# Distance and near contrast sensitivity function after multifocal intraocular lens implantation

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**Purpose:** To evaluate contrast sensitivity at distance and near after multifocal intraocular lens (IOL) implantation.

**Setting:** Ophthalmologic Institute of Alicante, University Miguel Hernández, Alicante, Spain.

**Methods:** Contrast sensitivity was measured with the Stereo Optical Functional Acuity Contrast Test at distance and near in 21 patients with a refractive multifocal IOL (Array SA-40N, AMO). A control group with a monofocal IOL (SI-40NB, AMO) was also studied to allow comparison of results. Contrast sensitivity was measured 1, 3, 6, 12, and 18 months after IOL implantation.

**Results:** There was a statistically significant greater reduction in contrast sensitivity at distance at all spatial frequencies in the multifocal group than in the monofocal group during the first month. At 3 months, contrast sensitivity at 12 and 18 cycles per deg remained reduced in the multifocal group; contrast sensitivity at the other frequencies did not differ from that in the monofocal group ($P > 0.1$). At 6, 12, and 18 months, contrast sensitivity at all spatial frequencies was not significantly different between groups ($P > 0.1$). There was a statistically significant greater reduction in near contrast sensitivity in the multifocal group than in the monofocal group at all spatial frequencies during the first and third month after surgery ($P < .01$). No statistically significant differences were found between groups after 6 months ($P > 0.1$). Contrast sensitivity at distance and near in the multifocal group improved over time ($P < .01$).

**Conclusions:** The Array IOL provided contrast sensitivity at distance comparable to that obtained with the monofocal IOL between 3 and 6 months after implantation. Near contrast sensitivity improved over time but was always lower than at distance and in the monofocal near-corrected patients, which is acceptable to avoid near visual function degradation.

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Multifocal intraocular lenses (IOLs) are designed to reduce dependence on eyeglasses after cataract surgery, and the IOL is gaining acceptance as a potential refractive surgical option in selected patients. Monofocal IOLs were designed to provide vision at 1 distance, typically far. Patients with traditional monofocal IOLs usually require glasses for near distance tasks such as reading. The introduction of bifocal and multifocal IOLs in the early 1980s offered cataract patients the potential to obtain a good range of uncorrected vision from near to far.[1–7] The multifocal IOL takes advantage of the brain's natural ability to adapt to near and far vision as it uses the different elements of the lens depending on what it is looking at. Multifocal IOLs do not offer true accommodating vision but rather are an alternative optical mechanism for providing distance and near vision.

The Array (AMO) is a 5-zone refractive multifocal IOL that has been approved for clinical use in the United States and Europe. It uses multiple concentric

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rings of varying optical power, extending the range of uncorrected vision. Many studies of the Array IOL show that it provides comparable distance visual acuity and affords better near visual acuity than conventional monofocal IOLs.[8–11] In general, patients are less dependent on eyeglasses and thus often enjoy an enhanced quality of life. Despite an improvement in uncorrected near visual acuity with these lenses, loss of clarity and low-contrast acuity and the presence of halos and glare have been reported.[12–14]

Montés-Micó and Charman[15,16] state that the effectiveness of refractive surgery can only be properly assessed through measurements of postoperative visual performance. The performance index most commonly used for spatial vision is high-contrast visual acuity. Such a measure, however, primarily relates to vision at high spatial frequencies; it gives little information on visual performance at lower spatial frequencies and contrasts. Thus, contrast sensitivity function should be used in addition to high-contrast acuity measures. Studies of multifocal IOLs report considerably different contrast sensitivity results[13,14,17–22]; however, caution should be exercised when comparing results, particularly contrast sensitivity, among different studies with different patients, contrast sensitivity charts, illumination conditions, and clinicians. Comparison with the results in the literature is useful; however, these considerations should be remembered when attempting direct comparisons.

Patients with multifocal IOLs use 2 focal points for sharp imaging on the retina depending on the object's distance. Multifocal IOLs enable projection onto the retinal plane of images set at various distances. Patients can use this feature after becoming accustomed to the IOL, which involves a cortical process of elaboration and selection.[23] Because patients need time to become accustomed to the IOL, the visual response may vary depending on the time after IOL implantation. Therefore, the differences in some studies may reflect the different evaluation times after IOL implantation.

The objective of this study was to see whether there is a correlation between contrast sensitivity at distance and near over a period of time after multifocal IOL implantation. To confirm whether correlations identified with the multifocal IOL are accurate, we also examined contrast sensitivity in age-matched control eyes with monofocal IOLs.

## Patients and Methods

This prospective study comprised 21 consecutive patients who had binocular implantation of an Array SA-40N multifocal IOL and 21 eyes of 21 age-matched patients who had binocular implantation of an SI-40NB monofocal IOL (AMO). For each patient with a multifocal IOL, a control patient with a monofocal IOL was selected who was within 5 years of the same age. Exclusion criteria in both groups included ocular disease other than cataract (eg, glaucoma, macular degeneration, corneal or neuroophthalmic diseases) and a history of ocular surgery or inflammation. Also excluded were patients with astigmatism greater than 1.50 diopters (D) as cylinder greater than this has been shown to decrease near vision abilities with the Array lens (R.F. Steinert, MD, "How to Use the New Multifocal IOL," Review of Ophthalmology, May 1988, pages 74–80).

The patients' demographics are shown in Table 1. There were no statistically significant differences between the multifocal and monofocal IOL groups in age, sex, or corneal astigmatism. Normality of the data distribution was evaluated using the Kolmogorov-Smirnov test.

The Array SA-40N multifocal IOL is structurally identical to the AMO SI-40NB monofocal IOL except for the optic's multifocal design. The overall diameter of both lenses is 13.0 mm and the optic diameter, 6.0 mm. The IOL power ranged from +19.50 to +22.50 D. With the Array multifocal IOL, the near power increases to +3.50 D.

All cataracts were extracted by phacoemulsification using topical anesthesia and a clear corneal 3.2 mm temporal incision, irrigation/aspiration of cortex, and IOL implantation in

**Table 1.** Demographics and characteristics of patients.

| Characteristic | Array | Monofocal | *P* Value |
|---|---|---|---|
| Number of eyes | 21 | 21 | — |
| Mean age (y) ± SD | 65.4 ± 3.8 | 64.9 ± 4.1 | .5261 |
| Sex (M/F) | 10/11 | 9/12 | .4158 |
| Mean astigmatism (D)* ± SD | 0.74 ± 0.51 | 0.87 ± 0.38 | .2583 |

*Postoperative corneal astigmatism measured by topography the capsular bag. There were no complications in any case, and all patients reported being happy with the outcome of their surgery.

The tenets of the Declaration of Helsinki were followed in this research. Informed consent was obtained from all patients after the nature and possible consequences of the study were explained.

*Contrast Sensitivity Evaluation*

Contrast sensitivity was measured with the Stereo Optical Functional Acuity Contrast Test (FACT) in both groups. This test allows presentation of sine-wave gratings of different spatial frequencies, with contrasts changing in steps corresponding to 0.15 log contrast sensitivity. The manufacturer's recommended testing procedures were followed; distance vision was tested at 3 m and near vision, at 40 cm. Absolute values of log contrast sensitivity were obtained for each eye at various spatial frequencies for distance and near vision. The means and standard deviations were calculated. Data were then expressed in the new notation of normalized contrast sensitivity values developed by Boxer Wachler and Krueger[24] to facilitate effective communication and evaluation of the results. This involved dividing the absolute log contrast sensitivity values for the FACT chart by the population mean obtained by Boxer Wachler and Krueger for each spatial frequency shown at a luminance of 85 cd/m$^2$. In these terms, "normal" performance always corresponds to a unit-normalized contrast sensitivity. This notation has been found useful in the evaluation of patients having refractive surgery[15,16] and in the assessment and diagnosis of diseases.[25]

Measurements were done monocularly in both groups 1, 3, 6, 12, and 18 months after IOL implantation. The nonviewing left eye was occluded for each measurement, and best distance correction was used with the viewing right eye (not necessarily the dominant eye). Near contrast sensitivity evaluation was done with the best distance correction and with near addition, separately. Contrast sensitivity function was always measured with best distance correction to prevent residual refractive error (defocus) from affecting the contrast sensitivity values.

Logarithmic contrast sensitivity values were used for statistical analysis, and normalized values were used for graphical representation.[15,16,24,25]

## Results

Figure 1 shows the changes over time in the mean and standard deviation of the normalized best corrected distance contrast sensitivity values in the multifocal and monofocal groups after IOL implantation. Data are shown separately for each spatial frequency (cycles per degree [cpd]). Figure 2 shows the normalized near contrast sensitivity values in both groups with best corrected distance and a near addition. A 1-way analysis of variance (ANOVA) assessing the interactions between the changes in log contrast sensitivity values and the time postoperatively in both groups at distance and near (Table 2) showed a statistically significant correlation in the multifocal group at distance and near ($P < .01$). No statistically significant correlation was found in the monofocal group at any distance or spatial frequency.

The results of a *t* test on the data of the 2 groups (absolute log contrast sensitivity values) at each spatial frequency to obtain the statistical significance of intergroup differences are shown in Tables 3 and 4 for distance and near vision, respectively. Differences with a *P* value less than 0.01 were considered statistically significant.

**Table 2.** The *P* values of the 1-way ANOVA.

| Spatial Frequency (cpd) | Distance Contrast Sensitivity | | Near Contrast Sensitivity | | |
|---|---|---|---|---|---|
| | MC | MoC | MC | MNC | MoNC |
| 1.5 | .007* | .202 | .006* | .008* | .324 |
| 3 | .008* | .310 | .005* | .007* | .277 |
| 6 | .006* | .132 | .005* | .006* | .310 |
| 12 | .005* | .259 | .003* | .002* | .182 |
| 18 | .009* | .287 | .002* | .002* | .194 |

MC = multifocal best corrected distance; MoC = monofocal best corrected distance; MNC = multifocal near corrected; MoNC = monofocal near corrected

*Statistically significant difference

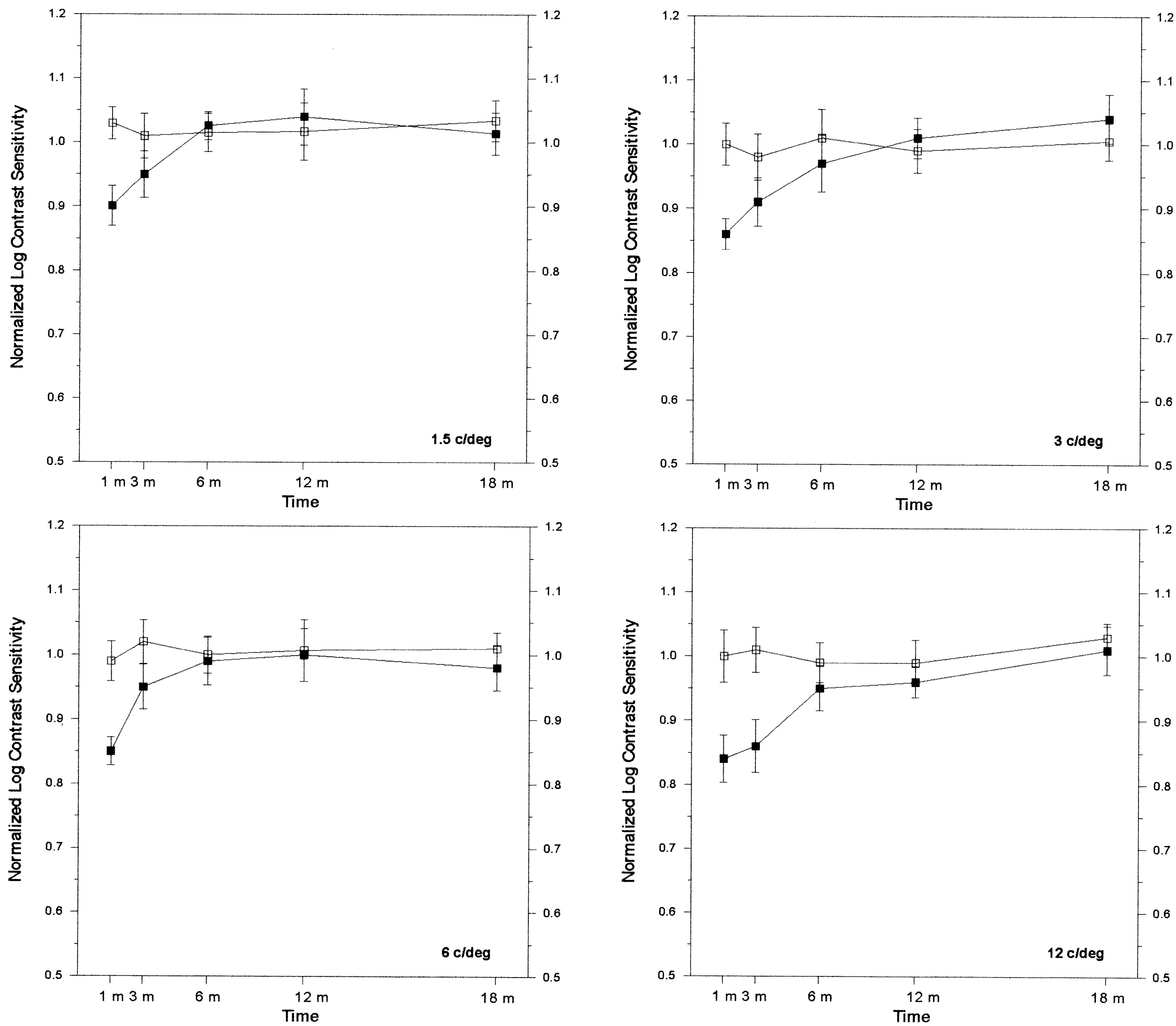
**Table 3.** Differences in log best corrected distance contrast sensitivity between the multifocal and monofocal groups postoperatively over time at each spatial frequency.

| Spatial Frequency (cpd) | *P* Value (*t* Test) | | | | |
|---|---|---|---|---|---|
| | 1 Mo | 3 Mo | 6 Mo | 12 Mo | 18 Mo |
| 1.5 | .005* | .348 | .376 | .434 | .261 |
| 3 | .008* | .102 | .269 | .210 | .399 |
| 6 | .004* | .296 | .328 | .365 | .166 |
| 12 | .005* | .003* | .355 | .294 | .155 |
| 18 | .001* | .002* | .273 | .185 | .213 |

*Statistically significant difference

## Discussion

Multinational clinical trials evaluating the clinical, functional, and quality-of-life outcomes after implanta-



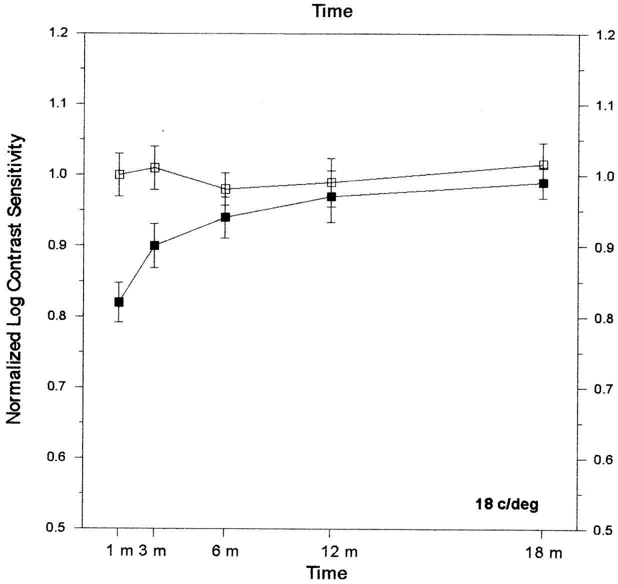
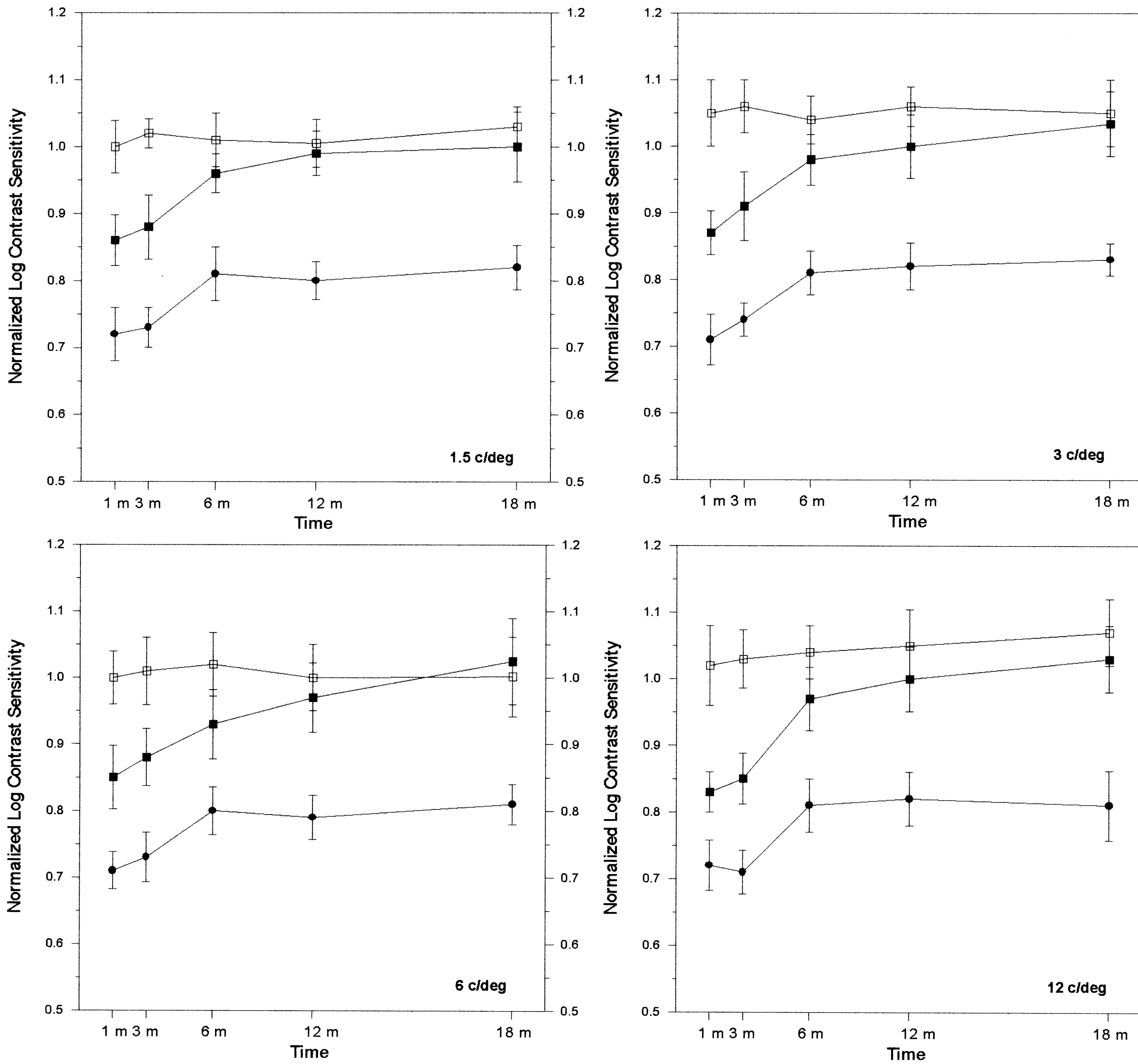




**Figure 1.** (Montés-Micó) Normalized monocular best corrected distance log contrast sensitivity after IOL implantation at 5 spatial frequencies (black squares = multifocal group; open squares = monofocal group; vertical bars = ±1.0 standard deviation; m = months postoperatively). Normalization at each spatial frequency is in terms of the mean log contrast sensitivity values in normal eyes[24]; that is, 1.5 cpd, 1.82; 3 cpd, 2.02; 6 cpd, 2.09; 12 cpd, 1.85; and 18 cpd, 1.45. The normalized values of log contrast sensitivity as plotted can be converted to absolute values by multiplying by the Boxer Wachler and Krueger means.[24]



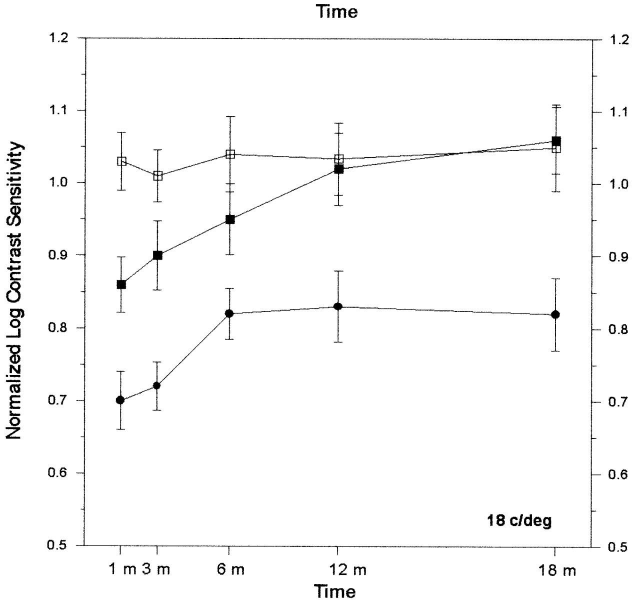




**Figure 2.** (Montés-Micó) Normalized monocular best corrected distance and near corrected log contrast sensitivity at near vision after IOL implantation at the 5 spatial frequencies (black points = multifocal best corrected distance group; black squares = multifocal near corrected group; open squares = monofocal near corrected group; vertical bars = ±1.0 standard deviations; m = months postoperatively).

**Table 4.** Differences in log near contrast sensitivity between the multifocal and monofocal groups postoperatively over time at each spatial frequency.

| Spatial Frequency (cpd) | | P Value (t Test) | | | | |
|---|---|---|---|---|---|---|
| | | 1 Mo | 3 Mo | 6 Mo | 12 Mo | 18 Mo |
| 1.5 | MNC/MoNC | .004* | .007* | .452 | .388 | .342 |
| | MC/MNC | .001* | .002* | .003* | .001* | .002* |
| 3 | MNC/MoNC | .007* | .008* | .311 | .180 | .283 |
| | MC/MNC | .004* | .005* | .003* | .003* | .002* |
| 6 | MNC/MoNC | .003* | .005* | .268 | .209 | .254 |
| | MC/MNC | .004* | .008* | .006* | .002* | .003* |
| 12 | MNC/MoNC | .002* | .007* | .545 | .339 | .269 |
| | MC/MNC | .008* | .005* | .006* | .003* | .004* |
| 18 | MNC/MoNC | .002* | .002* | .371 | .164 | .177 |
| | MC/MNC | .005* | .004* | .005* | .002* | .001* |

MNC = multifocal near corrected; MoNC = monofocal near corrected; MC = multifocal best-corrected distance
*Statistically significant difference

tion of the Array IOL[4–7] show that this lens improves near vision while providing a high level of distance vision. Patients with this lens report less limitation in visual function and less spectacle dependency than patients with a bilateral monofocal IOL, demonstrating that the Array IOL preserves the fundamental function associated with conventional monofocal optics with the additional benefit of increased range of vision from near to far and near vision without additional correction.

Our study showed that distance contrast sensitivity in the monofocal group achieved normal values (near to 1.0 normalized log contrast sensitivity at all spatial frequencies) that were stable over time. No statistically significant differences (1-way ANOVA) were found in the monofocal group between normalized log contrast sensitivity versus time postoperatively at any spatial frequency. However, the multifocal group had an initial reduction in contrast sensitivity after IOL implantation at each spatial frequency evaluated (between 0.8 and 0.9 normalized log contrast sensitivity). The contrast sensitivity increased gradually over time, becoming essentially stable 3 to 6 months postoperatively. There was a statistically significant increase in contrast sensitivity with time after IOL implantation in this group.

When intergroup differences were evaluated for best corrected distance contrast sensitivity, a *t* test revealed statistically significant differences between the multifocal and monofocal groups at 1 month at all spatial frequencies and at 3 months for 12 cpd and 18 cpd only. These results agree with the work of Hayashi and coauthors,[22] who found that distance contrast sensitivity with the Array multifocal IOL is reduced compared to that with a monofocal IOL 1 month after surgery at all spatial frequencies ($P < .05$). Sasaki[5] reports that after 3 months of Array multifocal IOL implantation, contrast sensitivity values were within normal limits at all spatial frequencies. Although Sasaki did not compare his data with the results in a monofocal IOL group, the values in the multifocal group were similar to ours.

Why is measured contrast sensitivity reduced in the immediate period after multifocal IOL implantation when compared with monofocal IOL implantation? One possibility is the division of light energy through 2 focal points produced by the multifocal IOL. Ravalico and coauthors,[26,27] using a laser optical bench, found that approximately 50% of the light energy in the Array IOL is concentrated at the distance focus and about 21% at the near focus. Recently, Pieh et al.[28] compared the optical properties of the Array IOL and a monofocal IOL, showing that the intensity of the distance focus reached 73.4% and the near focus attained 25.1% of intensity of a corresponding monofocal IOL. The reduced amount of light that is creating the distance focus as well as the overlying out-of-focus near image influences the multifocal IOL results. This explanation is plausible for our findings in the early postoperative period. However, other studies have shown a significant loss in contrast sensitivity only between 1 and 3 months after surgery, with normal values after. If we consider that patients require time to become accustomed to the multifocal IOL, the out-of-focus near image will not likely exert a great influence over time. It could be argued that depending on the time after IOL implantation, the patient is capable of adjusting to the new imagery created on the retina, with improving contrast sensitivity over time. Our results confirm this hypothesis because better results were found over time ($P < .01$) and were comparable to those obtained in the monofocal group ($P > .01$).

Interesting are the temporal changes in contrast sensitivity at each spatial frequency tested. One month after multifocal IOL implantation, the decrease in contrast sensitivity at all frequencies was greater in the multifocal group than in the monofocal group. The decrease was statistically significant and more severe at high spatial frequencies. At 3 months, a significant reduction occurred only at high spatial frequencies, 12 cpd and 18 cpd. Montés-Micó and Charman[15] showed that contrast sensitivity at 1.5 cpd and 3 cpd is affected primarily by light scatter associated with haze, whereas contrast sensitivity at 6 cpd, 12 cpd, and 18 cpd is degraded by haze and optical blur (defocus and optical aberrations). If we consider a degree of residual haze after IOL implantation, decreased contrast sensitivity is expected after surgery at all spatial frequencies. As the haze disappears, the contrast sensitivity improves over time. However, no eye in the multifocal or monofocal group had corneal haze at any postoperative examination. Thus, the differences between spatial frequencies were probably the result of the effect of optical aberrations. (Defocus does not play a role as patients were evaluated with best correction in place.) However, this explanation does not account for the normal contrast sensitivity in the monofocal group. Further study of high-order aberrations in patients with a multifocal IOL and the change versus time is needed.

At near vision, contrast sensitivity in the monofocal group with near correction was similar to distance vision, with values near the 1.0 normalized log contrast sensitivity. No statistically significant differences were found over time. Following the same pattern as distance, multifocal near corrected contrast sensitivity showed a contrast sensitivity loss after surgery that improved over time. The results in the multifocal group were compared with those in the monofocal group. Statistical analysis revealed differences in log contrast sensitivity values between the groups at 1 and 3 months. The *t* test values yielded a $P$ value less than 0.01 at every spatial frequency. However, at 6, 12, and 18 months, the differences were not significant. As discussed previously, contrast sensitivity reduction in multifocal patients comes from the division of light energy between distance and near focus.

When the evaluation was done without near addition in the multifocal group, corresponding to the normal visual condition of the patients, reduced contrast sensitivity values were found at 1 month at all spatial frequencies (about 0.7 normalized log contrast sensitivity). There was a trend toward an incremental increase in contrast sensitivity over time; values were higher than the 0.8 normalized log contrast sensitivity at 18 months. These results support the concept that after a period of the patient becoming accustomed to the multifocal IOL, contrast sensitivity is better. No comparison was possible with a monofocal best corrected distance group because this group could not detect the gratings at the maximum available chart contrast. These results were expected because of the lack of accommodation. Statistically significant differences at each spatial frequency and postoperative time studied were found between multifocal near corrected and multifocal best corrected distance. Contrast sensitivity improvement in the multifocal near corrected group in relation to multifocal best corrected distance group was a result of the magnification of the add power (near to 0.2 log contrast sensitivity).

Regarding temporal changes in spatial frequencies, our results show differences between near and distance vision. Both were reduced at all spatial frequencies 1 month after IOL implantation. However, at 3 months, only high spatial frequencies at distance were affected. In contrast, both high and low spatial frequencies (1.5 to 18 cpd) were affected at near. Pieh et al.[28] point out that the out-of-focus image overlaying the distance focus of the Array IOL is approximately 3% of the light intensity of the distance focus, whereas the point spread function of the near focus is substantially affected by the out-of-focus image. Thus, if there is greater degradation of the image at near vision in relation to distance, an attenuation across the spatial frequency spectrum (from high to low spatial frequencies) could be expected. High-order aberrations might play a role, and studying them may explain the degrading effects on contrast sensitivity found between spatial frequencies at distance and near with the multifocal IOL and the variation over time.

In our study, contrast sensitivity values were worse at near. This may be attributed to the light energy distribution found by Ravalico and coauthors[26,27] and Pieh et al.[28] that leads to lower values at near focus. Because of this, contrast sensitivity in the monofocal near corrected group was near to unity because the light energy was focused on a single point instead of 2, as in the multifocal group. These results agree with the work of Sasaki,[5] who found lower values of contrast sensitivity at near in relation to distance.

In conclusion, the Array multifocal IOL provided excellent contrast sensitivity at distance that was comparable to that obtained with monofocal IOLs between 3 months and 6 months after implantation. At near vision, results improved over time but were always lower than at distance and in monofocal near corrected patients, although acceptable to avoid near visual function degradation. Perhaps a near addition would be necessary for reading small letters because of the dominant distance acuity of the IOL. In all cases, contrast sensitivity improved over time, suggesting a learning process resulting from a brain adaptation phenomenon that overcomes the contrast sensitivity decrease at the initial stages after surgery. However, this needs to be proved by evaluating the optics of the eye over time. Future investigations of the visual performance of multifocal IOL patients should include, in addition to contrast sensitivity, evaluation of optical aberrations versus time to verify the existence of a brain adaptation phenomenon.

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