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Multifocal Intraocular Lenses: What Do They Offer Today?

Jorge L. Alió and Joseph Pikkel

When considering the latest innovations in ophthalmology, there is no doubt that one of the leading fields is multifocal intraocular lenses. The quest of patients to be free from wearing glass or using contact lenses meets the elongation of life expectancy as well as older people being more active than in previous years, with the improvement of optical technologies and new inventions, which results in a constant improvement of multifocal intraocular lenses. These new lenses and new technologies open a wide variety of solutions for those who seek to get rid of visual aids as spectacles or contact lenses. Though a great advancement has been made in recent years in multifocal intraocular lenses designs and production, there is still no perfect solution for all distances, and there is still a lot to be achieved. Accommodative lenses might be a solution, and this fascinating issue will be described and discussed later in this book. In this chapter, we will describe the current technologies and advances of multifocal intra ocular lenses.

1.1 How Can We Gain Multifocality in Lenses?

A multifocal intraocular lens must incorporate some mechanism to focus light from distant objects and light from near objects at the same time. A redistribution of the light energy will happen, with no single focus receiving all the energy as it happens in normal physiological accommodation. Unlike spectacle multifocal lenses, the multifocal intraocular lens refracts (or diffracts) light from any object for both near and distance vision at the same time. Thus there must always be some light that is not in focus with the light that is in focus. For distant objects, for example, the "add lens" steals some of the light that would have been focused and instead distributes relatively defocused light onto the retina, decreasing image contrast and reducing contrast sensitivity.

Multifocal intraocular lenses can obtain multifocality in different ways:

1. A combination of two or more different anterior spherical refractive surfaces for distance and near correction such as a combination of an anterior spherical and an anterior aspheric refractive surface for distance and near correction

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J. L. Alió (✉)
Research & Development Department and Department of Cornea, Cataract, and Refractive Surgery, VISSUM Corporation and Miguel Hernández University, Alicante, Spain
e-mail: jlalio@vissum.com

J. Pikkel
Department of Ophthalmology, Assuta Samson Hospital, Ashdod, Israel

Ben Gurion University, School of Medicine, Beer-Sheva, Israel
e-mail: yossefp@assuta.co.il

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2. A combination of a posterior spherical refractive surface and multiple anterior aspheric refractive surfaces
3. A combination of an anterior spherical refractive surface and multiple posterior diffractive structured surfaces for distance and near correction
4. A biconvex lens with longitudinal aberrations on the anterior surface (making it aspheric), providing near vision through the center of the lens, distance vision through the periphery, and intermediate vision in between

Intraocular multifocal lenses can be refractive, diffractive or of a combined design. Refractive lenses use only differing areas of refractive power to achieve their multifocality. They function by providing annular zones of different refractive power to provide an appropriate focus for objects near and far. Refractive bifocal/multifocal IOLs may be affected by pupil size and decentration, to a greater or lesser degree depending on the size, location, and number of refractive zones. The wavefront produced from the refractive lens is non-spherical, i.e., it does not have a focus. In these lenses the inner zone is powered for distance and outer zone is powered for intermediate vision. The middle zone has an add zone for near vision (Fig. 1.1).

The refractive multifocal lens implant provides excellent intermediate and distance vision. The near vision is typically adequate but may not be sufficient to see very small print.

Limitations of refractive multifocal intraocular lenses are:

1. Pupil dependence design
2. High sensitivity for lens centration
3. Intolerance to kappa angle which varies from patient to patient
4. Potential for halos and glare due to more non-transition area—rough area between the zones.
5. Loss of contrast sensitivity

The refractive models reach multifocality by their different refractive power annular zones and usually provide proper far and intermediate vision; however, sometimes, near vision is not sufficient. They are dependent of pupil dynamics, very sensitive to their centering, may cause halos and glare, and reduce the contrast sensitivity [1]. In addition, some refractive designs include a continuous change in curvature between zones providing functional vision across all distances [2].

Diffractive lenses are based on the principle that every point of a wavefront can be thought of as being its own source of secondary so-called wavelets, subsequently spreading in a spherical distribution (Huygens-Fresnel principle). The amplitude of the optic field beyond this point is simply the sum of all these wavelets. When a portion of a wavefront encounters an obstacle, a region of the wavefront is altered in amplitude or phase, and the various segments of the wavefront that propagate beyond

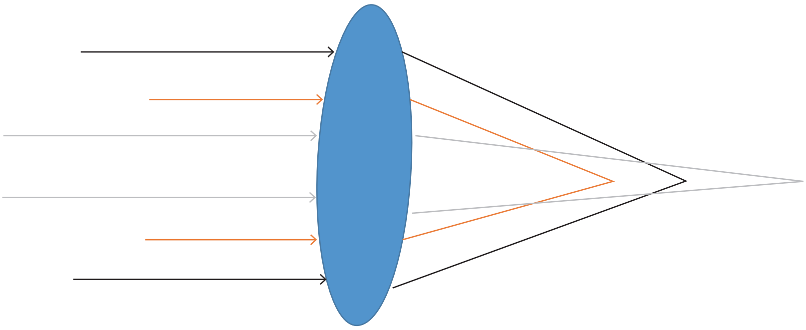

Fig. 1.1 Refractive lens design: the outer zone concentrates light rays from the intermediate distance (black arrows), the medial zone concentrates light rays from the near distance (red arrows), and the inner zone concentrates light rays from the far distance (green arrows)

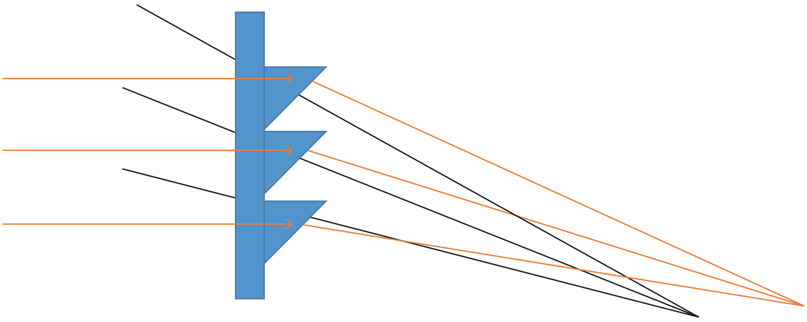

Fig. 1.2 The principle of a diffractive lens: light travels slower on the side of the step of the lens compared to the speed of light that moves through the aqueous resulting in producing two foci, one for near vision and one for far vision

the obstacle interfere and cause a diffractive pattern. As the spacing between the diffractive elements decreases, the spread in the diffractive pattern increases. By placing the diffractive microstructures in concentric zones and decreasing the distance between the zones as they get further from the center, a so-called Fresnel zone plate is produced that can produce optic foci. Thus the distance power is the combined optic power of the anterior and posterior lens surfaces and the zero order of diffraction, whereas the near power is the combined power of the anterior and posterior surfaces and the first order of diffraction (Fig. 1.2).

The diffractive multifocal lens implant provides excellent reading vision and very good distance vision. The intermediate vision is acceptable but not excellent as the far and near vision. However, multifocal diffractive intraocular lenses are less pupil size defendant and are more tolerant to differences of kappa angle.

Bifocal diffractive multifocal lenses only provide two focus points—far and near—and no intermediate foci; they have a high potential of producing halos and glare due to more nontransition area; and since they cause an equal distribution of light for both foci, they cause 18% loss of light in transaction. These disadvantages may decrease quality of vision especially in mesopic and scotopic conditions when more zones affect the incoming light rays to the retina. The modern trifocal diffractive IOLs, provided by different mechanisms that will be explained later on this book, are trying to provide intermediate vision by a redistribution of the diffracted light to other foci.

The diffractive models are composed by diffractive microstructures in concentric zones that get closer to each other as they distance from the center. They generally provide good far and near vision, but the intermediate vision may not be satisfactory in some cases. They are not so dependent of pupil dynamics and more tolerant to their centering, but they usually affect the contrast sensitivity in a greater scale [4]. Although contrast sensitivity in patients with multifocal IOLs is diminished compared with those with monofocal IOLs, it is usually within the normal range of contrast [3].

1.2 EDOF: Extended Depth of Focus

Extended depth of focus (EDOF), or extended range of vision, is a new technology in the treatment of presbyopia-correcting intraocular lenses. In contrast to multifocal intraocular lenses used in the treatment of presbyopia, EDOF lenses work by creating a single elongated focal point rather than several focal points, to enhance depth of focus. The aim of these lenses is to reduce aberrations, glare and halos, that are caused by the exciting multifocal intraocular lenses (Fig. 1.3).

The SYMPHONY lens uses the described technic to create EDOF; however, there are other

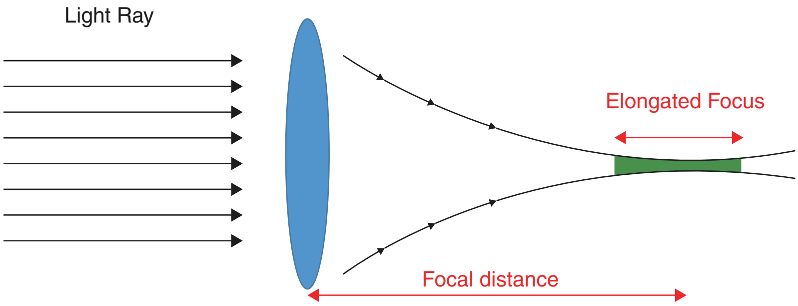

Fig. 1.3 EDOF lens design

technologies that can be applied to enhance the range of vision without splitting light. Small aperture designs and bioanalogic intraocular lenses can also enhance the depth of focus. In a "nut shell," there are three groups of design that can enhance EDO:

- Lenses that use a pinhole effect
- Bioanalogic lenses
- Echelette technology lenses

1.2.1 "Pinhole Lenses"

Lenses that use a pinhole effect are actually small lenses design like the IC-8 (AcuFocus, Inc., Irvine, CA) and the KAMRA corneal inlay (Acu-Focus, Inc.). These lenses are made with an embedded opaque annular mask measuring 3.23 mm in total diameter that blocks unfocused paracentral light rays while allowing paraxial light rays through its 1.36-mm central aperture. Actually, this creates a pinhole effect that produces an elongated focal range resulting in an extended and continuous range of functional vision.

The "pinhole lenses"like the IC-8 model may be suitable for post-refractive presbyopia, irregular corneas, and monofocal pseudophakic patients.

1.2.2 Bioanalogic Intraocular Lenses

These lenses use different materials that mimic the properties of the natural young crystalline lens. Such is the Wichterle Intraocular Lens-Continuous Focus (WIOL-CF) (Medicem, Czech Republic). This lens is a one-piece polyfocal hyperbolic optics with no haptic elements. It is made from a biocompatible hydrogel 42% water hydrogel and mimics the properties of a natural crystalline lens with a refractive index 1.43. The lens enables a continuous range of focus.

Since it is not an accommodative lens, the lens has several zones that create different foci, the refractive power is maximal in the center and continuously decreases without steps to the periphery. Observational studies indicated excellent visual acuity for far and intermediate vision and reasonably good near vision with minimal optical phenomena [4].

1.2.3 Echelette Technology Lenses

This technic is actually used in the Symphony lens and is based on a design that forms a step structure whose modification of height, spacing, and profile of the echelette extends the depth of focus. These designs in combination with achromatic technology and negative spherical aberration correction improve simulated retinal image quality without compromising depth of field or tolerance to decentration [5].

The first intraocular lens that was approved by the FDA was the TECNIS Symphony IOL (Abbott Medical Optics, Inc. of Santa Ana, California). This is a biconvex wavefront-designed anterior aspheric surface and a posterior achromatic diffractive surface with an echelette design. The lens creates an achromatic diffractive pattern that elongates a single focal point and compensates for the chromatic aberration of the cornea.

Overall, patients experience less glare and halos with EDOF lenses; however, there is a need of improving the near vision since the EDOF lenses are good for far and intermediate range and are less satisfactory for near-range vision.

One of the ways to compensate for the decrease in near vision in patients with EDOF lenses is the mini-mono vision, or mix-and-match strategies with diffractive low-add lenses should be considered; however, using the mini-mono vision may cause decrease in far vision and additional halos from the low myopia in the contralateral eye [6].

In any technique that is used to provide multifocality, the best visual result depends on patient selection, accurate biometry, astigmatism correction, and lens centration. These issues as well as others will be discussed in the next chapters of this book; a pedantic preoperative approach is necessary in order to succeed in multifocal intraocular lenses implant and eventually causing the patients to be happy [7].

Though, as said before, there is not a perfect solution yet for good vision in all distances, most of the patients who had a multifocal intraocular lens implant are happy and satisfied with the outcome. A recent meta-analysis of peer-reviewed publications revealed evidence of high levels of patient's satisfaction in general. The spectacle independence was 80% or more in 91.6% for distance vision, 100% for intermediate vision, and 70% for near vision in the different groups studied. The binocular uncorrected vision of 0.30 log MAR was achieved in 100% for distance visual acuity, 96% for intermediate visual acuity, and 97.3% for near visual acuity of the patients included in the study [8, 9].

So as described multifocal intraocular lenses do provide a good (not perfect) solution for patients who want to be spectacles free after cataract surgeries. More important is the fact that new techniques and new approaches are constantly invented giving us the feeling that the goal of multifocality to all distances far intermediate and near is reachable and might be available to use in the near future.

Compliance with Ethical Requirements Jorge L. Alió and Joseph Pikkel declare that they have no conflict of interest. No human or animal studies were carried out by the authors for this article.

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