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Young eyes for elderly people

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2009

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Gaalen, K. W. V. (2009). *Young eyes for elderly people: a clinical comparison of spherical and aspheric intraocular lenses*. s.n.

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General Discussion

Kim W. van Gaalen

The optical performance of the human eye after cataract surgery depends primarily on the optical quality of the intraocular lens (IOL) which is implanted. To optimize optical performance, an IOL with optical properties more similar to those of the clear young human lens, an aspheric IOL, has been designed.[1] The aim of this aspheric IOL is to compensate for the spherical aberration of the cornea and, hence, to reduce the total amount of spherical aberration of the eye.

In this thesis the influence of wavefront aberrations, mainly spherical aberration, on optical performance of the human eye was studied. The first aim of this thesis was to explore which commercially available contrast sensitivity test could be used clinically to evaluate interventions, for example cataract surgery, aimed at minimizing spherical aberration of the human eye optics. The second aim of this thesis was to compare the optical performance of eyes with several types of spherical IOLs and an aspheric IOL.

Contrast sensitivity and spherical aberration

Recent studies shave shown a relationship between spherical aberration and contrast sensitivity.[2-4] It seems, therefore, reasonable that the contrast sensitivity value could be used to obtain an estimate of spherical aberration of the human eye in a clinical setting. The advantages of contrast sensitivity tests are that they are cheaper than wavefront aberrometers and, unlike aberrometers, measure visual performance directly. The contrast sensitivity tests used in the literature, however, vary extensively. **Chapter 2** therefore compared seven different commercially available contrast sensitivity tests for their ability to show a relationship between contrast sensitivity and spherical aberration.

Retinal illumination has a strong effect on the shape of the contrast sensitivity function, especially at low retinal illuminations.[5,6] Van Nes et al.[5] and van Nes[6] showed that contrast sensitivity increases monotonically from 0.0009 trolands to 90 trolands (mesopic conditions) and stabilizes at higher retinal illumination (photopic conditions; Figure 1). Under photopic conditions the retinal illumination is high and, although the retinal illumination varies extensively between natural pupil sizes, contrast sensitivity remains constant (Figure 1). The influence of variation in retinal illumination on the contrast sensitivity function can, therefore, be ignored. None of the contrast sensitivity tests used in this thesis, however, revealed a relationship between contrast sensitivity and spherical aberration under photopic conditions. Small pupils have close to zero spherical aberration[4,7] and as a consequence decrease the possibility to establish a relationship between contrast sensitivity and spherical aberration. Although pupil sizes are larger under mesopic conditions, increasing the variation in spherical aberration,[4,7] no relationship between contrast sensitivity and spherical aberration could be established at these low lightning levels either, due to the variation in retinal illumination and the resulting variation in contrast sensitivity (Figure 1). By additionally measuring contrast sensitivity with an artificial pupil in front of a dilated pupil under photopic conditions, we were able to combine a larger pupil size and, hence, a larger spherical aberration value, with a high and constant retinal illumination. With dilated pupils, the computer driven Holladay circular sine-modulated patterns (HACSS) and the Vertical sine-modulated gratings (VSG) did reveal a significant relationship between contrast sensitivity and spherical aberration.

In conclusion, to evaluate the outcomes of cataract surgery, computer driven contrast sensitivity tests should be performed with artificial pupils.

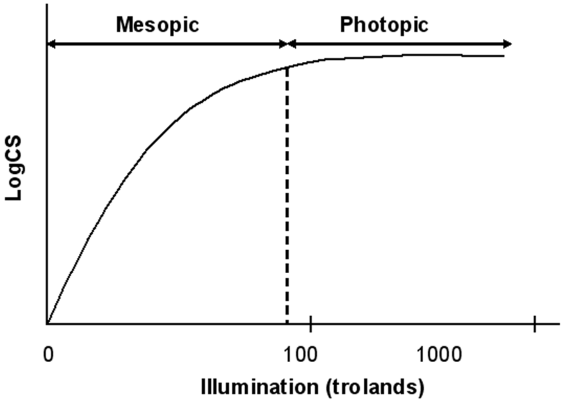

Figure 1. *Log contrast sensitivity as function of retinal illumination (LogCS = log contrast sensitivity).*

Pseudophakic eyes and optical performance

Initially, IOL designs were spherical, increasing the spherical aberration of the pseudophakic eye[8,9] and, hence, decreasing optical performance. To improve the optical performance of the pseudophakic eye, a new aspheric IOL design was introduced in 2002 to compensate for the positive spherical aberration of the cornea, by adding negative spherical aberration to the optical system.

The amount of negative spherical aberration induced by the aspheric IOL depends solely on the asphericity of the surfaces of the IOL and thus the amount of spherical aberration they are capable of correcting when implanted. Three types of aspheric IOLs can be discerned. An IOL with an aspheric anterior surface, the Tecnis IOL (AMO; spherical aberration = -0.27 µm at a pupil diameter of 6.0 mm), corrects the full corneal spherical aberration, an IOL with aan spheric posterior surface, the Acrysof IQ IOL (Alcon Laboratories; spherical aberration = -0.20 µm), compensates for the cornea in a lesser degree than the Tecnis IOL and an IOL with both an aspheric anterior and posterior surface, the Sofport AO IOL (Bausch&Lomb; spherical aberration = 0 μm), aims to produce minimal change in ocular spherical aberration. In this thesis the aspheric Tecnis ZA9003 has been studied.

Whether spherical aberration is beneficial for the human eye optics is subject of an ongoing discussion. Many previous studies have shown an improvement in contrast sensitivity in eyes with the aspheric IOL (all three types).[11-26] A majority of these studies measured the optical performance at the optimum refractive state for their viewing distance. In our study we did not find differences in contrast sensitivity measured with optimum refraction between the spherical and aspheric IOLs. However, some other optically related entities, such as depth of focus and myopic shift, have some influence on the optical performance of the pseudophakic eye too.[23,27,28]

Since the pseudophakic eye cannot accommodate, a large depth of focus may be of significant importance. Spherical aberration renders the eye more tolerant to defocus.[3] As a result, best-corrected eyes with a spherical IOL, when an emmetropic postoperative correction is aimed, should perform better at near tasks than best-corrected eyes with an aspheric IOL.[23,27,28] The higher depth of focus in eyes with more spherical aberration might impose an advantage over completely compensating spherical aberrations. In this thesis **(chapter 3, 4 and 5)** we showed that spherical aberration could indeed increase the depth of focus, without compromising visual acuity and contrast sensitivity at optimal focus. On the other hand, however, spherical aberration also increased the myopic shift **(chapter 3, 4 and 5).** Myopic shift is the shift of optimal focus towards more myopic values at lower spatial frequencies. Optimal contrast sensitivity at low spatial frequencies (3-5 cpd) is essential for viewing contours (edges) and these low spatial frequencies are very sensitive to defocus.[29,30] A large myopic shift should, therefore, be considered undesirable.

Marcos et al. found that the small incision used during cataract surgery induced significant changes in the root-mean-square (RMS) value of the corneal wavefront aberrations.[10] Spherical aberration and coma, however, did not change significantly.[10] Therefore, the amount of preoperatively measured spherical aberration of the cornea may determine which IOL should be implanted. Patients with a lower than average corneal spherical aberration might benefit from a conventional spherical IOL, whereas the use of an aspheric IOL should be the first preference for patients with a greater than average contribution corneal spherical aberration.

Pseudophakic eyes and straylight

Glare is a well-known visual symptom of cataract.[31] Cataractous changes in the transparency of the crystalline lens lead to an increase in straylight. After replacing the cataractous lens with an artificial, optically clear, IOL, straylight decreased significantly and the optical performance of the eye improved. Although the main source of ocular straylight is removed by replacing the cataractous lens with an IOL, a large number of pseudophakic patients still report glare and halo-like phenomena.

Franssen and co-authors showed that in healthy phakic eyes pupil size does not influence the amount of straylight.[32] In this thesis, however, we showed that straylight increased significantly with increasing pupil size when measured in pseudophakic patients. When the pupil size is large, parts of the peripheral anterior capsular bag and the edges of the IOL can become visible in the visual pathway, interfering with the light rays, thus increasing straylight **(chapter 6).** To further reduce the glare and halo-like phenomena after cataract surgery, it seems therefore reasonable to create a capsulorhexis as large as possible. Contradictory results, however, have been reported regarding the most favorable size of the capsulorhexis from the point of view of PCO (after cataract) formation.[33-35] Whether or not a large capsulorhexis is favorable or unfavorable should be subject of future research.

Conclusions

In summary, this thesis gives an overview to what extent the correction of aberrations in eyes with an aspheric IOL results in an improvement in optical performance. Very likely, some spherical aberration should be considered beneficial, since spherical aberration might increase depth of focus without compromising visual acuity and contrast sensitivity at optimal focus. However, since spherical aberration causes a myopic shift, it might – to some extent – produce unfavorable effects. To which extent some spherical aberration is favorable or unfavorable should, therefore, be subject of future research.

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