Evaluation of the impact of light scatter from glistenings in pseudophakic eyes

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PURPOSE: To study the impact of light scatter from glistenings in pseudophakic eyes using ray tracing in a model eye

SETTING: Department of Research, Advanced Vision Science, Inc., Goleta, California, USA.

DESIGN: Mathematical modeling and simulation.

METHODS: A pseudophakic eye model was constructed in Zemax using the Arizona eye model as the basis. The Mie scattering theory was used to describe the intensity and direction of light as it scatters for a spherical particle immersed in a given media (intraocular lens [IOL]). The modeling and evaluation of scatter and modulation transfer function (MTF) were performed for several biomaterials with various size and density of glistenings under scotopic, mesopic, and photopic conditions.

RESULTS: As predicted by the Mie theory, the amount of scatter was a function of the relative difference in refractive index between the media and the scatterer, the size of the scatterer, and the volume fraction of the scatterer. The simulation demonstrated that an increase in density of glistenings can lead to a significant drop in the MTF of the IOL and the pseudophakic eye. This effect was more pronounced in IOLs with smaller cavitations, and the observation was consistent for all tested biomaterials.

CONCLUSIONS: Mathematical modeling demonstrated that glistenings in IOLs will lead to reduction in the MTF of the IOL and the pseudophakic eye. The loss in MTF was more pronounced at high densities and small cavitation sizes across all biomaterials. Inconsistent and poor clinical quantification of glistenings in IOLs may explain some inconsistencies in the literature.

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Light scattering is primarily due to the relative difference between the scatterer and the media in the refractive index.[1] In intraocular lenses (IOLs), the medium is the IOL material and the scatterer can be a variety of entities including cells adhered to the anterior or posterior surface of the IOL, artifacts or foreign bodies on the surface or bulk of the IOL, and alterations within the IOL material itself. Among changes within the IOL material, formation of glistenings or osmotic cavitations or nano/microvacuoles is a phenomenon that can act as the scatterer in certain IOL materials.[2] Glistenings are nano- to micron-sized pockets of water that form in certain materials and conditions within the bulk of the material and tend to grow in size and density with age of the IOL. Glistenings or microvacuoles can form in spherical or ellipsoidal shape and range from 0.5 to 200 μm with varying densities.[3–5] Figure 1 illustrates the various size and density of glistenings, and Figure 2 shows optical micrographs of IOLs with glistenings of various sizes and densities. The propensity toward formation of glistenings or microvacuoles can vary depending on several factors including IOL material, manufacturing techniques, packaging conditions, osmolarity of the medium, patient conditions, and medications.[2–9]

Light scattering in IOLs due to glistenings has been studied and reported under various settings. The studies demonstrate that surface and subsurface nano- and micro-glistenings are primary causes of light scattering in IOLs.[10,11] Light scatter increases with an increase in the density of glistenings.[12,13] Studies have shown a potential increase in the deteriorative effects of light scatter from an increase in glistenings.[13] Several clinical studies have shown statistically

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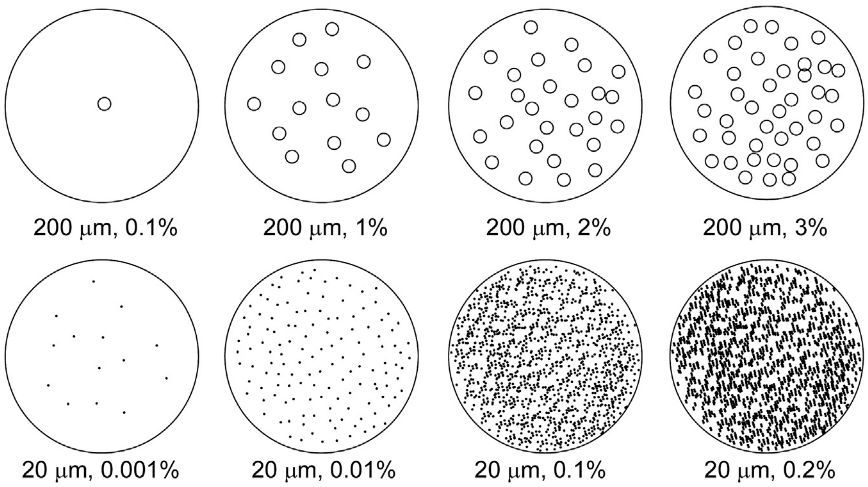

Figure 1. Size and density of glistenings.

significant visual acuity loss[14–17] and contrast sensitivity loss[18,19,A] in patients with severe glistenings. These studies highlight the risk for increasing light scatter from an increase in glistening density. Opacification from glistenings can also lead to loss of fundus visibility.[20] Other studies[20–26,A] have shown no significant effect on visual acuity from glistenings. Although most studies report that glistenings become progressively dense over time (and increase light scatter), the impact of light scatter from glistenings on visual quality remains inconclusive. Inconsistent and poor quantification of glistenings in IOLs may explain some inconsistencies in the literature. Currently, glistenings are primarily quantified by subjective evaluation at the slitlamp. Several efforts to quantify glistenings have been made using Scheimpflug photography[27,28] and image analysis.[B] However, the methods have limitations and are not widely used.[29]

Mathematical modeling using optical ray tracing and other analytical and/or numerical methods has been used to evaluate optical image quality metrics and have been well correlated with clinical findings.[30–35] Understanding the role of the scatterer involves significant variables including the various materials, diopters, and types of scatterers (size/density of glistenings). Further, inconsistency in quantifying the size and density of glistenings within the bulk and surface of the IOL make correlation between independent clinical studies inherently difficult. The role of glistening size, medium (IOL material), and pupil size on the extent of light scatter and its impact on quality of vision are still poorly understood. Until a consistent and objective method of clinical grading is available, it will be challenging to correlate the findings from this theoretical evaluation with clinical outcomes.

In this study, a mathematical model of a pseudophakic eye was constructed in optical ray-tracing software to understand scatter metrics in IOLs and the impact on quality of vision. The impact of light scattering due to glistenings on visual quality was evaluated as a function of glistening size and density and the IOL material at various pupil sizes to simulate photopic, mesopic, and scotopic vision.

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MATERIALS AND METHODS

Eye Model

A pseudophakic eye model was constructed in Zemax (Radiant Zemax) using the Arizona eye model (Table 1) as the basis. To create a pseudophakic eye model, the natural lens of the eye was replaced with a 20.0 diopter equiconvex IOL. The position of the IOL was optimized for a polychromatic modulation transfer function (MTF) for field angles 0, 1.4, and 20.0 degrees corresponding to foveal vision. Models of 3 IOL materials—poly(methyl methacrylate) (PMMA), hydrophilic acrylic, and hydrophobic acrylic—were examined using this eye model. Although refractive index and Abbe numbers vary within these classes of biomaterials, the models were used as examples to evaluate dependency on refractive index. Figure 3 is a schematic of the pseudophakic eye model. Table 2 gives the refractive index and IOL design assumptions for the 3 materials used in the pseudophakic eye model.

Scattering Parameters

For this analysis, the primary goal was to simulate the scatter from glistenings. Glistenings are formed by the cavitation of water within the IOL material and are commonly