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Tolerance to rotation of toric monofocal and bifocal intraocular lenses. A theoretical study

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ABSTRACT

This manuscript aims to evaluate the tolerance to rotation of a toric monofocal and a toric bifocal intraocular lenses with different cylinder powers. Theoretical designs based on wavefront aberrations were created to simulate a toric monofocal and a toric bifocal intraocular lens. Cylinder power ranged from −1 D to −6 D, in steps of −1 D. Tolerance to rotation was estimated by the visual Strehl ratio based on the optical transfer function (VSOTF) metric. Tolerance to rotation for both monofocal and bifocal intraocular lenses decreased when the cylinder power increased. For the bifocal design studied, the tolerance to rotation was larger for the near focus than for the far, however the overall quality was poorer for the near focus. Our findings show evidence that rotation tolerance depends both on the design of the intraocular lens and the cylinder power. This approach could be useful for predicting the tolerance to rotation of monofocal and multifocal toric intraocular lenses prior the surgery.

1. Introduction

Presbyopia is the result of the accommodative ability loss experienced by the aging eye as deterioration of the near vision clarity [1,2]. This loss of accommodation is inherent to the senescence of the human eye and is related to biochemical changes of the crystalline lens structure due to aging [3]. Among various solutions, multifocal corrections are a popular approach for compensating presbyopic symptoms [2]. Many multifocal solutions work under the strategy of simultaneous vision [4], which is based on the projection of several images on the retina at the same time. Depending on the working distance, one of these images will be focused, while the rest will present different amounts of blur. The success of simultaneous vision lies then in the subjects' ability to select the best focused image and suppress the rest [2,4].

Several types of multifocal solutions based on simultaneous vision can be distinguished, according to the symmetry and the structure of the correcting element. Thus, there are symmetrical, asymmetrical, concentric and aspheric designs. The majority of the commercially available solutions in contact lenses (CLs) and some intraocular lenses (IOLs) have concentric designs, which consist of several annular refractive zones for achieving vision at different distances [2]. All these solutions for presbyopia aim to compensate also for the rest of the subjects' refractive errors. Astigmatism is a fairly common refractive error among the population [5,6] and can have a severe impact in visual quality if not corrected. For this purpose, toric

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multifocal CLs and IOLs are available in the market which aim to increase spectacle independence by correcting astigmatism along with presbyopia, myopia and hyperopia.

The axis of a toric optical solution has to be aligned with the astigmatism axis to correctly compensate the refractive error and, hence, provide good vision. Toric CLs have stabilization systems [7] for avoiding undesired rotations that occur with blinks and can influence the visual performance [8]. When treating with IOLs, however, this issue gets more complex. It is known that IOLs can rotate after they have been implanted in the eye [9–11], which is not impactful for vision if the IOL has rotational symmetry. Nevertheless, if the IOL does not present rotational symmetry, visual outcomes can change depending on the angle of rotation [12,13]. If the IOL is toric, then, even relatively small rotations can have a large impact in the subjects' vision [14,15]. Stability is a crucial factor regarding the efficacy of toric IOLs, since a 10° rotation can reduce the effectiveness of the toric correction by 33%, whereas a rotation of more than 30° can induce undesired astigmatism [16]. Unfortunately, the impact of IOL rotations in visual acuity is evaluated after the IOL has been implanted in the eye, which can lead unavoidably to a follow-up surgery.

Multifocal refractive designs have been previously used to study the impact of the number of zones [17,18] or the zone distribution [17] on vision. In this work, we used these type of simulated typical multifocal corrections based on wavefront aberrations for assessing theoretically the tolerance to rotation of a concentric bifocal and of a monofocal IOL under different cylinder powers when combined with corneal aberrations from different eyes.

2. Methods

2.1. Corneal aberrations

Retrospective corneal aberrations from six right eyes of six healthy subjects (26.2 ± 6.1 years old) obtained with the Pentacam HR (Oculus, Wetzlar, Germany) were used in this study. Data comprised Zernike coefficients from the whole cornea up to and including 6th order. Participants gave written informed consent and the study adhered to the tenets of the Declaration of Helsinki. A seventh set of corneal aberrations was introduced into the study. This set is identical to the first, but we substituted the 4th order spherical aberration (SA) value by 0.41 μm (0.20 μm for a 5-mm pupil), which is the typical value for a 60 year-old subject, according to Navarro et al. model cornea [19].

2.2. Intraocular lenses designs

Two IOLs designs were generated for this study: one monofocal and one bifocal. The designs were created using wavefronts [17] as if they were obtained in the pupil plane of the eye and they were made trying to match some characteristics of commercially available lenses. The only aberrations that they presented were astigmatism (since we were interested in toric IOLs) and SA. Both designs were given a Zernike 4th order SA value of −0.24 μm, for a 6-mm pupil, which is a typical value that some commercially available IOLs incorporate [20,21]. Different values of cylinder power were given to the IOLs, depending on the corneal astigmatism we wished to compensate, as it will be explained later.

The bifocal lens was of center-near [2] design and consisted of two different refractive annular concentric zones: a 2-mm diameter central zone dedicated for near vision with an addition power of 3 D and an annular zone dedicated for far vision.

2.3. General procedure

An example of the general methodology followed in this work is illustrated in Fig. 1. The IOL's cylinder power in this example is −3 D at 90°. For compensating all the corneal astigmatism with this IOL, the lens astigmatism should have the same magnitude, but opposite sign. Hence, the astigmatism that we wanted to compensate with the IOL was simulated in the cornea. The axis of the corneal astigmatism was calculated taking into account Zernike coefficients up to 6th order, and the different cylinder powers were simulated in this axis. It should be taken into account that when we refer to the IOL's cylinder throughout this text, we mean the astigmatic power needed to compensate the corneal astigmatism.

Once the astigmatism was set in both the cornea and the IOL, we started rotating the IOL by rotating its wavefront [22]. Rotations from −24° to +24° in steps of 0.5° were simulated for the monofocal IOL, whereas for the bifocal the rotations were simulated from −20° to +20°, using the same step. We considered negative angles as counter-clockwise rotations and positive angles as clockwise rotations. At each rotation angle, a visual Strehl ratio based on the optical transfer function (VSOTF) through-focus curve was computed for vergences ranging from −2 to +2 D for the monofocal IOL, and from −4 to +1 D for the bifocal IOL. The through-focus step was 0.125 D. The selection of the VSOTF [23,24] is justified by the fact that is an optical quality metric highly correlated with visual acuity [25,26] (VA). Following this, we located the maximum (monofocal IOL) or maxima (bifocal IOL) from the through-focus curves, which will be called from now on peak VSOTF, and we evaluated the variation of the peak VSOTF with the rotation angle. For assessing the tolerance to rotation, we selected a threshold value that has been used before (VSOTF = 0.12) [17]. This threshold corresponds to a 0.2 logMAR VA [25] and it can be considered as the limit where half of the people show difficulty reading [27]. Therefore, the interval or range of the peak VSOTF curve which was above that threshold indicated the tolerance to rotation of each IOL design.

The tolerance to rotation was assessed for the combination between each IOL design and each of the seven corneal wavefronts and the case where the cornea had zero higher-order aberrations (HOAs). Cylinder power ranging from −1 to