Impact of glistenings on optical image quality of intraocular lenses – a preliminary study

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Abstract—The aim of the study was to determine how glistenings phenomenon affects the quality of the retinal image. The long presence of an artificial intraocular lens (IOL) inside the eye causes different defects to appear in a lens implant. In particular, the appearance of liquid-filled microvacuoles inside a lens is known as glistenings. These changes affect the imaging properties of the lens and hence influence the quality of the retinal image. As a result of imaging deterioration, significant worsening of eyesight may occur. Such defects occur in all types of IOLs and are quite common. In this paper, numerical investigation is presented, of imaging quality of IOLs with glistening. Three intraocular lenses were examined in the study, two made of acrylic and one made of PMMA. The Atchison eye model was adopted for calculations. Microvacuoles of different size and density were modeled. This paper shows the dependence of retinal image quality and the parameters above. The results proved that the degree of deterioration in image quality in IOLs with microvacuoles of the same size and density differs for each IOL type of different construction parameters.

Prolonged exposure in the environment of aqueous humor results in aging of an intraocular lens (IOL), which leads to progressive degradation of an IOL surface and other changes in its material properties. Further, it may result in degradation of the patient's visual quality and his/her comfort of living.

Due to an increasing range of the problem, plenty of research is being conducted, describing and systematizing lesions in intraocular lenses after implantation [1-14]. However, the majority of them concern IOL materials, while very few focus on the impact of lesions on visual quality.

One of the most frequently observed and discussed forms of material degradation is the formation of microvacuoles filled with fluid, which tend to affect IOL optical properties and cause the scattering of light passing through the lens. This phenomenon is called glistenings [5-14].

In order to evaluate the impact of glistenings on retinal image quality, an Atchison eye model [15] was implemented in professional software used for ray-tracing – Zemax.

The crystalline lens was replaced with three commercially available IOLs made of different materials – acrylic and PMMA. The position of the IOL was identical to the position of the crystalline lens (the geometrical center of the IOL was located in the same place).

The modulation transfer function (MTF) was used to evaluate the difference in retinal image for eye models containing an IOL with glisenings. In order to study the impact of scattering on image quality in optical materials of different refractive indices, the analysis included different materials of IOLs.

On the basis of an Atchison eye model [15], a pseudophakic eye model was constructed by replacing the crystalline lens with a 21.0 D intraocular lens. Abbe number of each optical material in the model was calculated in order to receive optical image quality parameters in non-monochromatic light. Models of three IOL materials – two acrylic of different refractive indexes and one of PMMA, were analyzed in the study. Table 1 gives the parameters of the IOLs used.

Table. 1

Material	Manufacturer	Refractive index	Abbe number	Radius of curvature 1 [mm]	Thickness [mm]	Radius of curvature 2 [mm]
AR40N	Allergan	1.470	71.0	12.71	1.008	-12.71
P359UV	Bausch&Lomb	1.493	57.4	15.00	1.000	-15.00
Acrysoft MA60BM	Alcon	1.552	46.4	32.00	0.800	-15.00

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The retina position in every model was optimized by Zemax tools to receive the best polychromatic optical quality for the paraxial rays.

For this analysis, we simulated the scattering on microvacuoles in intraocular lenses. Glistenings were modeled as spherical inhomogeneities filled with aqueous humor randomly located in the IOL material.

These inhomogeneities cause the scattering of the light passing through the intraocular lens. Mie scattering was used in the study. This scattering was simulated in Zemax using a built-in source code. A few variables characterizing the modeled inhomogeneities were used in the analysis – the number of vacuoles per cm^3, the diameter of a single microvacuole and factors describing the probability of scattering. Three grades of glistenings introduced by Miyata [1] were considered. Additionally, the eye pupil diameter was taken into account.

MTF was calculated for each elements: lenses with and without glistenings. Moreover, normalized *MTF* (*MTFDrop*) was calculated to determine the degree of deterioration [16].

$$MTFDrop(f)= \frac{MTF_{IOL}(f) - MTF_{scatter}(f)}{MTF_{IOL}(f)}, \qquad (1)$$

where $MTF_{IOL}(f)$–*MTF* value of pseudophakic eye without scatter, while $MTF_{scatter}(f)$–*MTF* value of pseudophakic eye with glistenings, f – spatial frequency.

The *MTFDrop* was calculated for a frequency of 4.35 cycles/degree in order to simplify the comparison. It was the value for which at least one model reached the first minimum. This choice prevented us from analyzing noises.

MTFDrop was calculated for three different pupil diameters: 3mm, 4.5mm, and 6mm.

The highest *MTFDrop*, irrespective of the lens material, was observed for the narrowest eye pupil.

Models with pupils 4.5 and 6mm give similar results. There is no significant difference ($p>0.05$), which could result in clear dependency between pupil diameter and *MTFDrop*. The biggest decrease in optical image quality for lenses AR40N (acrylic), P359UV (PMMA) and MA60BM (acrylic), was observed in photopic conditions (pupil diameter 3mm) for vacuoles of 20μm diameter and grade III in Miyata scale.

In scotopic, mesopic and photopic conditions (respectively 6, 4.5 and 3mm) *MTFDrop* reached its highest value for P359UV lens (vacuole diameter Φw=20μm, glistenings of grade III in Miyata scale). Acrylic lens MA60BM gave the best optical image quality.

The following graphs show the dependence of the parameter *MTFDrop* change as a function of the diameter of a single microvacuole for three degrees of density (I, II, III) in photopic conditions for entrance pupil diameter of 3mm. The decrease in retinal image quality, determined by *MTFDrop*, is greater the larger the diameter and the density of microvacuoles are. It can be noticed that the degree of deterioration in the image quality of models with the same microvacuoles parameters is different for each IOL.

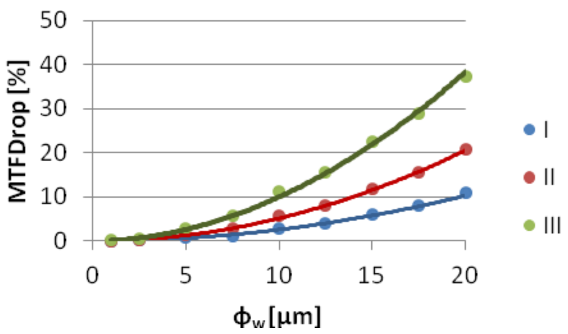

Fig. 1. Decrease in retinal image quality determined by *MTFDrop* as a result of microvacuoles inside the lens AR40N depending on the diameter microvacuoles ϕ_w and the degree of density (I, II, III).

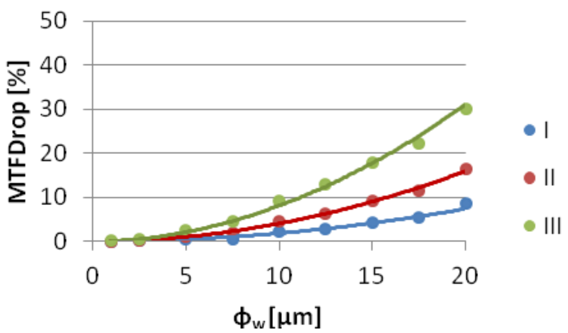

Fig. 2. Decrease in retinal image quality determined by *MTFDrop* as a result of microvacuoles inside the lens MA60BM depending on the diameter microvacuoles ϕ_w and the degree of density (I, II, III).

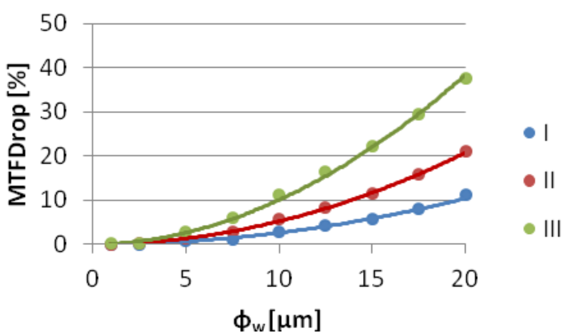

Fig. 3. Decrease in retinal image quality determined by *MTFDrop* as a result of microvacuoles inside the lens P369UV depending on the diameter microvacuoles ϕ_w and the degree of density (I, II, III).

As light scattering is primarily caused by the difference of refractive indices between the scatterer and the media, it might be expected that the lenses, in which this relative difference is more significant, should show more scattering effects.

In this case, the sequence of lenses, starting from the one which gives the worst image quality, should be: MA60BM, P359UV and AR40N. However, it is not the case. Because of the fact that MA60BM lens has a lower thickness (as a result of higher refractive index), it causes relatively low deterioration of image quality. It might be explained by the dependence between the probability of scattering and the length of light propagation, which is described by the equation:

$$I(\chi)=e^{-\alpha\chi}, \quad (2)$$

where α is the coefficient in mm^{-1}, whilst χ is the length of propagation [16]. Regarding the dependence above, the impact of the refractive index of MA60BM lens is compensated by its axial thickness, which is 0.2mm lower compared to other lenses. Two other lenses, having similar thicknesses (the difference is 0.008mm) gives the expected results – *MTFDrop* of P359UV reaches higher values than AR40N (differences at $p<0.05$, Wilcoxon test). It is consistent with Mie scattering theory, because the lens of greater difference between the material and scatterers, more significant) change in the modulation transfer function (greater value of *MTFDrop*).

The study considers only a simplified model of intraocular lens with glistenings. In a real situation, microvacuoles tend to occur in different sizes. Their location is also very irregular, depending on the structure of a polymer. Because of this diversity, experimental studies, which could precisely define the relation between optical image quality and glistenings, are impossible. After further development, our analytical technique could be used to investigate precisely the influence of density and diameter of microvacuoles and the parameters of lens design on retinal image quality. Further research could systematize the knowledge of glistenings and at the same time might be helpful for intraocular lens designers. Based on our study, it is believed that microvacuoles diameter, density of their location, eye pupil diameter, lens thickness and lens refractive index have an influence on lowering image quality, which might be measured by *MTFDrop*. The results of our study confirmed the interpretation by DeHoog *et al*. [16]. In order to minimalize the scattering and its negative effects, the thickness of an element needs to be as low as possible. A new method of modelling individual cases should be developed in further research. A more detailed analysis should consider irregular vacuoles location and different diameters of microvacuoles in one lens.

Another issue is to investigate the effect of established glistenings on the quality of vision, which can be compensated by a number of neuro-psychiatric processes [17].

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