Structure and Selected Properties of Intraocular Implants (PMMA, Acrylic)

MARCIN GACEK[1], JERZY WYSLOCKI[1]*, JOANNA GONDRO[1], FRANCISZEK BADURA[1], SLAWOMIR LETKIEWICZ[2,3]

[1] Institute of Physics, Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, 19 Armii Krajowej Str., 42-200 Czêstochowa, Poland

[2] Ludwik Hirszfeld Institute of Immunology and Experimental Therapy in Wroc³aw Polish Academy of Sciences, 12 Rudolfa Weigla Str., 53-114 Wroclaw, Poland

[3] Jan Dlugosz University in Czestochowa, Faculty of Pedagogy, Institute of Physical Education, Tourism and Physiotherapy, 4/8 Waszyngtona Str., 42-200 Czestochowa, Poland

This paper presents the results of an investigation into the structure and properties of intraocular lenses (IOL) that are available on the ophthalmological market. The majority of implants of this type are based on acrylics or poly(methyl methacrylate) (PMMA). The acrylic lenses can be curled, which allows the making of just a minor incision during the associated implant surgery. The drawback of PMMA implants is their high rigidity, resulting in the need for a larger incision during the implant surgery. The benefits accrued from wearing such an implant are (1) the correction of focus for clear vision and (2) protection of the retina against UV-A radiation. X-ray diffractometry has confirmed the amorphous structure of all of the lenses investigated in this paper. The absorption and transmittance of the selected implants have been measured; differences found in the directional values of the transmittance and absorbance suggest the presence of differences in the implant coating (such as: different thickness or lack of coating on one side). It has been found that the PMMA-based implants exhibit the better properties with a level of light transmission in the visible spectrum of almost 40% and total protection against UV radiation. The acrylic implants feature lower transmittance in the visible light spectrum, and two of the investigated acrylic lenses failed to provide adequate protection against the UV radiation.

Keywords: intraocular implants; UV-VIS, X-ray diffractometry; transmittance, UV radiation

For a few decades now, refractive eye surgery and lens replacement operations have been performed successfully. Intraocular lens implantation (or lens replacement) has a major impact on vision quality, and the resulting quality of life. All of this has resulted from co-operation between materials science and medicine. Intraocular implants can be divided into two groups: hard and soft [1,2]. The first group consists of implants based on PMMA, whereas the implants in the second group are based on silicone and hydrogel. Nowadays, silicone implants are very rarely used and they have been almost entirely replaced by acrylic intraocular implants. In order to implant the lens, eye surgery is required. In the case of the *hard* implants (PMMA), there is the need for a major incision (of about 6.5 mm); conversely, for the *soft* lenses (the so-called *flexible* IOL) the size of the incision can be reduced to approximately 1.8 mm. The intraocular lenses usually comprise of a central lens and haptics. Haptics are usually made of PMMA and are used to hold the lens in place inside the capsular bag within the eye.

As with all surgery, intraocular implantation carries a risk of bacterial or fungal infection. Such infections can lead to severe complications and even to blindness. Other risks associated with intraocular implants are: retinal detachment, corneal swelling, cataract, glaucoma, and astigmatism. There is also the risk of rotation of the lens within the eye after the surgery.

Intraocular lenses are constructed in the shape of an actual lens. An important aspect of intraocular implants is the level of transmittance of visible light. Progress in the field of materials engineering has facilitated the design and production of implants that are impenetrable to ultraviolet radiation, and which are free of crystallites within their volume. The application of an anti-UV filter protects the human visual system and helps to eliminate the requirement for additional external devices. UV radiation has a negative effect on the dioptric system of the eye: it can result potentially in a cataract and the degradation of the retina [3-14].

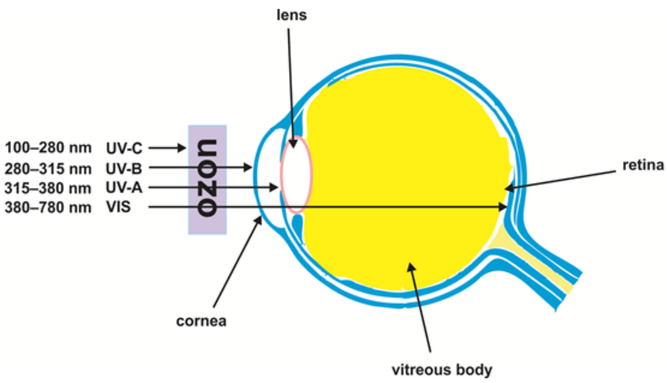

Fig. 1. Outline of the eye - absorption of electromagnetic radiation

The cornea absorbs shorter-wavelength radiation (Fig. 1). Protection against UV-A (315-380 nm) is normally delivered by the lens, which absorbs most of the radiation with wavelengths between 300-400 nm [15]. Therefore, in the case of replacement of a lens, the intraocular implant should take over this additional role of the removed lens and assure protection of the retina against harmful UV radiation.

In this paper, the results of an investigation into the structure and magnetic properties of intraocular implants made from PMMA and acrylics are presented.

* email: wyslocki.jerzy@wip.pcz.pl

Experimental part

Materials and methods

Four different intraocular implants, available on the ophthalmological market, were chosen for these studies. Table 1 presents a summary of their characteristics.

Table 1

CHARACTERISTICS OF THE CHOSEN INTRAOCULAR IMPLANTS

Implant number	Material	Anti-UV layer	Hydrophobic layer
No. 1	PMMA	Yes	Yes
No. 2	Acrylics	Yes	Yes
No. 3	Acrylics	Yes	Yes
No. 4	Acrylics	Yes	Yes

The chosen implants were free of defects and were of standard quality. The structure of the implants was investigated by means of X-ray diffractometry; a BRUKER Advance D8 X-ray diffractometer was used, featuring a CuKα radiation source and LynxEye semi-conductor counter. The samples were exposed for 7s per measurement step (0.02°).

The implants were studied using a UV-Vis spectrophotometer [16-17]. The spectrophotometer is an optical instrument for measuring the intensity of light relative to wavelength. This device offered the opportunity for quantitative and qualitative chemical analysis, based on the transmittance and absorbance of the electromagnetic radiation spectrum present. For the investigated intraocular implants, the transmittance and absorbance of the electromagnetic wave in the visible light, infrared and ultraviolet rangeswere studied (i.e. wavelengths ranging from 190 to 900 nm). The studies concentrated on the wavelengths of UV radiation and those associated with the photopic vision.

Results and discussions

Results of Investigations

In Fig. 2, the X-ray diffraction patterns for the investigated intraocular implants are presented.

The recorded X-ray diffraction patterns are typical of materials with an amorphous structure: they each consist of a broad peak within the 2θ range of 25° - 35°,derived from X-rays dispersed by the atoms randomly distributed within the sample volume. Moreover, within the 2θ range of 40° - 50°, the broadening of the spectra is clearly visible.

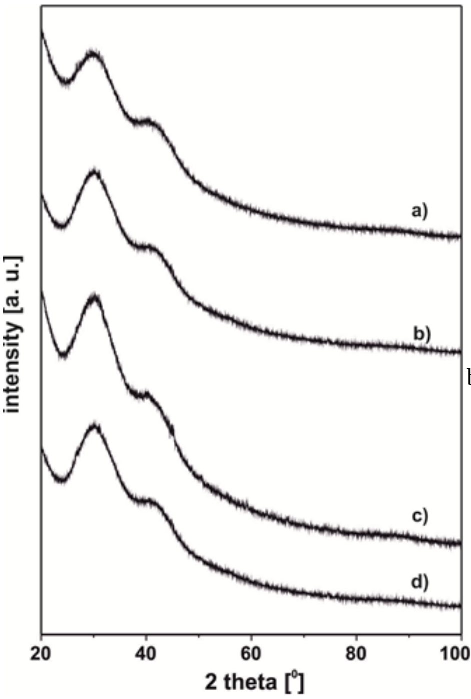

Fig. 2. The X-ray diffraction patterns for the investigated implants: a) No.1, b) No.2, c) No.3, and d) No.4.

This is most likely to be the result of broad maxima overlapping, with the second maximum occurring within the 2θ range of 30° - 50°.

In figure 3 and figure 4, the transmittance of electromagnetic radiation characteristics are presented, as measured for the wavelength range of: 190 to 900 nm.

All of the investigated samples exhibited similar transmittance characteristics, within the studied wavelength range. For the wavelength range corresponding to ultraviolet radiation, the implants showed low transmittance levels. The value of transmittance was found to increase rapidly for the wavelengths visible to the human eye. The transmittance for all of the samples was measured from both sides of the lens. It is worth noting the differences in the values of transmittance for the investigated implants, and in particular samples No. 1 (Fig. 2a and 3a), and No. 2 (Fig. 2b and Fig. 3b). In the case of the implants made from PMMA, there is a major difference in the level of transmittance - depending on the direction of the light exposure. The transmittance for sample No. 4 changes only slightly with the change of light direction.

Fig. 5 and Fig. 6 show the absorbances for the investigated samples.

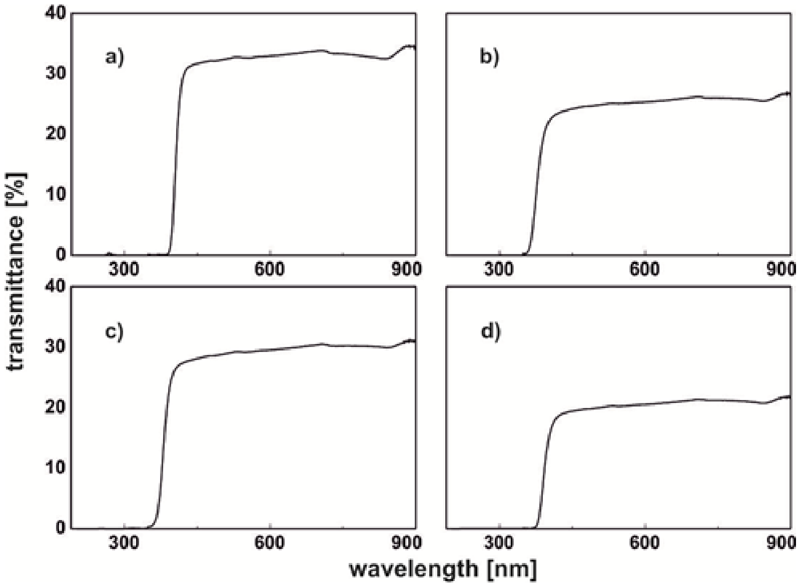

Fig. 3. Transmittance measured for the implants (side one): a) No.1, b) No.2, c) No.3, and d) No.4.

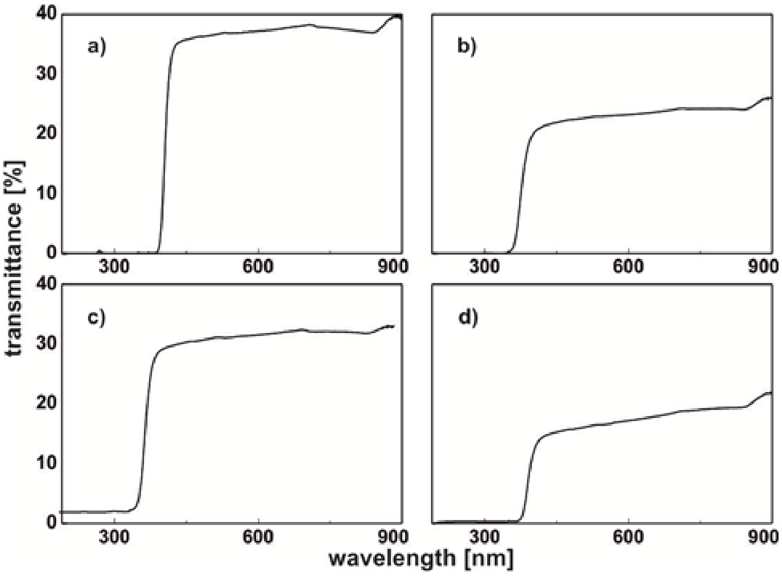

Fig. 4. Transmittance measured for the implants (side two): a) No.1, b) No.2, c) No.3, and d) No.4

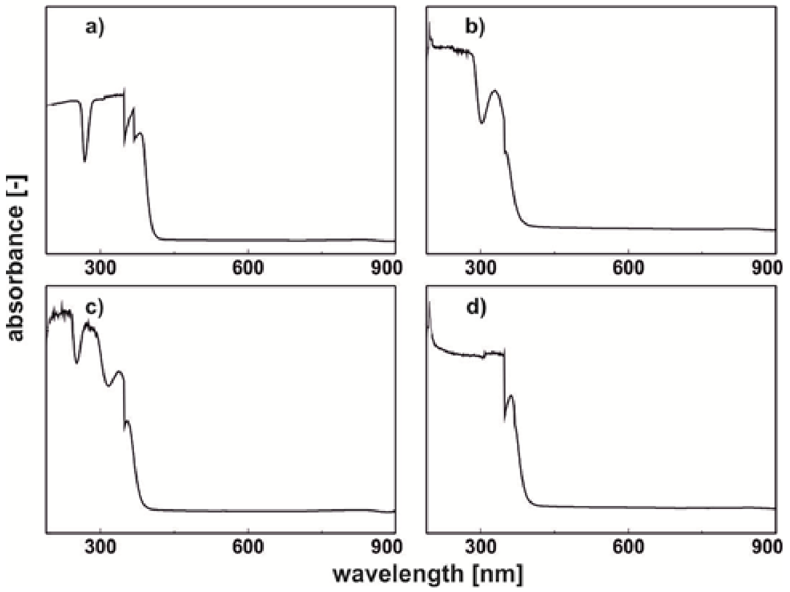

Fig. 5. The absorbance for the implants (side one): a) No.1, b) No.2, c) No.3, and d) No.4.

In the case of samples No. 1 and No. 2 (Fig. 5a and 5b, and Fig. 6a and 6b) the absorbance is independent of the direction to the light exposure. The remaining samples exhibit differences in the absorbances related to the direction of the exposure to the light. In the case of lens No. 4 there is a difference in the value of the absorbance. However, in the case of lens No. 3 there is also a difference in the shape of the relationship. This could suggest a structure differing from that of the other implants. During the production process of the intraocular lenses, a coating is applied to ensure that they are hydrophobic, as well as offering protection against UV radiation. In the specifications for the studied implants, the method by which this coating has been applied was not specified.

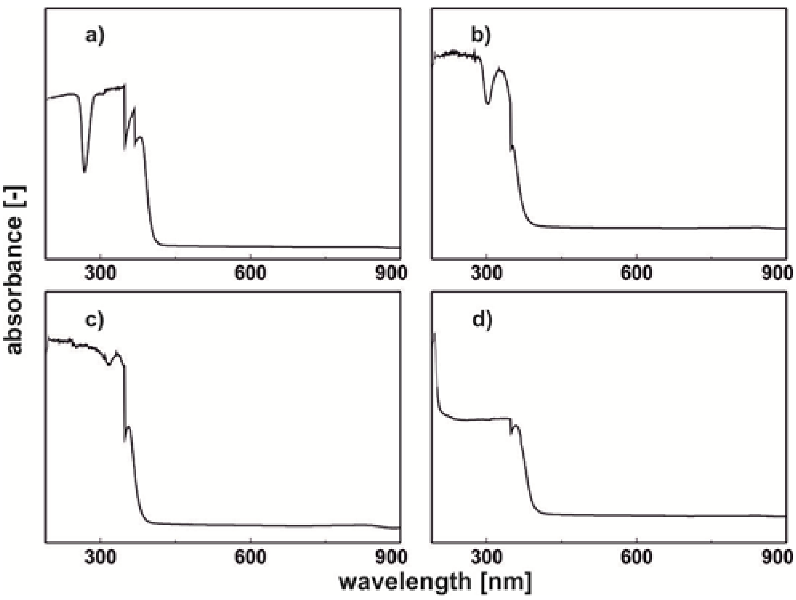

Fig. 6. The absorbance for the implants (side two): a) No.1, b) No.2, c) No.3, and d) No.4.

Implant		Max transmittance [%]	Transmittance for 555 nm [%]	Transmittance for 315 nm [%]	Transmittance for 380 nm [%]
No.1	Side 1	34.72	32.63	0.02	0.09
	Side 2	39.85	36.86	0.00	0.09
No. 2	Side 1	27.03	25.13	0.00	13.81
	Side 2	26.11	23.00	0.03	12.96
No. 3	Side 1	31.30	29.22	0.13	12.92
	Side 2	24.31	21.65	0.00	7.79
No. 4	Side 1	22.08	20.28	0.03	1.35
	Side 2	22.09	16.58	0.27	1.68

Table 2
DATA OBTAINED FROM ANALYSIS OF THE TRANSMITTANCE RESULTS FOR THE INVESTIGATED IMPLANTS

The differences in the values of transmittance and absorbance due to direction of the light exposure could be associated with differences in the thickness of the layer of coating, depending on the exposed side of the implant; or the application of a coating only on one side. Table 2 shows results arising from analysis of the values of transmittance for the investigated samples.

In Table 2, the values of transmittance are presented for radiation with the wavelength of 315 nm (agreed start of UV-A radiation range), 380 nm (agreed end of UV-A radiation range), and 555 nm (the maximum sensitivity of the human eye within the visible range - photopic vision). On the basis of this data, it can be seen that the best level of transmittance within both the visible range and the UV-range was achieved by the PMMA implant. This lens yielded a transmittance level of greater than 30% for photopic vision in the range of visible light, whereas the other samples (acrylics-based) featured transmittance values in the range from 16.58 to 29.22 %. In addition, implant No. 1 offered the best protection against UV radiation. Samples No. 2 and No. 3 did not offer sufficient protection for the retina; for the wavelength of 380 nm, the transmittance was found to be well above 10%.

Conclusions

The aim of this work was to investigate the structure, as well as the light transmittance and absorbance values for the selected intraocular lenses. All of the investigated implant samples were characterised by an amorphous structure. The studied lenses exhibited some difference in their properties, depending on the direction of their exposure to the light source during the investigations. The amount of light passing through the implants was found to be relatively low. The best performing sample of the investigated lenses was characterised by a transmittance level of 37%. A properly functioning human vision system consisting of: cornea, lens and vitreous body should ensure transmittance at a level as high as 90% behind the lens, or from 50 to 90% in front of the retina. Therefore, the obtained low level of transmittance for the intraocular implants does not ensure complete comfort of vision. However, in the case of surgical removal of a degraded lens due to clouding (cataract) a lens-replacement is the only way to ensure retention of the vision.

The structure and properties of the human eye allow the absorption of radiation with short wavelengths (cornea) and from UV-A (lens). Therefore, it should be expected from intraocular implants to be able to block radiation within the wavelength range from 300 to 400 nm. In the case of the studied lenses only two samples (No. 1 and No. 4), were found to fulfil this requirement. Letting through a significant amount of UV light within the UV-A range could lead to retina degeneration. Therefore, it is very important that modern implants ensure the best possible protection against radiation within this wavelength range. The addition of filters protecting the retina against blue light (absorbing radiation up to 475 nm) are becoming very popular. The applied blue light chromophores cause yellow colouration of the lens. Unfortunately, as a result, there are problems with night vision and some degree of deterioration in colour vision.

From the studied set of samples, the best parameters of transmittance and absorbance were exhibited by the implant made from PMMA. However, the main disadvantage of implants made from this material is their rigidity; during the surgical operation, they require an incision of several millimetres' length. Conversely, the more flexible acrylic lenses require an incision of just 1.8 mm.

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