E-mail: stathise@med.uoa.gr

KEY WORDS X-ray radiation; Intraocular lenses; Transparency; Protective filter

Introduction

Human prosthetic lenses replacements are the most efficient technique to restore vision after cataract or in cases of high levels myopia or hyperopia. However, postoperative complications such as capsular opacification, considerable cloudiness or discoloration may appear 2-3 years after the surgery. The factors affecting the postoperative "life" of the intraocular lens (IOL) have not yet been fully clarified. It has been reported that the IOL's material [1, 2], the fabrication method of the IOL e.g. by injection moulding or lathe-cut [3], the eye exposure to UV light [4] have been correlated with postoperative complications. In modern cataract surgery the rigid IOLs made of conventional polymeric materials, such as Poly (methyl methacrylate) (PMMA), are replaced by foldable IOLs fabricated by flexible materials, such as silicone and hydrophilic or hydrophobic acrylates. However, several materials and patterns are still studied for the formation of IOLs to improve vision quality and to reduce the postoperative complications [5]. Modern IOLs stained with chromophores e.g. yellow-azo dyes which block the UV-A and blue-light radiation, are commonly used in cataract surgery. The main advantage of yellow-tinted IOLs is the reduction of chromatic aberration under photopic conditions and protection of the retina from phototoxic short-wavelength light, especially in eyes at risk of age-related macular degeneration (AMD) [6].

Economically well-developed countries usually perform 4000 to 6000 cataract operations per million population per year and this number is expected to increase extremely by 2030 [7]. Thus, there is a need to monitor not only the patients' eyes exposure to ionising radiation but also those of occupationally exposed medical staff who have IOL implants. Even though several epidemiological studies have been conducted on cataract frequency in relation to radiation doses for natural eye lens, very few studies have explored the effect of IR on the optical properties of implanted IOLs and the vision quality [8, 9]. Megavoltage photon ionising radiation for radiotherapy in the 2 Gy and 100 Gy range produce no significant alteration in the absorption spectra of undoped PMMA and silicone IOLs in the UV and visible range [8]. Gamma radiation at a dose of either 25 kGy or 35 kGy used for IOLs sterilisation was found to affect the absorption spectra of undoped PMMA IOLs in the UV and visible spectral region and causing PMMA chain scission, decarboxylation and colour change [9].

To the best of our knowledge, this is the first time that the effect of x-rays on the protective filter of yellow-tined IOLs is examined for low-dose radiation delivered to patient's eye during plain radiography, computed tomography (CT) and fluoroscopically guided procedures [10-12]. Preliminary measurements have been taken addressing the effect in a prior published work in even higher doses used in cerebral embolisations or interventional neuroradiology and in the blue light region [13]. This study focuses on the alterations to the transparency of yellow-tinted IOLs' protection filter in the harmful UV-A and blue light region after exposure to x-ray irradiation, as these wavelength regions are transparent from the human cornea and can be absorbed from the natural human lens (UV-A) or reach the human retina (blue light) [14, 15].

Material and Methods

5 yellow azo-dye doped IOLs (2 SN60AT and 3 SN6AD from Alcon) which are widely used in cataract surgery were irradiated in air at a radiographic unit (AGFA DR 600) with doses ranging from 1.1 to 22.6 mGy. The doses measured by a suitable dosimeter (Piranha RTI Electronics AB), calibrated at energies between 50 to 140 keV. These doses can be delivered to patient's eye during plain radiography, CT and fluoroscopically guided procedures, e.g. interventional neuroradiology and cardiology for diagnostic and therapeutic uses [11]. The transmission spectra of the IOLs were recorded pre-irradiation and post-irradiation using a 360 - 2400 nm Tungsten Halogen lamp (LS-1, Ocean Optics) as light source. A Labsphere integrating sphere (819C-SF-6, NRC Newport Research) with spectraflect coating was connected with a USB 4000 ultraviolet/visible (UV/VIS) spectrophotometer (Ocean

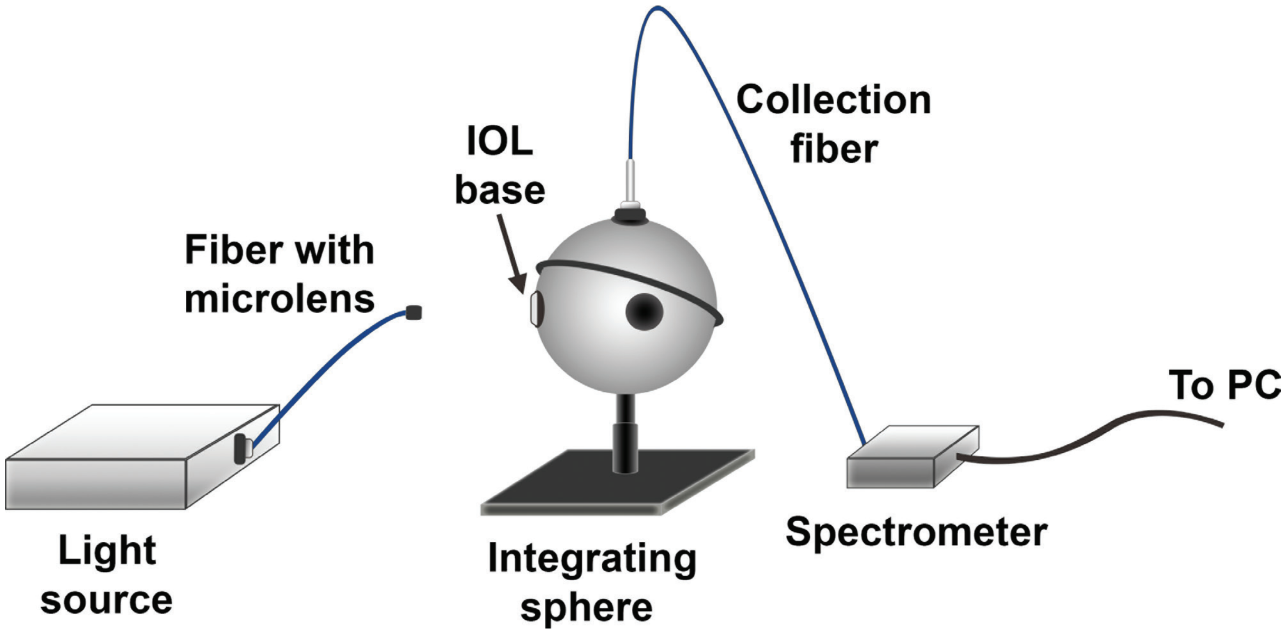

Fig. 1. *Schematic image of the experimental set-up for the transmission measurements of the IOLs*

optics) with operating wavelength range from 360 to 1100 nm. The IOL was adjusted to the port of the integrating sphere by using a plastic custom-made base to hold the haptics of the IOL. The light source was related to a UV/VIS optical fiber coupled with a microlens at the edge to focus the light on the IOL surface. Another optical fiber was adjusted perpendicular to the integration sphere to collect the diffused light. The collected signal was analyzed by the spectrometer and was processed by spectrum-analysis software (SpectraSuite, Ocean optics) (**Fig. 1**) [13]. This integrating-sphere configuration offers consistent transmission measurements of IOLs with varying lens power in comparison with other measurements set-ups like double-beam model [16].

The transmission spectrum of each IOL was recorded over the operation spectrum range of the spectrometer from 360 to 1100 nm. However, the region from 380 - 900 nm was selected for analysis as the signal noise was increased at the spectrum regions close to the response of the spectrophotometer. A dark spectrum was recorded as a background correction with an empty plastic base and a light trap cover placed in the port of the sphere to block the light. A reference spectrum was recorded by replacing the light trap cover with the spectraflect cover to ensure 100% transmittance [13].

The transmittance was calculated according to the equation:

$$T_{(\lambda)} = \frac{I_{S(\lambda)} - I_{D(\lambda)}}{I_{O(\lambda)} - I_{D(\lambda)}} \cdot 100\%$$

where, I_D is the intensity of the dark spectrum recorded by the spectrometer with the light source blocked by the light trap cover, I_o is the reference light intensity passing through the empty plastic base and I_s is the intensity spectrum recorded with the IOL placed in the plastic base and illuminated by the light source.

Results and Discussion

(**Fig. 2.**) illustrates the pre- and post-irradiation transmission spectrum of the five IOLs in the region from 380 to 900 nm at the respective irradiation doses 1.1 mGy, 5.5 mGy, 11 mGy, 14 mGy and 22.6 mGy. According to the spectra graphs, the transmittance of the IOLs pre-irradiation (0 mGy) is close to zero in the UV-A light region due to the yellow protection filter of the IOLs, then increases almost linearly in the spectrum region from 400 to 550 nm and reaches to a plateau of approximately 90% in the spectrum region from 550 to 900 nm. Some spikes which appear are attributed to signal noise of the spectrophotometer. After the x-ray irradiation, the transmittance of the yellow azo-dye doped IOLs is raised in the UV-A and blue light region of 380-450 nm and in

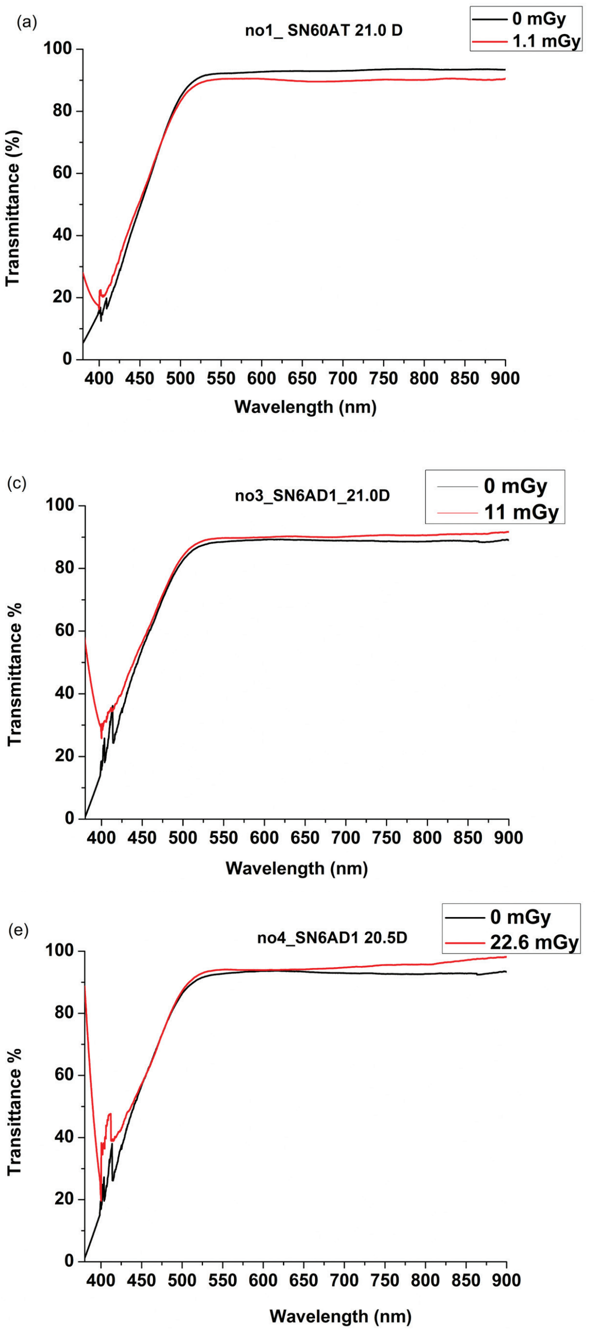

Fig. 2. (a)-(e). *Pre- and post-irradiation total transmittance spectra of intraocular lens in the region of 380 - 900 nm at irradiation doses* ***a.*** *1.1 mGy,* ***b.*** *5.5 mGy,* ***c.*** *11 mGy* ***d.*** *14 mGy,* ***e.*** *22.6 mGy, respectively.*

the VIS/NIR spectrum range of 550-900 nm reaches to a plateau close to 90%.

The comparison of the transmission spectra of each IOL pre- and post-irradiation shows that in the UV-A and blue light region there is a systematically increase of the transmittance as the irradiation dose increases. Statistically significant difference was observed in all the cases between pre- and post-irradiation transmission spectra by using the nonparametric Wilcoxon test. P values less than 0.05 were considered significant. **Fig. 3** demonstrates a linear dependence between the percentage increase of transmittance and the irradiation dose at 380 nm.

Yellow-tinted hydrophobic acrylic IOLs are designed to reduce the absorption of phototoxic UV and short wavelength (400 – 500 nm) visible light by adding a yellow dye to the IOL and a UV blocking material. UV-A poses to induce thymine dimerisation in human reti-

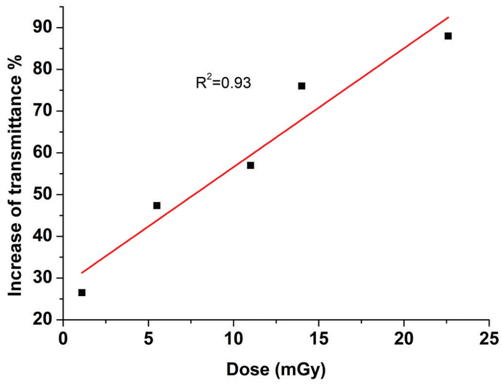

Fig. 3. *Percentage change of the transmittance of each intraocular lens vs irradiation dose in the UV region, at 380 nm.*

nal melanocytes, DNA to protein cross-links and single-strand breaks DNA in cultured human cells [8, 17]. Over exposure to blue light could cause cell apoptosis in retinal neurocytes and retinal ganglion cells and photoreceptor degeneration [18, 19].

Combining our current and previous published results, it is obvious that the yellow azo-dye IOLs show a different transmission behavior in the UV-A and blue light region even at low- or high-level exposures to ionising irradiation. In all irradiation doses the transmittance of the yellow azo-dye doped IOLs was increased both in the UV-A and in the blue light region and reaches to a plateau of approximately 90% in the visible-near infrared spectrum region from 550 to 900 nm. On the contrary, the transmittance of white IOL (undoped IOL) is not affected even at very high irradiation dose [9]. The same findings arise from other studies conducted by UV-visible spectrometry on undoped IOLs made of poly(methyl methacrylate) (PMMA) or silicon irradiated by megavoltage photon irradiation used in radiotherapy [8]. To our knowledge, this is the first time that the effect of x-rays on yellow azo-dye doped IOLs filter protection is examined by our research team and moreover at low irradiation doses. The IOLs were exposed to doses consistent with the measured eye lens doses which the occupational medical staff can receive annually [12].

Our results reveal that x-ray irradiation affects the protection filter of the yellow azo-dye doped IOLs against the harmful for the retina UV-A radiation and blue light regardless of their model or their diopter. Ionising radiation even at low doses is able to alter the optical properties of the yellow azo dye (R-N=N-R') which is incorporated into the acrylic IOL. It has been demonstrated that ionising radiation causes discoloration, decomposition and degradation of azo dyes [20].

This effect should be considered by the medical staff and patients who wear yellow-tinted IOLs and are exposed to ionising radiation during diagnostic and therapeutic procedures. Even if the effective dose which patients receive through head CT scans is lower compared to thoracic, abdominal or pelvic scans, the radiation dose delivered to the eye lens during head scanning is high enough. In monophasic head CT scans the eye lens dose can range from 0.07 Gy up to 0.13 Gy depending on the head region [21].

One way to protect the patient's IOL in lower dose procedures would be the use of appropriate x-ray shielding for the eyes. For head diagnostic procedures (e.g. x-ray radiography or scans) substitution methods should be considered (e.g. magnetic resonance imaging - MRI), if applicable; while for body scans (e.g. CT scans) close to the head area the use of protective eyeglasses is proposed. The use of radioprotective bismuth garments to shield the patient's eyes can result to a significant reduction in eye lens doses. A reduction around 34% was estimated for CT scans by using anthropomorphic phantoms, when eye globes were entirely included [22, 23]. However, when eye bismuth shields are used, artifacts can appear. The image quality deterioration can be reduced by using a topogram-based tube current modulation (TCM) instead of a fixed tube current [24].

As far as higher dose schemes, like therapeutic procedures, are concerned (e.g. radiotherapy), the medical physicists should take into account the above mentioned phenomenon during the treatment planning, if possible. Certainly, the prescribing physician along with the medical physicists should balance the pros and cons of the use of protective eye-ware for the patient, since they may affect the dose distribution and hence the treatment outcome. Studies on the effect of ocular implants of various materials on the dose distribution of photon beam have shown beam attenuation [25]. An optimal design of dose planning could be a coupling between the imperative need for the right treatment and the use of appropriate x-ray shielding for the eyes. This can prevent the possible alteration of IOL's protective filter avoiding the development of age-related macular degeneration and reducing the possible glare [26]. Finally, the occupational medical staff should wear eye-protecting glasses during all IR involving procedures.

Conclusions

IOLs stained with chromophores e.g. yellow-azo dyes have become part of the modern cataract treatment for vision restoration. X-ray irradiation of yellow-tined acrylic hydrophobic IOLs react on the filter protection of the IOLs even at low doses and this should be considered as one of the factors that can affect the post-operative "life-expectancy" of the IOL and the quality of vision. The medical staff and patients which wear yellow-tinted IOLs and are exposed to ionising radiation during diagnostic and therapeutic procedures should be informed about this. Moreover, other types of material of IOLs filters less radiosensitive could be a new subject of research in the field of IOLs fabrication. **R**

Funding

This project did not receive any specific funding.

Conflict of interest

The authors declared no conflicts of interest.

References

1. Sen HN, Sarikkola A U, Uusitalo RJ, et al. Quality of vision after AMO Array multifocal intraocular lens implantation. *J Cataract Refract Surg* 2004; 30: 2483–2493.
2. Javitt JC, Steinert R F. Cataract extraction with multifocal intraocular lens implantation: a multinational clinical trial evaluating clinical functional, and quality-of-life outcomes. *Opthalmology* 2000; 107: 2040–2048.
3. Kraff MC, Sanders D, Lieberman H L. Serial corneal endothelial cell loss with lathe-cut and injection-molded posterior chamber intraocular lenses. *J Am Intraocul Implant Soc* 1983; 93: 301–305.
4. Linetsky M, Raghavan CT, Kaid J, et al. UVA light-excited kynurenines oxidize ascorbate and modify lens proteins through the formation of advanced glycation end products: implications for human lens aging and cataract formation. *J Biol Chem* 2014; 289: 17111-23.
5. Sathyan S. Advanced technology intraocular lenses: Current trends. *Kerala J Ophthalmol* 2020; 3:112.
6. Ardjomand N, Wirtitsch M G, Wenzl E. Yellow Intraocular lenses-to block or not to block. *European Ophthalmic Review* 2009; 3: 77-9.
7. Foster A. VISION 2020: The cataract challenge. *Community Eye Health* 2000; 13: 17–19
8. Ellerin BE, Nisce L Z, Roberts C W, et al. The effect of ionizing radiation of intraocular lenses. *Int J Radiation Oncology Biol Phys* 2001; 51: 184–208.
9. Pratt CM, Barton S, McGonigle E, et al. The effect of ionising radiation on poly (methyl methacrylate) used in intraocular lenses *Polymer Degradation and Stability* 2006; 91: 2315-2317.
10. Spyratou E, Antonakos I, Platoni K, et al. Investigating the Effect of Ionizing Radiation on Intraocular Lenses at Clinical Doses. *Insights Med Phys* 2017; 2: 1-5.
11. Moritake T, Matsumaru Y, Takigawa T, et al. Dose measurement on both patients and operators during neuro interventional procedures using photoluminiscence glass dosimeters. *AJNR Am J Neuroradiol* 2008; 29: 1910–17
12. Sánchez RM, Vañó, E, Fernández J M, et al. Radiation Doses in Patient Eye Lenses during Interventional Neuroradiology Procedures *AJNR Am J Neuroradiol* 2016; 37: 402-407
13. Vanhaverea F, Carinoub E, Domienikc J, et al. Measurements of eye lens doses in interventional radiology and cardiology: Final results of the ORAMED project *Radiation Measurements* 2011; 46: 1243-1247.
14. Sarna T, Rozanowska M. Phototoxicity to the eye. In: Jori G, Pottier RH, Rodgers MAJ, Truscott TG (eds) *Photobiology in Medicine*. New York: Plenum Press; 1994, pp125-142.
15. Glickman RD. Phototoxicity to the Retina: Mechanism of Damage. *International Journal of Toxicology.* 2002; 21: 473–490.
16. Akinay A, Ong MD, Choi M, et al. Measuring ul-

traviolet-visible light transmission of intraocular lenses: Double-beam mode versus integrating-sphere mode. *J Biomed Opt* 2012; 17: 105001-105007.

17. Peak JG, Peak M J. Comparison of initial yields of DNA-to protein crosslinks and single-strand breaks induced in cultured human cells by far- and near-ultraviolet light, blue light and X-rays. *Mutat Res* 1991; 246: 187-191.
18. Chen P, Lai Z, Wu Y, et al. Retinal Neuron Is More Sensitive to Blue Light-Induced Damage than Glia Cell Due to DNA Double-Strand Breaks. *Cells* 2019; 8: 68-82.
19. Narimatsu T, Ozawa Y, Miyake S, et al. Biological effects of blocking blue and other visible light on the mouse retina. *Clin Exp Ophthalmol* 2014; 42: 555-63.
20. Rauf MA, Ashraf S S. Radiation induced degradation of dyes-An overview. *Journal of hazardous materials* 2008; 166: 6-16.
21. International Commission on Radiological Protection, Managing Patient Dose in Computed tomography, in *Ann ICRP 2000* Pergamon Oxford, 2000d, *ICRP Publication* 87, Vol. 30, Issue 4.
22. Perisinakis K, Raissaki M, Theocharopoulos N, et al. Reduction of eye lens radiation dose by orbital bismuth shielding in pediatric patients undergoing CT of the head: a Monte Carlo study. *Med Phys,* 2005; 32: 1024-30.
23. Raissaki M, Perisinakis K, Damilakis J, et al. Eye-lens bismuth shielding in paediatric head CT: artefact evaluation and reduction. *Pediatr Radiol* 2010; 40: 1748-54.
24. Lee YH, Yang SH, Lin YK, et al. Eye Shielding During Head CT Scans: Dose Reduction and Image Quality Evaluation. *Acad Radiol* 2020; 27: 1523-1530.
25. Fontenla DP, Ahmad M, Chui CS, et al. Effect of ocular implants of different materials on the dosimetry of external beam radiation therapy. *Int J Radial Oncol Biol Phys* 1995; 32: 1477–1480.
26. Downes S M. Ultraviolet or blue-filtering intraocular lenses: What is the evidence? *Eye* 2016; 30: 215-21.

READY - MADE CITATION

Spyratou E, Antonakos I, Kareliotis G, Bacharis C, Efstathopoulos E. X-ray radiation affects the protection filter of yellow-tinted acrylic hydrophobic intraocular lenses against harmful UV-A and blue light. *Hell J Radiol* 2021; 6(3): 2-8.