Optical Quality Differences Between Three Multifocal Intraocular Lenses: Bifocal Low Add, Bifocal Moderate Add, and Trifocal

David Madrid-Costa, PhD; Javier Ruiz-Alcocer, PhD; Teresa Ferrer-Blasco, PhD; Santiago García-Lázaro, PhD; Robert Montés-Micó, PhD

ABSTRACT

PURPOSE: To compare the in vitro optical quality at different focal points of two new bifocal intraocular lenses (IOLs) and one new trifocal IOL.

METHODS: The AcrySof ReSTOR SV25T0 (+2.5 diopter [D] add) and the AcrySof ReSTOR SN6AD1 (+3.0 D add) with two main foci (Alcon Laboratories, Fort Worth, TX) and the AT LISA tri 839MP with three main foci (Carl Zeiss Meditec, Dublin, CA) were evaluated. The optical quality of the IOLs was measured with the PMTF optical bench (LAMBDAX, Nivelles, Belgium). The optical quality of the IOLs was quantified by the modulation transfer function (MTF) at five different focal points (0.0, -1.5, -2.0, -2.5, and -3.0 D) and for 3.0- and 4.5-mm apertures. The through-focus MTF of the IOLs was also recorded.

RESULTS: For the 0.0 D focal point, the AcrySof ReSTOR (+2.5 D add) obtained the highest MTF values for all apertures. For the -2.5 D focal point, the AcrySof ReSTOR (+3.0 D add) showed the highest MTF values for 3.0 mm. For the -3.0 D focal point at 3.0- and 4.5-mm aperture, the best values were obtained with the AcrySof ReSTOR (+3.0 D add) and the AT LISA, respectively. For the -1.5 D focal point, the trifocal IOL provided better values. For the -2.0 D focal point, all IOLs provided comparable results. The through-focus MTF curves showed three and two peaks for the trifocal and bifocal IOLs, respectively.

CONCLUSIONS: The trifocal IOL provides a better optical quality at the -1.5 D focal point. However, the optical quality of the trifocal IOL significantly decreases compared to the bifocal IOLs at far distance and -2.5 D focal points.

anterior surface. This area consists of nine concentric steps of gradually decreasing height, thus producing bifocality from near to far. The lens’ refractive region surrounds the apodized diffractive region and directs the light onto a distant focal point for larger pupil diameters. The IOL incorporates a +3.0 D near add and both ultraviolet and blue-light filters.

The AcrySof ReSTOR SV25T0 IOL (Alcon Laboratories) is a bifocal IOL that comprises an annulus apodized diffractive region and two refractive regions. The former is located within the central 3.4-mm optic zone of the IOL’s anterior surface. This area presents an apodized diffractive design and consists of seven concentric steps of gradually decreasing height, thus producing bifocality from near to far (two foci). The central (approximately 1.0 mm) and the outer (2.6 mm over the inner zone of 3.4 mm) zones of the lens are refractive and are dedicated to distance vision. The lens incorporates a +2.5 D near add and both ultraviolet and blue-light filters.

The AT LISA tri 839MP IOL (Carl Zeiss Meditec, Dublin, CA) has a trifocal diffractive design with a +3.33 D near add and +1.66 D intermediate add at the IOL plane. The lens presents an asymmetrical light distribution for far distance, intermediate, and near focal points. The lens allocates light energy to the three focal points within the central 4.34-mm optical zone. Beyond 4.34 mm, the diffractive optic structure is dedicated to distance and near vision only. The lens has an aspheric design and also incorporates an ultraviolet blocker.

**Image Quality Description**

The modulation transfer function (MTF) is a measure of the attenuation that each spatial frequency undergoes when the wavefront goes through a given optical system. Similarly, an optical system’s MTF describes the amount of contrast that is passed through the system for a given spatial frequency or target size. In general, the higher the spatial frequency, the larger the drop in contrast caused by the optical system. At the same time, MTF measurements based on eye models is a widespread international standard method used to estimate an IOL’s image quality. A decrease of the MTF results in image contrast variations that could lead to a worsening of the optical system’s performance.

For this work, the MTF was assessed for both the 3.0- and 4.5-mm aperture, which could represent photopic and mesopic conditions, respectively. We wanted to assess the optical quality at different distances. Data were recorded for five different focal points from the base power of the lens (0.0, -1.5, -2.0, -2.5, and -3.0 D). In addition, to compare the MTF of the IOLs, we followed the methodology described in previous publications where the value of each MTF was considered as the average modulation value, which is the modulation averaged across all frequencies within the 0.0 to 100.0 cycles/mm range. The average modulation value is proportional to the area under the MTF curve between 0.0 and 120.0 cycles/mm. The averaged modulation values were analyzed for different diameters of aperture (2.0, 3.0, 3.75, and 4.5 mm) to assess the effect of pupil size on the IOL’s optical quality.

Finally, through-focus MTF curves comprising nine different focal points (addition powers at steps of 0.5 D) were obtained for 3.0 and 4.5 mm and for a spatial frequency of 50 cycles/mm, which could approximately correspond to an optotype for 0.5 Snellen equivalent visual acuity in white light. The higher the MTF value in the curve, the lower the degradation of the image quality of the optotype (and the better optical quality of the lens). Then, a peak value throughout the curves corresponds to a main addition power of the lens.

**Optical Quality Assessment**

The image quality of the IOLs was performed with the PMTF optical bench (LAMBDA-X, Nivelles, Belgium) with software version 1.13.6. The device complies with International Standard Organization (ISO) 11979-2 and 11979-9 requirements; that is, it comes with additional lenses for an aberration-free model cornea. It allows MTF measurements for different apertures at various frequencies and at different focal planes. The experimental set-up was assessed according to previous investigations in which other IOLs were analyzed by the same optical bench.

**Results**

The top section of Figure 1 (labeled A) shows the MTF curves (focal points: 0.0, -1.5, -2.0, -2.5, and -3.0 D) for the three IOLs for a 3-mm pupil size. The middle section (labeled B) shows similar MTF curves (same focal points as above), but for a 4.5-mm pupil size. For the 0.0 D focal point, the AcrySof ReSTOR SV25T0 IOL (bifocal +2.5 D add IOL) showed the better optical quality. At the -1.5 D focal point (intermediate distance), the AT LISA tri 839MP IOL (trifocal IOL) showed the best results. At near distances (-2.5 and -3.0 D), the AcrySof ReSTOR SN6AD1 IOL (bifocal +3.0 D add IOL) showed the best optical quality. Table 1 summarizes the average modulation values at these five focal points for both a 3- and 4.5-mm aperture.

The bottom part of Figure 1 (labeled C) presents the average modulation values as a function of the aperture diameter (2, 3, 3.75, and 4.5 mm) for the 0.0, -1.5, -2.0, -2.5, and -3.0 D focal points. A sloped line represents less pupil independence of the lens. For the 0.0 D
Figure 1. Modulation transfer function (MTF) curves of the three intraocular lenses (IOLs) for the (A) 3.0- and (B) 4.5-mm aperture. (C) Average modulation values as a function of the diameter of aperture for both IOLs. The bifocal AcrySof ReSTOR SV25T0 IOL and SN6AD1 IOL are manufactured by Alcon Laboratories, Fort Worth, TX, and the trifocal AT LISA tri 839MP IOL is manufactured by Carl Zeiss Meditec, Dublin, CA.
focal point, the trifocal IOL showed worse values than bifocal IOLs but pupil independence. Within the bifocal IOLs, the bifocal +2.5 D add IOL showed better results than the bifocal +3.0 D add IOL but a higher pupil dependence. For the rest of the focal points, the three IOLs showed a slight decrease on the optical quality toward larger pupils.

**Figure 2** illustrates the through-focus MTF curves for the three intraocular lenses (IOLs) for the (A) 3.0- and (B) 4.5-mm aperture. The curves were calculated for a spatial frequency of 50 cycles/mm. The bifocal AcrySof ReSTOR SV25T0 IOL and SN6AD1 IOL are manufactured by Alcon Laboratories, Fort Worth, TX, and the trifocal AT LISA tri 839MP IOL is manufactured by Carl Zeiss Meditec, Dublin, CA.

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**DISCUSSION**

The results of this study demonstrate that at the 0.0 D focal point (far distance) the best optical quality results were obtained with the bifocal +2.5 D add IOL, the second best results were obtained with bifocal +3.0 D add IOL, and the trifocal IOL had the worst results. At the -2.5 and -3.0 D focal points for the 3.0-mm aperture, the bifocal +3.0 D add IOL provided the best results, followed by the bifocal +2.5 D add IOL. For the intermediate focal point (-1.5 D), it was the trifocal IOL that provided the best MTF values. At the -2.0 D focal point, all IOLs provided comparable results. If one observed all mentioned results it is possible to see that the most significant differences within the lenses are shown at 0.0 D focal point (far distance), in which the bifocal +2.5 D add IOL obtained better results than the other lenses.

We have also assessed the through-focus optical quality. Gatinel et al.\(^1\) recently studied a different design of trifocal IOL and reported three different peaks corresponding to three main foci. Similarly, our data for the trifocal IOL revealed three peaks corresponding to far, intermediate, and near focal points, whereas bifocal IOLs showed two peaks (far and near). Both bifocal IOL designs performed better than the trifocal IOL at all distances except -1.5 and -3.5 D. All three lenses had a similar performance at the -2.0 D.

The variation in the optical quality of the IOLs (given by the average modulation value, see bottom sections

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**TABLE 1**

Average Modulation Values of the Three IOLs With 3.0- and 4.5-mm Aperture for the Five Focal Points (Add Powers)

<table>
<thead>
<tr>
<th>Focal Point</th>
<th>3-mm Aperture</th>
<th>4.5-mm Aperture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AcrySof ReSTOR +2.5</td>
<td>AcrySof ReSTOR +3.0</td>
</tr>
<tr>
<td>0.0 D</td>
<td>59.04</td>
<td>49.11</td>
</tr>
<tr>
<td>1.5 D</td>
<td>16.91</td>
<td>15.71</td>
</tr>
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<td>2.0 D</td>
<td>17.81</td>
<td>16.98</td>
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<td>2.5 D</td>
<td>25.34</td>
<td>28.03</td>
</tr>
<tr>
<td>3.0 D</td>
<td>16.61</td>
<td>30.30</td>
</tr>
</tbody>
</table>

IOL = intraocular lens; D = diopters

The bifocal AcrySof ReSTOR SV25T0 IOL and SN6AD1 IOL are manufactured by Alcon Laboratories, Fort Worth, TX, and the trifocal AT LISA tri 839MP IOL is manufactured by Carl Zeiss Meditec, Dublin, CA.
of Figure 1) as a function of pupil size was also analyzed. In the case of the 0.0 D focal point (Figure 1C), the trifocal IOL showed a constant optical quality for all of the diameters (pupil independence at far distance), whereas the optical quality of both bifocal IOLs depended on pupil size. The pupil dependence of the bifocal lenses is explained by their designs in which they present an inner diffractive apodized zone with a gradual decrease in step height toward the periphery of this inner zone. In addition, the outer zone of the lenses presents a refractive design purely dedicated to far vision. Therefore, due to the refractive + apodized diffractive design, some dependence on pupil diameter is expected for these bifocal IOLs. But the most important issue is that the results with bifocal IOLs for far distance were significantly better than the trifocal IOL for all apertures. Particularly, the bifocal +2.5 D add IOL obtained the best results between the two bifocal lenses because it incorporates a small central zone devoted to far distance and it correlates to the good results obtained with this lens at distance focal point for both larger and smaller diameters of aperture (Figure A, available in the online version of this article).

For the -1.5 D focal point, the trifocal IOL showed better optical quality than the bifocal IOLs for all apertures, with differences lower for smaller diameters. These results are directly related to the creation of the intermediate focus (-1.66 D) in the trifocal IOL. Logically, these results are due to the trifocal IOL having a diffractive optic with a near addition focus at +3.33 D and the bifocal +3.0 D add IOL having a +3.0 D addition power.

To better correlate the optical quality of the lenses to the potential visual quality of the patients, Felipe et al. performed a study to determine whether there is a correlation between IOL optics and visual parameters. The authors assessed the optical quality of IOLs by average modulation parameter and the patient’s visual quality by the visual acuity. They found that the visual acuity varied 0.24 and 0.18 decimal units per 10 units of average modulation variation under mesopic and photopic conditions, respectively. Thus, in light of this relation it should be possible to estimate potential visual quality results for the three lenses and the different pupil sizes. Considering the study of Felipe et al., an interesting outcome could be that the bifocal +2.5 D add IOL will provide a significant better visual quality in far vision for both apertures if it is compared to the trifocal IOL (approximately two lines of decimal Snellen visual acuity for both pupil diameters). There were also differences with the bifocal +3.0 D add IOL for both the 3.0- and 4.5-mm aperture, but in this case the differences were lower (approximately one line of decimal Snellen visual acuity). This range of pupil diameters could affect different tasks such as driving at night (larger pupils) or distance viewing in direct and indirect sunlight (smaller pupils). At the same time, the bifocal +3.0 D add IOL presents the best results at the -2.5 and -3.0 D focal points for the smaller pupil diameter (3.0 mm). These results could have an impact on reading tasks for presbyopic patients. It is important to take into account that near activities are usually performed under photopic conditions, bright light makes the pupils contract and, at the same time, the pupil size decreases due to the accommodative reflex. On the other hand, the trifocal IOL presents better results at the -1.5 D focal point for all pupil sizes, which will probably provide a better visual performance at intermediate distances for all light conditions. Therefore, attending to our results, one could suggest that for patients with strong need for reading and who do not want to significantly compromise distance vision, the bifocal +3.0 D add IOL should be considered. Patients not willing to compromise distance vision but willing to have a larger range of intermediate and near distances should receive the bifocal +2.5 D add IOL and patients with a preference for intermediate vision should consider the trifocal IOL.

It is necessary to point out that the results in this study were obtained for an ideal centration of the IOLs. Previous studies have shown that tilt and decentration have an important impact on the visual performance of different IOL designs. Hence, it would be interesting to perform further studies to evaluate the impact of different degrees of tilt and decentration on both the optical and visual performance of these three IOLs. These studies will help the surgeons to know the impact of a wrong centration of these complex IOLs.

The results of the current study suggest that the creation of an intermediate focus provides a better optical quality only at intermediate focal points. However, the inherent loss of energy into the eye that occurs when this third focus is created significantly decreases the optical quality at far distance and at -2.5 D focal points for the trifocal IOL.

**AUTHOR CONTRIBUTIONS**

Study concept and design (TF-B, SG-L, DM-C, RM-M); data collection (JR-A); analysis and interpretation of data (TF-B, SG-L, DM-C, RM-M); drafting of the manuscript (DM-C, JR-A); critical revision of the manuscript (TF-B, SG-L, DM-C, RM-M); statistical expertise (TF-B); supervision (DM-C)

**REFERENCES**

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Figure A. Scheme of the design of the AcrySof ReSTOR SV25T0 IOL (left) and the AcrySof ReSTOR SN6AD1 IOL (right) (Alcon Laboratories, Fort Worth, TX).