Multifocal Intraocular Lenses for the Treatment of Presbyopia: Benefits and Side-effects

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Introduction

Accommodation is the ability of the eye to create a sharp image on the retina of objects viewed, regardless of their distance to the observer. Eyes from younger subjects, when corrected for refractive error, are able to adapt the optical power to such an extent that objects at near point up to infinity are seen as sharp images. Von Helmholtz pioneered the theory that accommodation is the result of changes in optical power of the crystalline lens, as a result of changes in shape and position of the crystalline lens due to changes in tensile strength of the zonular fibers after relaxation or contraction of the ciliary muscle [1]. After the age of 40, the ability to accommodate decreases to such an extent that visual tasks at a normal near distance (e.g. 35-40 cm) become increasingly difficult in the majority of subjects. This is thought to be the result of changes in elasticity of the crystalline lens and of changes in the contractility of the ciliary muscle [2]. Thus, even emmetropic patients who were spectacle independent beforehand will eventually become dependent on reading spectacles once they have become presbyopic.

Similar to changes in the crystalline lens which lead to presbyopia, changes in the proteins and the protein structure lead to cataract formation, i.e. clouding of the crystalline lens [3]. In typical cataract surgery, the cloudy crystalline lens is removed (usually by phacoemulsification) from its capsular bag and is replaced by an artificial intraocular lens (IOL). Ideally, this IOL would not only increase visual acuity, but could also allow the presbyopic patient to regain their ability to accommodate. Although refilling the capsular bag with a clear, but elastic substance, theoretically would lead to the desirable result, experiments in this field have been unsuccessful so far [4]. Similarly, an IOL of more rigid material which could (partially) change its position within the eye would allow patients to regain accommodation. In clinical practice however, movement of these IOLs has been shown to be insufficient to result in large changes in power of the optical system [5].

A third way of adapting IOLs to increase the depth of field of subjects (i.e. the difference between
the smallest and largest distance where visual acuity is sufficient for the execution of visual tasks) is to give them two or more fixed optical powers. These IOLs are known as multifocal IOLs. In multifocal spectacles there is only one retinal image at a time, which is the result of the focal point of the part of the spectacle glass best-suited for the distance of the object viewed.

Multifocal IOLs however, present the subject with two or more coexisting retinal images where only the image corresponding to either the distance or near focal point is sharp. This concept is known as “simultaneous vision” [6], or more appropriately, “simultaneous imaging”. Although these IOLs are pseudo-accommodative rather than truly accommodative (since they have several fixed rather than one adapting focal point) they have been the most widely used IOLs in cases where replacing the natural crystalline lens is used to overcome presbyopia following cataract surgery of refractive lens exchange. An example of a multifocal IOL is shown in figure 1.

![Slitlamp photograph of a multifocal diffractive intracocular lens in the capsular bag.](image)

**Examples of multifocal IOLs**

The earliest multifocal IOLs were introduced in the late 1980’s [7, 8]. Since then, two types of multifocal IOLs have been available for clinical use: refractive and diffractive multifocal IOLs. Refraction is based on a change in direction of the light ray due to a change in optical density encountered by the light ray. Diffraction is based on the observation that light that encounters a
discontinuity or edge in the material where it travels in, scatters in numerous different directions. Light energy arriving at an edge or discontinuity can thus be divided over two or more focal points, similar to refractive lenses. Both effects were described by Fresnel in the 1820’s when working on lenses for lighthouses, and can be used to design IOLs with multiple focal points [6]. Additionally, so-called “aspheric” multifocal IOLs have been introduced, where the optical properties of the IOL have been altered to decrease higher order aberrations of the total optical system, mainly by compensating for the increased spherical aberration of the cornea in older subjects.

Benefits of multifocal IOLs

Multifocal IOLs are primarily aimed at providing patients with good uncorrected visual acuity for both distance and near visual tasks. In numerous studies different models of both refractive [9, 10] and diffractive [9, 14] multifocal IOLs have been shown to result in high levels of uncorrected distance and near visual acuity: both mean uncorrected near and distance visual acuity are 20/25 or better in most studies, resulting in complete spectacle independence in around 75% of patients [9, 12]. Uncorrected near visual acuity is generally slightly better for diffractive IOLs compared to refractive IOLs, and uncorrected distance visual acuity is comparable for the two types of IOLs [9, 10]. Patients with a monofocal IOL can have both good uncorrected distance and near visual acuity as well as the result of favorable corneal astigmatism [15, 16], favorable corneal wavefront aberrations [17, 18] or myopic undercorrection in one eye, resulting in “pseudophakic monovision” [19, 20]. Despite large differences in the percentages of patients with a monofocal IOL being able to read Jaeger [3] print size, a meta-analysis concluded that uncorrected near vision is improved by implantation of a multifocal IOL compared to implantation of a monofocal IOL [21]. The increased uncorrected near visual acuity resulting in decreased spectacle dependence is the main benefit of multifocal IOLs [21].

Potential side-effects of multifocal IOLs

When compared to monofocal IOLs, i.e. IOLs with one fixed focal point, multifocal IOLs are generally

Tab. 1: Examples of accommodating intraocular lenses (IOLs).

<table>
<thead>
<tr>
<th>IOL Type</th>
<th>Array</th>
<th>ReZoom</th>
<th>ReStOR (SNIAD1, SNIAD3)</th>
<th>AcryLISA (366D, 376D, 536D)</th>
<th>Tecnis ZMA900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td>Abbott Medical Optics</td>
<td>Abbott Medical Optics</td>
<td>Alcon Laboratories</td>
<td>Carl Zeiss Meditec</td>
<td>Abbott Medical Optics</td>
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<tr>
<td>Design</td>
<td>refractive</td>
<td>refractive</td>
<td>diffractive + refractive</td>
<td>diffractive + refractive</td>
<td>diffractive</td>
</tr>
<tr>
<td>Pupil</td>
<td>dependent</td>
<td>dependent</td>
<td>dependent</td>
<td>independent</td>
<td>independent</td>
</tr>
<tr>
<td>Near add</td>
<td>+3.50</td>
<td>+3.50</td>
<td>+3.00, +4.00</td>
<td>+3.75</td>
<td>+4.00</td>
</tr>
<tr>
<td>Toric available</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes (466TD)</td>
<td>no</td>
</tr>
<tr>
<td>Aspheric</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Tab. 2: Examples of accommodating intraocular lenses (IOLs).

<table>
<thead>
<tr>
<th>IOL Type</th>
<th>Array</th>
<th>ReZoom</th>
<th>ReStOR (SNIAD1, SNIAD3)</th>
<th>AcryLISA (366D, 376D, 536D)</th>
<th>Tecnis ZMA900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
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<td>Bausch and Lomb</td>
<td>Abbott Medical Optics</td>
<td>Lenstec</td>
<td>Abbott Medical Optics</td>
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<tr>
<td>Design</td>
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<td>single optic</td>
<td>single optic</td>
<td>single optic</td>
<td>dual optic</td>
</tr>
<tr>
<td>Pupil</td>
<td>independent</td>
<td>independent</td>
<td>independent</td>
<td>independent</td>
<td>independent</td>
</tr>
<tr>
<td>Near add</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Toric available</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Aspheric</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>
associated with more photic phenomena, a decreased contrast sensitivity function and a decreased visual acuity at intermediate rather than far and near distance.

1. photic phenomena

Halos and glare are more often reported by individuals with a multifocal IOL compared to patients with a monofocal IOL [22, 23]. Refractive multifocal IOLs appear to be associated with more photic phenomena compared to diffractive multifocal IOLs [10]. Photic phenomena are among the most frequent reasons for patients’ dissatisfaction following implantation of multifocal IOLs [24, 25].

2. contrast sensitivity

Multifocal IOLs result in coexisting images, one sharp and one out of focus with the light from the latter reducing the detectability of the former image due to the reduced contrast difference between target image and its surrounding secondare image. Multifocal IOLs are therefore associated with lower contrast sensitivity [10]. Especially in mesopic circumstances [26, 27], or in patients with decreased contrast sensitivity due to ocular pathology, such as macular degeneration or corneal dystrophies, this can become clinically relevant [28, 30]. Diffractive multifocal IOLs appear to be either equal or superior to refractive multifocal IOLs with respect to contrast sensitivity [28, 30]. Although contrast sensitivity in individuals with multifocal IOLs is diminished compared to individuals with monofocal IOLs [31], it is within the normal range compared to age-matched phakic individuals [26, 31].

3. visual acuity at intermediate distance

Multifocal IOLs, unlike accommodative IOLs, depend on two fixed focal points which each represent two fixed working distances (far and near) at which they deliver a sharp image to the retina (surrounded by a blurred retinal image or images resulting from the other focal point or points). Working distances in between these “sweet spots” are associated with suboptimal visual acuity, potentially resulting in difficulties with computer work and similar activities. Traditionally, refractive multifocal IOLs performed better at intermediate than near distance [32, 23]. The latter were therefore sometimes implanted bilaterally in patients with strong intermediate vision demands, sometimes combined with refractive multifocal IOLs in the nondominant eye or sometimes combined with mini-monovision strategies leaving the non-dominant eye slightly myopic to increase visual function at near distances [32]. The introduction of diffractive multifocal IOLs with lower near adds however, has increased visual acuity at intermediate distance without decreasing near and distance visual acuity [11, 12, 33], as is also demonstrated in figure 2.
Fig. 2: Mean high-contrast binocular visual acuity (logMAR) with best correction for distance vision as a function of the chart vergence for the +3 ReSTOR group (solid line) and +4 ReSTOR group (dotted line) demonstrating an increased intermediate visual acuity with lower near add. (source: de Vries NE, Webers CA, Montes-Mico R, et al. Visual outcomes after cataract surgery with implantation of a +3.00 D or +4.00 D aspheric diffractive multifocal intraocular lens: Comparative study. J Cataract Refract Surg;36(8):1316-22).

Discussion

Despite the large number of published papers on the performance of single or multiple types of multifocal IOLs as presented above, comparing the performance of different multifocal IOLs is currently hampered for several reasons. First, despite work to develop instruments to measure subjective quality of vision [34], there is no consensus on which test or questionnaire to use for the measurement of the occurrence and severity of photic symptoms, resulting in many different questionnaires and grading systems being used in different papers. Since photic phenomena such as glare and halos seem to wean with time [14], a standardized followup time would also be essential to compare results of different IOLs from different studies. Secondly, there is no standardized test for near visual acuity. Some studies use single-character reading charts, such as Snellen [10] and ETRDS33 near visual acuity charts. Other studies use function-based tests such as the MNread chart [35] and variations thereof [20], measuring reading speed, number of mistakes and critical character size when using sentences rather than single characters. Thirdly, there is no consensus whether visual acuity measurements should be measured either binocular or monocular. Binocular visual acuity is generally higher, which might be the result of slight refractive differences between both eyes (resulting in an effect comparable to pseudophakic monovision) or this might be the result of more complex and less understood neurological processes. In clinical practice, binocular implantation has indeed been shown to be preferable to monocular implantation [36]. Fourthly, contrast sensitivity measurements are currently not standardized, with the CSV-1000 [9, 13], the Functional Acuity Test Chart [37, 38], Ginsburg box [33] and the CAT-200027 [39], systems being most widely used. Discussion exists what levels should be considered normal, given the large standard deviation of contrast sensitivity in normal subjects, and whether multifocal IOLs should be compared to age-matched phakic subjects or subjects with monofocal IOLs. Finally, multifocal IOLs have been associated with higher levels of higher order aberrations compared to monofocal IOLs [40]. The role of these aberrations, however, is not clear. Not only is their value for the depth of focus disputed [17, 18], but also the ability of wavefront analyzers to correctly measure aberrations in the subjects with a multifocal IOL [41, 42]. Lower levels of higher order aberrations in so-called

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“aspheric optics” have been shown to be beneficial in monofocal IOLs [43], but this is less clear for multifocal IOLs [44]. Since no consensus has been reached on these five items, a direct comparison between different types of IOLs in order to decide which IOL leads to the most desirable results is still difficult.

However, in general the current multifocal IOLs are able to provide patients with excellent uncorrected distance and near visual acuity resulting in high levels of spectacle independence. Although superior from a theoretical point of view, currently available accommodating IOLs are unable to offer the same level of near visual acuity. Pseudoaccomodative multifocal IOLs are either diffractive or refractive designs, and diffractive designs appear to deliver equal or superior results compared to refractive designs with respect to near visual acuity, occurrence of photic phenomena and possibly with respect to contrast sensitivity. Dissatisfaction following implantation is rare, and is often amenable for treatment (e.g. posterior capsule opacification which can be treated with laser capsulotomy, or residual refractive error which can be treated with spectacles or laser refractive surgery) [24, 25]. Other cases of dissatisfaction are due to the occurrence of phenomena inherent to the design of multifocal IOLs (such as glare and halos) and are therefore more difficult to treat [24, 25]. This demonstrates the importance of preoperative patient education, careful selection of cases and individualized weighing of benefits and side-effects of multifocal IOLs [45, 46]. If these principles are respected, multifocal IOLs can lead to excellent results and are of great value to present-day ophthalmology.

References