www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

Arch. Metall. Mater. **66** (2021), 2, 477-481

DOI: 10.24425/amm.2021.135881

K. JEŻ[1*], M. GACEK[1], M. NABIAŁEK[1], L. TOTH[2], M. PIKE-BIEGUNSKI[3]

OPTICAL PROPERTIES OF INTRAOCULAR IMPLANTS COATED WITH SILVER NANOPARTICLES

Prolonged exposure to UV radiation, and ever-increasing life expectancy, mean that an increasing proportion of the population suffers from clouding of the intraocular lens. Nowadays, the performance of intraocular implantation procedures is commonplace. Unfortunately, with the increasing number of operations, the number of postoperative complications is also increasing. One way to avoid complications may be to use an intraocular implant that has been immersed in a solution containing silver nanoparticles. As part of the study, four selected intraocular implants – that are available on the ophthalmic market – were tested. In order to investigate the effect of silver particles on the optical properties of the implants, tests were carried out using a UV-VIS spectrophotometer. Two series of implants were tested: before and after immersion in a silver solution. The implants were immersed for a period of 7 days. It was found that the presence of silver particles does not have a negative impact on the translucency of the implants.

Keywords: UV-Vis spectroscopy, intraocular lenses, silver nanoparticles

1. Introduction

An intraocular implant is a lens that is implanted into the human eye. Usually, such an implant is implanted after cataract surgery in order to obtain correction of lenslessness. The material from which intraocular lenses are made exhibits properties that can focus or scatter light rays. The lenses are made of plastics with differing properties but all showing good transmission in the visible region of the light spectrum.

The construction of implants is very complex and depends largely on the particular manufacturer. It should be noted, however, that intraocular implants must always have a kind of stabilizer, commonly known as a haptic [1]. Most lenses feature a pair of haptics placed adjacent to the periphery of the implant. Haptics are usually made from PMMA, polyamide or polyvinylidene fluoride PVDF. With the exception of the PMMA lens, these haptic materials are harder than the lens itself. In the central part of the intraocular lens there is an optical part, the size of which is usually approximately 6 mm and its optical power is selected appropriately in relation to the entire optical system of the eye. Most of the intraocular lenses currently used have a UV (ultraviolet) filter that stops harmful radiation from entering the eye [2-4].

Materials from which intraocular lenses are made can be divided into two groups: hard and soft. The ‘hard’ group includes PMMA (polymethyl methacrylate) and the ‘soft’ group includes: silicone, acrylic, hydrogel and Collamer [5,6]. The use of soft, so-called ‘foldable’ implants allows for much easier implant application. During the procedure, it is necessary to make a 1.8 mm incision, while for hard lenses it is about 6 mm [7].

The problem of postoperative complications is increasing in frequency, due to the very large number of procedures performed on a European scale [8-10]. Despite the strictest precautions, thousands of people – especially the elderly – suffer from complications after implant surgery. Due to devices that emit harmful UV radiation, and the human population’s ever-increasing average life expectancy, the number of intraocular implants will tend to increase. Therefore, intensive research is underway to solve the problem of complications.

Any material, from which intraocular implants are made, is exposed to bacteria and fungi. The implant itself does not ensure sterile application in the posterior or anterior chamber of the eye. The surface of each intraocular lens is not even and has some surface treatment. The roughness can be sufficient for encouraging the growth and multiplication of parasites.

---

[1] CZESTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF PRODUCTION ENGINEERING AND MATERIALS TECHNOLOGY, DEPARTMENT OF PHYSICS, 19 ARMII KRAJOWEJ STR., 42-200 CZĘSTOCHOWA, POLAND
[2] ÓBUDA UNIVERSITY, BÁNKI DONÁT FACULTY OF MECHANICAL AND SAFETY ENGINEERING, MATERIAL SCIENCE DEPARTMENT, 1081, NÉPSZÍNHÁZ 8, BUDAPEST, HUNGARY
[3] NANO KOLOID SP Z O. O, HOŻA 62/37, 00-682 WARSZAWA, POLAND

* Coressponding author: kingagagor@o2.pl

One solution may be the use of silver particles [11-13]. The bactericidal properties of silver have been known for many years. Silver particles are used, for example, in wound dressings. However, ingestion of silver into the body can negatively affect human health. Excess silver accumulates under the skin, which leads to untreatable silver disease. It is possible to use silver particles during implant production or just before the planned surgery for the prepared implant. Due to the location of the intraocular lens and the lack of blood vessels in this area of the eye, the risk of silver particles entering the body is reduced significantly.

It is well known that silver has the highest light reflectance among metals. Therefore, the arrangement of silver nanoparticles on the implant can have a significant impact on the resulting optical properties of the latter. The aim of this study was to determine the effect on light transmittance of immersion of intraocular lenses in silver solution.

2. Experimental

Four intraocular implants, that are available on the ophthalmic market, were selected for testing. Table 1 presents the characteristics of the investigated implants. Implants made from different materials were selected. The lenses were immersed in a solution of silver nanoparticles. The solution contained 25 ppm of plate-shaped silver particles. The silver particles had an average size of 3.5 nm and a thickness of several atomic layers. A physically prepared solution was used – the silver particles were in a non-ionic form. The implants were left immersed in the solution for a period of 7 days. All tested implants feature anti-UV and hydrophobic coatings.

TABLE 1

Characteristics of the investigated implants

No.	Implant material	Haptic material	Layers	Thickness/ Diameter [mm]
1	PMMA	PMMA	Anti-UV/Hydrophobic	2.2; 5.67
2	Acrylic	PMMA	Anti-UV/Hydrophobic	2.3; 6
3	Acrylic	PMMA	Anti-UV/Hydrophobic	2.3; 6
4	Acrylic	PMMA	Anti-UV/Hydrophobic	2.4; 6

Figure 1 shows the absorption of silver nanoparticles.

Silver nanoparticles exhibit radiation absorption in the UV range and in part of the visible range [15,16]. Due to the process of absorption, a reduction in the transmission level could be expected in the range of wavelengths corresponding to the UV radiation spectrum and part of the visible light spectrum. The intraocular implants were subjected to light transmittance tests. The optical properties of the implants were tested using a UV-VIS spectrophotometer [18]. The transmittance was measured at room temperature in the visible light range, in infrared and ultraviolet (the range of tested wavelengths was: 190-900 nm). The implants were glued to the device holder with double-sided tape. "Wet" implants taken directly from the packaging and silver solutions were tested. The transmittance measurements were repeated twice for each implant.

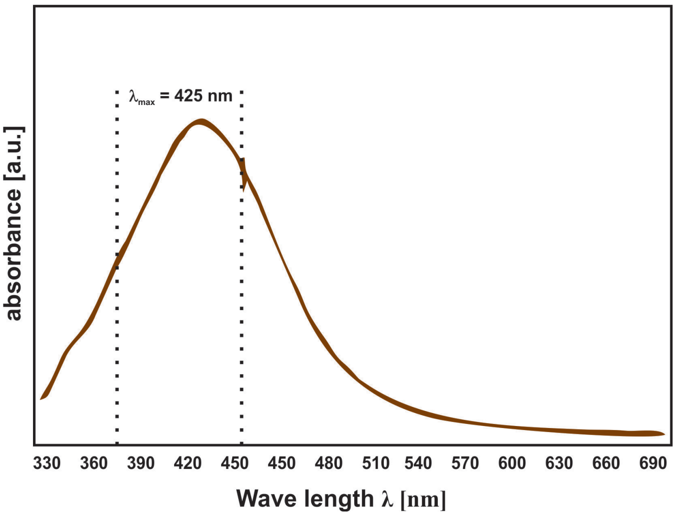

Fig. 1. Absorbance for silver nanoparticles in the range 330-690 nm [14]

3. Results and discussion

Figure 2 shows the transmittance curves, measured for implants after removal from their original packaging.

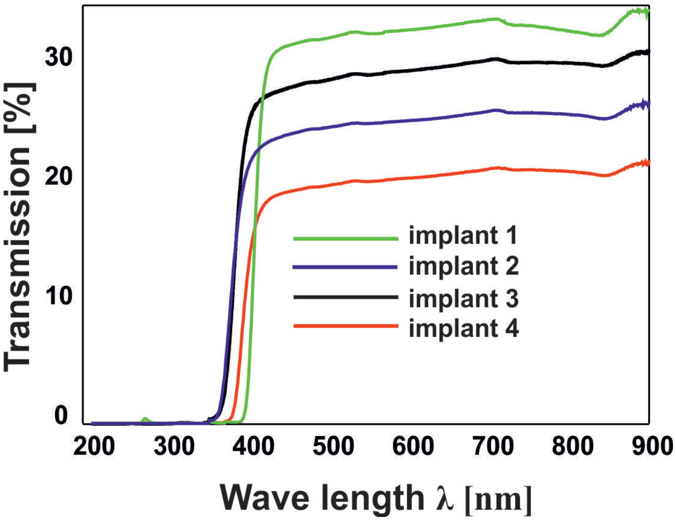

Fig. 2. Transmittance for original lenses

The tested implants were found to have low visible transmission values. Only an implant made from PMMA provided transmission of greater than 30%. Other lenses yielded lower transmittance values. Lens Number 4 had a transmittance of only 20%. Despite the differences in the amount of transmitted radiation, it should be stated that all of the tested materials showed a similar transmittance course in the tested range. In the wavelength range corresponding to ultraviolet radiation, the lenses showed almost complete absorption of radiation. The value of transmittance increased rapidly for the range of wavelengths to

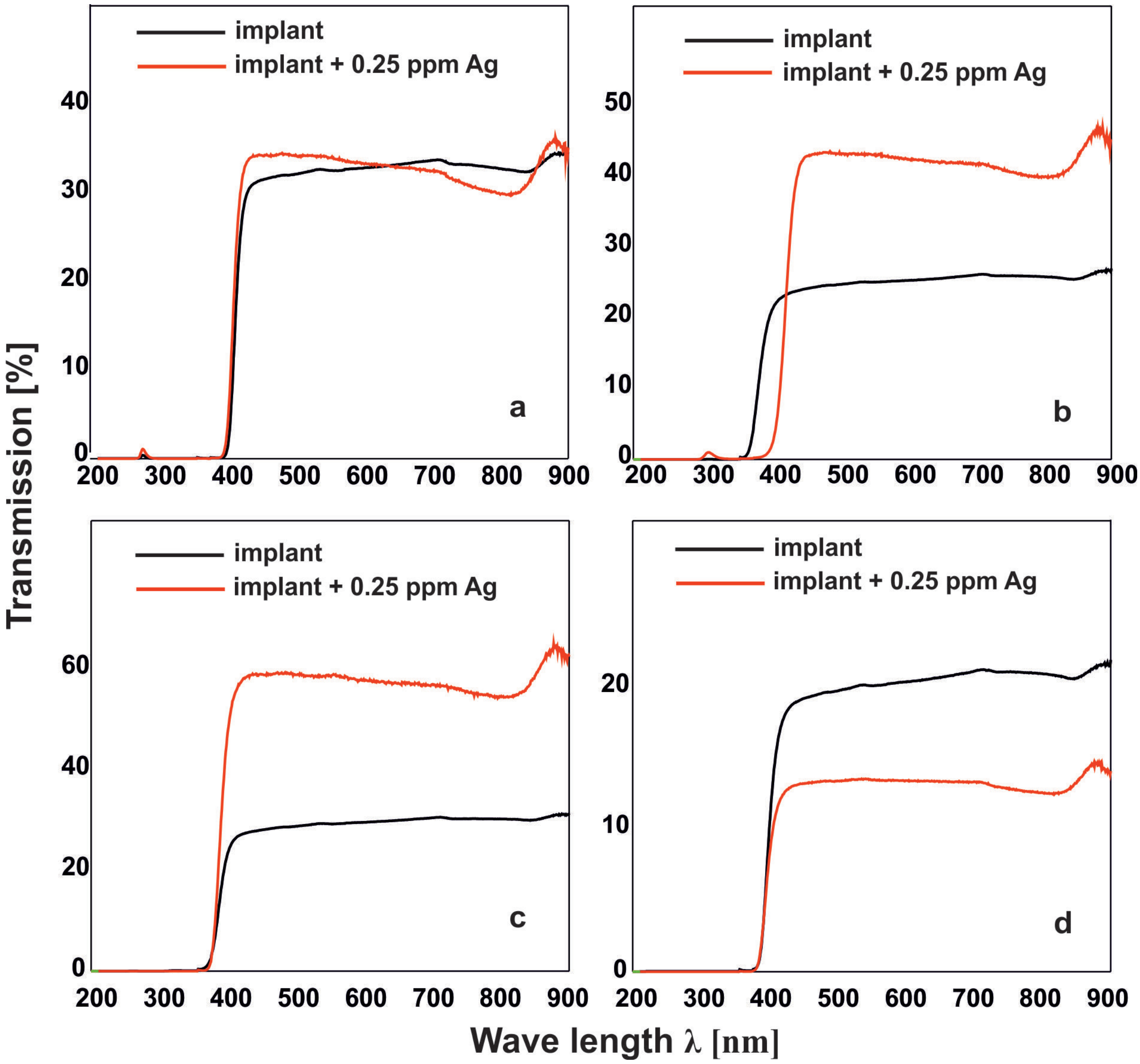

Fig. 3. Transmittance for tested implants, before and after soaking in silver solution: a) implant No. 1, b) implant No. 2, c) implant No. 3, d) implant No. 4

which the human optical system is optically sensitive. Figure 3 shows the transmittance measured for implants, before and after immersion in silver solution.

The nanometric size of the silver particles and their relatively low concentration in the solution means that they should not have a significant impact on the transmittance. However, the presented research results show that the optical properties of the implants do change slightly after immersion in the silver solution. An immersion in a solution with a silver concentration of 25 ppm increased the transmittance in some ranges. The trajectories of transmittance curves for lenses after immersion in the silver solution are significantly different, compared with the curves recorded before immersion. After reaching a maximum value for an electromagnetic wavelength of approximately 420 nm, the transmittance begins to decrease, up to a wavelength of 800 nm, after which the transmittance increases again. The smallest differences between the transmittance values, recorded before and after immersion in the silver solution, were recorded for an implant made of PMMA. In the case of implant number 4, silver particles reduced the transmittance over the entire tested wavelength range. Interestingly, a significant increase in the level of transmittance in the visible light range was observed for implant numbers 2 and 3. In addition, in the case of implant number 2, immersion in the silver solution effected almost complete absorption of electromagnetic radiation of wavelengths up to 400 nm. Figure 4 shows the transmittance for the implants after immersion in the silver solution. Table 1 summarizes the transmittance values for the characteristic wavelengths.

For radiation with a wavelength corresponding to the conventional beginning of the UV-A radiation range (315 nm), all implants tested both before and after immersion exhibit almost complete absorption or reflection of the light. For the 380 nm wavelength (the conventional end of the UV-A radiation range) in the case of acrylic lenses, the immersion yielded different results. The presence of silver reduced the harmful radiation for implant 2. In implant 3, bathing in a 25 ppm solution resulted in increased transmission. The same relationship was found for implant 4. The lens made of PMMA was found to give the

TABLE 2

List of transmittances for characteristic wavelengths

Implant No.		Maximum transmittance [%]	Transmittance for 555 nm [%]	Transmittance for 315 nm [%]	Transmittance for 380 nm [%]
1	Implant	34.72	32.63	0.02	0.09
	+ 25 ppm Ag	35.24	33.91	0	0.08
2	Implant	27.03	25.13	0	13.81
	+ 25 ppm Ag	45.06	43.1	0.30	0.35
3	Implant	31.30	29.22	0.13	12.92
	+ 25 ppm Ag	62.36	58.46	0	22.43
4	Implant	22.08	20.28	0.03	1.35
	+ 25 ppm Ag	14.22	13.56	0	1.56

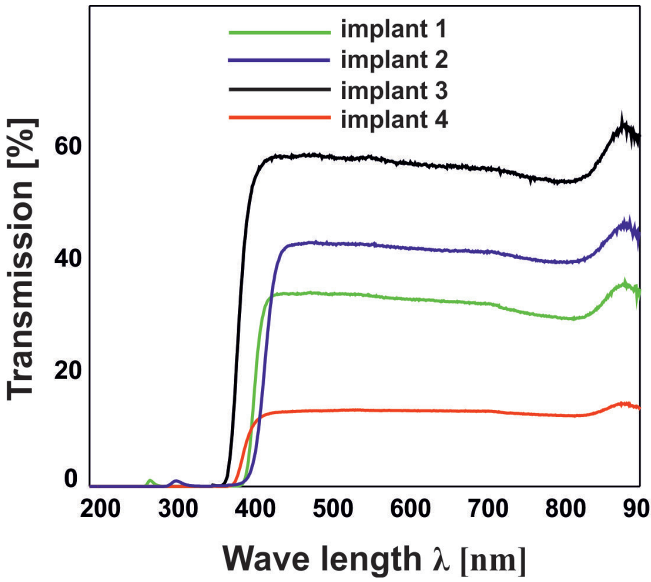

Fig. 4. Transmittance for implants, after immersion in a 25 ppm silver solution

TABLE 3

Electromagnetic radiation absorption threshold

Implant No.		Radiation absorption threshold [nm]
1	Implant	—
	+ 25 ppm Ag	251
2	Implant	294
	+ 25 ppm Ag	282
3	Implant	214
	+ 25 ppm Ag	340
4	Implant	200
	+ 25 ppm Ag	348

optimum performance of the group of samples, absorbing or reflecting harmful UV radiation over virtually the entire spectrum range – regardless of immersion. The human eye shows maximum sensitivity to 555 nm wavelength radiation (photopic vision). In the case of the tested implants, silver particles increase the transmittance for this wavelength – with the exception of implant number 4. The data in Table 2 shows that, due to the level of transmittance in the range of visible light and UV radiation, the best properties are exhibited by the implant made from PMMA. The lens provides light transmission for photopic vision at a level well above 30% and virtually complete absorption of UV radiation. In addition, it can be stated that the optical properties of the implant made from PMMA are less dependent on the immersion than those of acrylic lenses. Implant 3 does not protect the retina of the eye to a satisfactory degree (there is a significant value of transmittance for 380 nm wavelength) even despite immersion. Table 3 shows the thresholds for complete absorption or reflection of electromagnetic spectrum waves in the tested range.

Based on the data presented in Table 3, it can be concluded that the presence of silver nanoparticles on implants may have a positive (although not very significant) effect on the protection of the optical system against UV radiation.

It should be noted that the amount of light transmitted through the implants is relatively small. The optical system of a healthy human eye, consisting of the cornea, lens and vitreous humour provides transmittance of up to 90% behind the lens and up to 50-90% before the retina. Because of this, low levels of light transmission through implants may not provide optimal visual comfort. The surgical removal of a degraded (cloudy) lens and its replacement with an implant is, however, the only way to restore vision.

The human optical system absorbs a proportion of the harmful UV radiation, to some extent. Short wavelength radiation is scattered by the cornea while the UV-A range is absorbed in the lens. Due to the above, intraocular implants should also be required to block wavelengths of 300-400 nm. Transmission of significant amounts of ultraviolet light in the UV-A range can lead to retinal degeneration. Therefore, it is extremely important that modern implants provide the best protection against radiation in this area. Manufacturers are increasingly proposing additional filters to protect the retina from blue light (i.e. absorption of radiation up to 475 nm). The blue light chromophores used cause the lens to turn yellow. Unfortunately, this solution can cause the deterioration of visual comfort: night vision problems and deterioration of colour vision.

An implant made of PMMA shows the best parameters with respect to transmission. Unfortunately, the disadvantage of this type of implant is its high rigidity. A large incision (several millimetres) must be made during the surgical procedure to implant the lens, while a 1.8 mm cut would be sufficient for curl lenses made of acrylic material.

4. Conclusions

The study investigated the influence of silver particles on the optical properties of intraocular implants. In most cases, implants subjected to immersion in a silver solution have a higher transmittance value in the visible light range and a lower transmittance value in the wavelength range corresponding to UV radiation. It is worth noting that implant manufacturers claim complete absorption of harmful UV radiation; however, the presented studies do not confirm this. Due to the difficulty of performing structural tests without interfering with the shape and properties of implants, it cannot be stated clearly how the silver particles cover the lens. However, knowing the shape of the particles (plates), and taking into account the high light reflection coefficient and the increase in transmittance, it should be assumed that at least a proportion of the silver particles are positioned perpendicular to the surface of the implants. In this case, some kind of mirrors may form, which may increase the value of transmittance.

REFERENCES

[1] P. Aaltonen, P. Oskala, I. Immonen, Acta Ophthalmologica **97** (4), e506-e513 (2019). Doi:10.1111/aos.13931

[2] T.H. Margrain, M. Boulton, J. Marshall, D.H. Sliney, Progress in Retinal and Eye Research **23**, 523-531 (2004). Doi:10.1016/j.preteyeres.2004.05.001

[3] M. Boulton, M. Różanowska, B. Różanowski, Journal of Photochemistry and Photobiology B: Biology **64**, 144-161 (2001). Doi:10.1016/S1011-1344(01)00227-5

[4] J. Biszczuk-Jakubowska, A. Curyło, B. Kois, G. Zabłocki, Prace Instytutu Elektrotechniki **255**, 251-258 (2012) (in Polish).

[5] L. Allarakhia, R.L. Knoll, R.L. Lindstrom, Journal of Cataract and Refractive Surgery **13**, 607-620 (1987). Doi:10.1016/S0886-3350(87)80149-9

[6] A. Hennig, L.R. Puri, H. Sharma, J.R. Evans, D. Yorston, Eye **28** (5), 567-575 (2014). Doi:10.1038/eye.2014.26

[7] M. Gacek, J. Wyslocki, J. Gondro, F. Badura, S. Letkiewicz, Materiale Plastice **56** (3), 621-624 (2019). Doi:10.37358/MP.19.3.5241

[8] T. Thevi, Z. Maizura, A.L. Abas, Indian Journal of Ophthalmology **65** (1), 24-29 (2017). Doi:10.4103/ijo.IJO_452_16

[9] S. Louison, J. Blanc, C. Pallot, S. Alassane, A. Praudel, A.M. Bron, C. Creuzot-Garcher, Journal Françaisd' Ophtalmologie **42** (4), 368-374 (2019). Doi:10.1016/j.jfo.2018.10.007

[10] S. Pershing, D.E. Morrison, T. Hernandez-Boussard, American Journal of Ophthalmology **171**, 130-138 (2016). Doi:10.1016/j.ajo.2016.08.036

[11] P. Gong, H. Li, X. He, K. Wang, J. Hu, W. Tan, Nanotechnology **18**, 604-11 (2007). Doi: 10.1088/0957-4484/18/28/285604

[12] K.M. Alananbeh, W.J. Al-Refaee Z. Al-Qodah, Indian J. Pharm. Sci. **79** (4), 559-567 (2017). Doi: 10.4172/pharmaceutical-sciences.1000263

[13] M. Guzman, J. Dille, S. Godet, Nanomed-Nanotechnol **8**, 37-45 (2012). Doi: 10.1016/j.nano.2011.05.007

[14] K. Wolny-Koładka, D. Malina, A. Sobczak-kupiec, Z. Wzorek, Polish Journal of Agronom **15**, 69-74 (2013).

[15] A. Sobczak-Kupiec, Z.J. Burgieł, A. Wójcik, D. Malina, Z. Wzorek, Przem. Chem. **9**/91, 1816-1819 (2012).

[16] A. Slistan-Grijalva, R. Herrera-Urbina, J.F. Rivas-Silva, M. Avalos-Borja, F.F. Castillon-Barraza, A. Posada-Amarillas, Physica E **27**, 104-112 (2005). Doi: 10.1016/j.physe.2004.10.014

[17] C. Sönnichsen, T. Franzl, T. Wilk, G. Plessen, J. Feldmann, New Journal of Physics **4**, 93.1-93.8 (2002). Doi: 10.1088/1367-2630/4/1/393

[18] K. Jez, M. Nabialek, K. Gruszka, M. Deka, S. Letkiewicz, B. Jez, Materiale Plastice **55** (3), 438-441 (2018). Doi:10.37358/MP.18.3.5046