ABSTRACT

PURPOSE: To evaluate distance, intermediate and near visual performance in patients who had undergone implantation of the multifocal aspheric AcrySof ReSTOR intraocular lens (IOL)

METHODS: Binocular best distance corrected visual acuity (BCVA) at high and low contrast [4 m], best distance corrected near visual acuity (BCNVA) [40 cm], intermediate visual acuity [80 and 60 cm], and distance contrast sensitivity (CS) under photopic [85 cd/m²] and mesopic [3 cd/m²] conditions, were measured in 36 eyes that underwent implantation of the AcrySof ReSTOR Aspheric IOL (SN6AD3).

RESULTS: At the 3-month postoperative visit, binocular BCVA was -0.058±0.091, 0.200±0.079, and 0.258±0.071 logMAR, for 100%, 25% and 12.5% of contrast, respectively. Binocular BCNVA was -0.025±0.062 logMAR. Intermediate visual acuity varied significantly as a function of the distance to the test (P<0.01), but all patients showed 20/25 or better visual acuity at any distance. Photopic CS was within the standard normal range. Under mesopic conditions, all patients showed 20/25 or better visual acuity at any distance.

CONCLUSIONS: The AcrySof ReSTOR Aspheric IOL provide good high-contrast visual acuity at both distance and near; and CS at photopic and mesopic conditions. Intermediate vision is improved in relation to that found with the spherical AcrySof ReSTOR model.

INTRODUCTION

Implantation of pseudoaccommodative intraocular lenses (IOLs) has gained wide popularity among ocular surgeons. These IOLs are designed to reduce dependence on eyeglasses after cataract or refractive lens exchange surgery. Monofocal IOLs provide excellent visual function but for many patients their limited depth-of-focus means that they cannot provide clear vision at both distance and near.

It remains for optical scientists to design a pseudoaccommodative IOL that provides unaberrated optical imagery at all focal distances. Two separate focal points along the optical axis are generated to provide good unaided distance and near vision as well as functional intermediate vision. Current designs of pseudoaccommodative IOLs use diffractive optics3,5, zones of differing refractive power6-9 or both principles (hybrid IOLs)10-13. Recent studies performed on hybrid AcrySof ReSTOR IOL pointed out satisfactory visual results. An improvement of this concept was recently introduced by the same company on an aspheric platform under the name AcrySof ReSTOR Aspheric IOL. The addition of asphericity aims to reduce unwanted visual phenomena, associated with multifocal IOL performance, and to increase the range of focus improving image quality. Then, it is expected to obtain good distance and near vision as well as (due to the asphericity) functional intermediate vision.

The purpose of this study was to assess distance, intermediate and near visual acuity, distance contrast sensitivity (CS) under photopic and mesopic conditions in patients who had undergone bilateral implantation of the AcrySof ReSTOR Aspheric IOL in the capsular bag after lens extraction.

PATIENTS AND METHODS

Study Design

We prospectively examined 36 eyes of 18 consecutive patients who underwent bilateral implantation of the AcrySof...
ReSTOR Aspheric IOL (SN6AD3 model) at the Fernández-Vega Ophthalmological Institute (Oviedo, Spain). Inclusion criteria were age between 50 and 70 years, bilateral implantation (considering the visual benefit of bilateral implantation) and their motivation: the desire to no longer wear any form of spectacle or contact lens correction for distance and near.

Exclusion criteria included ≥1D of corneal astigmatism, history of glaucoma or retinal detachment, corneal disease, previous corneal or intraocular surgery, abnormal iris, pupil deformation, macular degeneration or retinopathy, neuro-ophthalmic diseases and history of prior ocular inflammation.

The AcrySof ReSTOR aspheric multifocal IOL combined the functions of both apodized diffractive and refractive regions (Figure 1). The apodized diffractive optics is found within the central 3.6 mm optic zone of the anterior surface of the IOL. This area comprises 12 concentric steps of gradually decreasing (1.3-0.2 microns) step heights creating a multifocality from near to distant (2 foci). The refractive region of the optic surrounds the apodized diffractive region. This area directs light to a distance focal point for larger pupil diameter, and is dedicated to distance vision. The IOL has a symmetric biconvex design with an anterior aspheric optic to reduce whole-eye spherical aberration (The IOL has a negative spherical aberration of -0.10 µm for a 6 mm pupil). The aspheric optics flattens the edge and reduces the central thickness (about 4.5% thinner for a 20D IOL compared to the spherical model). The overall diameter of the lens is 13.0 mm and the optical diameter is 6.0 mm. 

Pupil diameter in distance vision was measured in each patient under the two levels of illumination by means of a pupillometer (Colvard pupillometer, OASIS, Irvine, CA) before and after IOL implantation. Tilt and centration of the multifocal IOL in relation to the visual axis was assessed using a Scheimpflug videophotography system (EAS-1000, Nidek). Multifocal projection (Figure 1) A: Front view and B: Side view. Image B includes the SN60D3 spherical model to show differences between both models in the biconvex (symmetric and asymmetric) and optical (anterior asphericity) design.

FIGURE 1
AcrySof ReSTOR aspheric apodized diffractive IOL (SN6AD3 IOL model). A: Front view and B: Side view. Image B includes the SN60D3 spherical model to show differences between both models in the biconvex (symmetric and asymmetric) and optical (anterior asphericity) design.

Visual Performance Measurements
Binocular uncorrected distance visual acuity (UCVA) and best-corrected distance visual acuity (BCVA) were measured by means of the logarithm of the minimum angle of resolution (logMAR) for 100% contrast EDTRS charts under photopic conditions (85 cd/m²) with the Optec 6500 at 4 m (Stereo Optical Company, CA). BCVA was also measured at low contrast with the 25% and 12.5% contrast EDTRS charts. Binocular uncorrected distance visual acuity (UCNVA) and best distance-corrected near visual acuity (BCNVA) were measured by means of the Precision Vision Logarithmic Visual Acuity Chart 2000 New EDTRS at 40 cm under photopic conditions (85 cd/m²). Binocular best distance-corrected intermediate visual acuity (BCIVA) was measured at 60 and 80 cm with the same test used for near assessment but adjusting for the distance.

Binocular photopic (85 cd/m²) and mesopic (3 cd/m²) CS was measured with the best distance correction using the Optec 6500 with a Functional Acuity Contrast Test chart. Absolute values of log CS were obtained for each combination of patient, spatial frequency and luminance, and means and standard deviations were calculated.

The pupil diameter in distance vision was measured in each patient under the two levels of illumination by means of a pupillometer (Colvard pupillometer, OASIS, Irvine, CA) before and after IOL implantation. Tilt and centration of the multifocal IOL in relation to the visual axis was assessed using a Scheimpflug videophotography system (EAS-1000, Nidek).

Data Analysis
All examinations were performed at 3 months after implantation by one ophthalmic technician who was unaware of the objective of the study. Data analysis was performed using SPSS for Windows version 12.0 (SPSS Inc., Chicago, IL). Differences were considered to be statistically significant when the P value was <0.01 (i.e., at the 1% level). To explore any correlation between the visual acuity measured at different distances (far, intermediate and near), a one-way ANOVA test was carried out, in which the interactions between the changes in visual acuity and the distance of the test were assessed. Statistical significance of any intergroup CS differences was assessed with a t-test (absolute log CS values) at each frequency for both illumination conditions.
### TABLE 1
Demographic characteristics of participants

<table>
<thead>
<tr>
<th>AcrySof ReSTOR Aspheric IOL (SN6AD3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eyes</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Gender (Male/Female)</td>
</tr>
<tr>
<td>IOL Power (D)</td>
</tr>
<tr>
<td>Axial Length (mm)</td>
</tr>
<tr>
<td>Preoperative Sphere (D)</td>
</tr>
<tr>
<td>Postoperative Sphere (D)</td>
</tr>
<tr>
<td>Postoperative Cylinder (D)</td>
</tr>
<tr>
<td>Pupil diameter (mm)</td>
</tr>
<tr>
<td>Photopic (5 cd/m²)</td>
</tr>
<tr>
<td>Mesopic (3 cd/m²)</td>
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</tbody>
</table>

IOL = intraocular lens; mean ± standard deviation.

### RESULTS
Eighteen patients were enrolled in this study. The mean age of the 7 men and 11 women was 61.0±6.6 years (range 50 to 70 years). Mean IOL power was 21.04±2.93 D. Patient demographics are shown in table 1. After the surgery and IOL implantation, the pupils of all patients were round, without iris trauma, and showed a good responsiveness to light. All cases showed good centration and no tilt of the IOLs.

### Visual Acuity Results
The means and standard deviations of binocular visual acuity for distance, intermediate and near vision are summarized in table 2.

**High and Low Contrast Distance Visual Acuity.** Mean UCVA was 0.050 logMAR (about 20/20). When postoperative residual refractive error was corrected (see table 2) it improved to -0.058 logMAR (>20/20). 100% of the patients achieved a BCVA of 20/25 or better. Low contrast BCVA was 0.200 (20/32) and 0.258 (20/40) logMAR for 25% and 12.5% of contrast, respectively. In both cases, 100% of the patients achieved a BCVA of 20/40 or better. However, these percentages were reduced to 22.2% and 11.1%, respectively, for a BCVA of 20/25 or better. For a detailed description of the efficacy at different contrast under corrected and uncorrected conditions see table 2.

**Intermediate Visual Acuity.** Mean BCIVA was 0.222 and 0.201 logMAR (about 20/32) for 80 cm and 60 cm, respectively. At both distances, 100% of the patients achieved a BCVA of 20/25 or better. To better illustrate the change in visual acuity at different distances, figure 2 was created. The mean value ranged from -0.005 logMAR (about 20/20) at 40 cm to 0.201 and 0.222 logMAR (about 20/32) at 60 and 80 cm, respectively. Red circular symbols in figure 2 show the post-implantation, best-corrected binocular logMAR visual acuity. Data of Blaylock et al.18 (black circles), Alfonso et al.12 (blue circles) and Montés-Micó et al.19 (green circles) with the ReSTOR Natural IOL have been included for comparison. The one-way ANOVA revealed a statistically significant variation in the intermediate visual acuity as a function of the distance to the test for the AcrySof ReSTOR aspheric IOL (P<0.01).

**Near Visual Acuity.** Mean binocular UCNVA and BCNVA were -0.005 and 0.037 logMAR (about 20/20 in both cases), respectively. In both situations, uncorrected and best distance corrected, all patients (100%) achieved a visual acuity of 20/40 and better. 83.3% and 100% of the patients achieved a UCNVA and a BCNVA of 20/25 or better, respectively.

**CS under Bright and Dim Conditions**
The mean values of log_2(CS) are plotted as a series of CS Functions (CSFs) in figure 3 for the two luminance levels. For comparison, data corresponding to the standard photopic CSF, to the CSF for the AcrySof ReSTOR (SA60D3) and to that for the AcrySof Natural ReSTOR (SN60D3) IOLs were included. Under photopic conditions (85 cd/m²), the performance was very similar for all groups and was close to the standard CSF. At a mesopic level of 3 cd/m², however, the CS for all groups was generally lower, particularly at higher spatial frequencies. No statistically significant differences in photopic and mesopic log_2(CS) were found between the three groups at all spatial frequencies (P>0.1).

**DISCUSSION**
Previous clinical trials evaluating clinical, optical, functional and quality-of-life outcomes after AcrySof ReSTOR IOL implantation10-13,18,19 have shown that this IOL can improve near vision while providing a good level of distance vision. Multifocal patients reported less limitation in visual function and less spectacle dependency than patients with
bilateral monofocal IOLs. In the current study, we have assessed the performance of the new AcrySof ReSTOR aspheric IOL. This IOL is based on the previous ReSTOR IOL but improving its optical design with aspheric technology to achieve better visual outcomes. We have evaluated visual acuity and CS measured at different distances and lighting conditions in patients implanted with this IOL.

Our study shows an excellent binocular BCVA, with 100% of the patients having BCVA of 20/25 or better at 3 months (Table 2). Kohnen et al.¹⁰ using the AcrySof ReSTOR IOL (SA60D3) reported similar values and percentages of binocular BCVA in 118 patients at 120-180 days after the surgery (mean BCVA of -0.05 logMAR (20/20); 100% of the patients with 20/40 or better and 97.5% of the patients with 20/25 or better). Alfonso et al.¹² on a sample of 335 patients implanted with the AcrySof Natural ReSTOR IOL (SN60D3) at 6 months found a mean BCVA of 0.01 logMAR (about 20/20) and 100% of the patients with 20/40 or better and 95.5% of the patients with 20/25 or better. Alfonso et al.¹² found a 99.1% of patients with 20/25 or better binocular BCNVA at the same near distance (mean 0.03 logMAR). Despite of slight differences between the three models of the ReSTOR IOL, the new aspheric design shows the best outcomes. The addition of asphericity aims to improve image quality, thus, yielding a better near visual acuity.

In relation to intermediate visual acuity, we may observe, from figure 2, a statistically significant change of the binocular visual acuity as a function of the distance to the test. However, a better intermediate visual performance is found compared to that yielded by monofocal IOLs (Souza et al.¹¹ reported a mean BCIVA of 0.23±0.12 logMAR at 60 cm with the AcrySof ReSTOR IOL). If we analyse figure 2, the through-focus measurements of binocular visual acuity show that, as expected, although acuity is good at distance and near, there is some loss in vision at intermediate distances. For the spherical ReSTOR Natural IOL (data from Blaylock et al.¹⁸, Alfonso et al.¹² and Montés-Micó et al.¹⁹) we may observe two peaks in the graph at the expected near and far foci (corresponding to 0 and -3.2 D, respectively) with somewhat reduced acuity (0.3 logMAR, equivalent to 20/40) at intermediate distances. The results with the aspheric ReSTOR IOL show a V-pattern similar to that found by these authors with the spherical IOL.¹²,¹⁸,¹⁹ However, the visual acuity at intermediate distance is better: 0.2 logMAR (about 20/30). The asphericity of the IOL improves functional intermediate vision. Blaylock et al.¹⁸ and Alfonso et al.¹² have previously reported that patients implanted with the AcrySof ReSTOR IOL may experience difficulties at intermediate distances and have suggested that, for patients for whom intermediate vision is important, this can be overcome by aiming for a partial monovision correction. One may argue that the improvement reported in this study for intermediate vision achieved with the aspheric design, would be enough to alleviate the difficulties reported by some patients at intermediate distances. Further analysis with a quality of

### Table 2

<table>
<thead>
<tr>
<th>Distance (4 m)</th>
<th>Mean</th>
<th>20/40 or better</th>
<th>20/25 or better</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCVA</td>
<td>0.050 ± 0.188</td>
<td>16/18 (88.8%)</td>
<td>14/18 (77.7%)</td>
</tr>
<tr>
<td>BCVA</td>
<td>-0.058 ± 0.091</td>
<td>18/18 (100%)</td>
<td>18/18 (100%)</td>
</tr>
<tr>
<td>Low contrast BCVA (25%)</td>
<td>0.200 ± 0.079</td>
<td>18/18 (100%)</td>
<td>4/18 (22.2%)</td>
</tr>
<tr>
<td>Low contrast BCVA (12.5%)</td>
<td>0.258 ± 0.071</td>
<td>18/18 (100%)</td>
<td>2/18 (11.1%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intermediate (80 cm)</th>
<th>Mean</th>
<th>20/40 or better</th>
<th>20/25 or better</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCIVA</td>
<td>0.222 ± 0.065</td>
<td>18/18 (100%)</td>
<td>18/18 (100%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intermediate (60 cm)</th>
<th>Mean</th>
<th>20/40 or better</th>
<th>20/25 or better</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCIVA</td>
<td>0.201 ± 0.082</td>
<td>18/18 (100%)</td>
<td>18/18 (100%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Near (40 cm)</th>
<th>Mean</th>
<th>20/40 or better</th>
<th>20/25 or better</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCNVA</td>
<td>-0.005 ± 0.085</td>
<td>18/18 (100%)</td>
<td>15/18 (83.3%)</td>
</tr>
<tr>
<td>BCNVA</td>
<td>-0.025 ± 0.062</td>
<td>18/18 (100%)</td>
<td>18/18 (100%)</td>
</tr>
</tbody>
</table>

UCVA= uncorrected distance visual acuity; BCVA= best-corrected distance visual acuity; BCIVA= best-corrected distance intermediate visual acuity; UCNVA= uncorrected distance near visual acuity; BCNVA= best distance-corrected near visual acuity.
vision questionnaire on this should be performed to prove this statement.

There have been several previous studies of photopic CS after multifocal IOL implantation (see Montés-Micó et al. for a review). Most of the literature published on this topic point out that photopic CS with a multifocal IOL is reduced compared with that for a monocentric IOL, being, however, within the normal range. The results found for the AcrySof ReSTOR aspheric IOL agree with this (Figure 3). Decreased CS in patients with multifocal IOLs, as compared with patients with monocentric IOLs (as observed by Rocha et al. and Souza et al.) or phakic eyes (standard, 3 cd/m²), is explained by the multifocal’s division of the available light energy in the image between two or more focal points. Light energy distribution for the AcrySof ReSTOR IOL depends on the pupil diameter and varies approximately from 40 to 90% at the far focus and from 9 to 40% at the near focus. The loss in photopic CS observed for the aspheric ReSTOR IOL is somewhat smaller compared to standard values and comparable to that found for spherical ReSTOR IOLs (P > 0.1). It may be that the effect of the aspheric profile combined with the ocular longitudinal chromatic and other types of ocular aberration, together with the blending zones of the IOL, tend to mask the differences in CS.

Under mesopic conditions distance CS would be expected to be little affected since, thanks to the relatively small diameter of the apodized diffractive zone and the contribution of the purely refractive outer zone (pupils > 5 mm), more than 80% of the light contributes directly to the distance image. Correspondingly less than 20% of the light contributes to the near image, leading to noticeably worse mesopic CS at near. Differences between the three IOLs at all spatial frequencies were not significant (P > 0.1). Note the different lighting condition for mesopic examination across studies: 5 cd/m² for the spherical ReSTOR IOLs versus 3 cd/m² for the aspheric ReSTOR IOL. One should consider that the loss in retinal image contrast has little effect on acuity as measured with high-contrast letters, since contrast can be reduced to quite low levels before acuity is affected.

In conclusion, the present study shows that the AcrySof ReSTOR aspheric apodized diffractive IOL yields good high-contrast visual acuity at both distance and near; as well as a good CS at photopic and mesopic conditions. Intermediate vision is improved in relation to that found with the spherical AcrySof ReSTOR.

REFERENCES

14. Data on file, Alcon Labs. Forth Worth TX, USA.


