ARTICLE

Outcomes of a new diffractive trifocal intraocular lens

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PURPOSE: To evaluate refractive and visual parameters related to distance, intermediate, and near vision after cataract surgery and the optical quality of a new diffractive trifocal intraocular lens (IOL).

SETTING: Vissum Instituto Oftalmologico de Alicante, Alicante, Spain.

DESIGN: Case series.

METHODS: Patients had bilateral refractive lens exchange and multifocal diffractive IOL (AT Lisa tri 839 MP) implantation. A complete ophthalmology examination was performed preoperatively and postoperatively. The follow-up was 6 months. The main outcome measures were uncorrected distance (UDVA) and corrected distance (CDVA), intermediate, and near visual acuities; keratometry; manifest refraction; and aberrations (total, corneal, internal).

RESULTS: The study comprised 60 eyes of 30 patients (mean age 57.9 years $\pm$ 7.8 [SD]; range 42 to 76 years). There was significant improvement in UDVA, uncorrected intermediate visual acuity, uncorrected near visual acuity, CDVA, and distance-corrected intermediate and near visual acuity. The postoperative refractive status was within the range of $+1.00$ to -1.00 diopter. Total internal aberrations decreased significantly (P<.001).

CONCLUSIONS: The trifocal IOL improved near, intermediate, and distance vision in presbyopic patients. The use of 3 foci provided significant intermediate visual results without sacrificing near or distance vision.

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The prevalence of presbyopia[1,2] and the importance of near and intermediate vision in modern society are the main reasons that motivated the development of techniques to compensate for this refractive condition. Examples of nonsurgical procedures are the use of progressive spectacles and contact lenses. Examples of surgical methods[3] include scleral expansion and sclerotomy,[4,5] corneal procedures (presbyopic laser in situ keratomileusis),[6] corneal inlays,[7,8] conductive keratoplasty,[9] monovision,[10] and multifocal intraocular lenses (IOLs).[11,12]

Studies[13–16] report that the loss of reading skills can reduce the quality of life of presbyopic patients. It has been shown that the use of multifocal IOLs can improve uncorrected near visual acuity (UNVA) and uncorrected distance visual acuity (UDVA) and therefore reduce spectacle dependence.[17] Toward this purpose, many designs based on different physics principles have been applied in the manufacturing of IOLs. Basically, 4 types of IOLs are available; that is, refractive, diffractive, refractive–diffractive, and accommodating. Although all can improve UNVA and UDVA, there are collateral effects that should be avoided, such as halos, glare, and loss of contrast sensitivity.[18–21] Moreover, great variability in uncorrected intermediate visual acuity (UIVA) results has been observed with the use of different commercial IOL models. Therefore, improvement in intermediate vision is still needed to increase the level of patient satisfaction.

Many professional and domestic tasks, especially the use of computers, require good intermediate vision. In this sense, the achievement of an intermediate focus in IOLs might help solve this problem. In the present study, bilateral implantation of the AT Lisa tri 839MP (Carl Zeiss Meditec AG), a new diffractive IOL with a trifocal design, was tested. To our knowledge, this is the first study of the behavior of this model and one of the few studies of trifocal IOL technology.[22–25]

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The aim of this study was to evaluate and to discuss the results obtained for distance, intermediate, and near visual acuity; defocus and contrast sensitivity curves; and quality of vision after implantation of the trifocal IOL. Surgical complications during the follow-up and the negative side effects were also evaluated.

PATIENTS AND METHODS

Patients had bilateral phacoemulsification with trifocal IOL implantation for presbyopic correction. All patients were adequately informed and signed a consent form. The study adhered to the tenets of the Declaration of Helsinki and was approved by the local ethics committee.

The inclusion criteria were refractive lens exchange for presbyopia, bilateral surgery, astigmatism of less than 1.0 diopter (D), uneventful surgery, and IOL power between 0.0 D and +32.0 D. The exclusion criteria were previous ocular surgery, ocular disease, complications during surgery, and corneal astigmatism of more than 1.0 D.

Preoperative and Postoperative Examinations

Preoperatively, all patients had an ophthalmologic examination including UDVA and CDVA (4 m, Early Treatment of Diabetic Retinopathy Study [ETDRS]), UNVA and corrected near visual acuity (CNVA) (33 cm), and UIVA and corrected intermediate visual acuity (CIVA) (66 cm) (modified ETDRS for European-wide use for near and intermediate distance recordings, Precision Vision). Other examinations were Goldmann applanation tonometry, slitlamp evaluation, fundoscopy, corneal topography, biometry (IOLMaster, version 4.3, Carl Zeiss Meditec AG), contrast sensitivity measurements under photopic conditions (85 candelas/m^2), (CSV 1000, Vector Vision), optical

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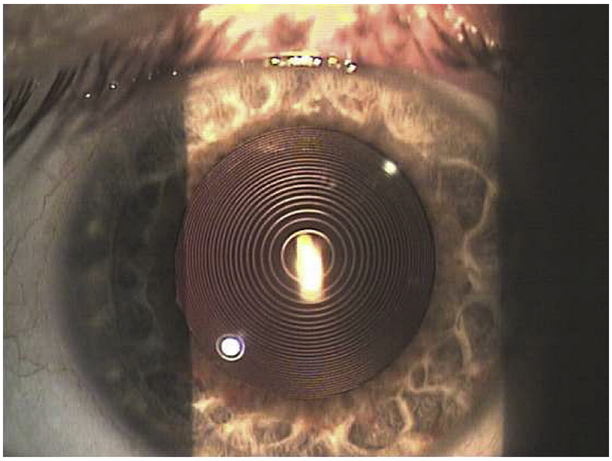


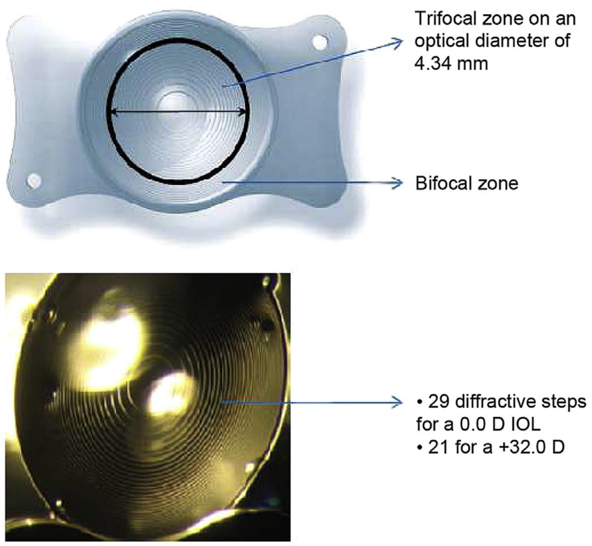
Figure 1. Implanted trifocal IOL.

aberrations (ocular, corneal, and internal), root mean-square (RMS) values and the Strehl ratio (OPD Scan III, Nidek Co. Ltd.). These measurements were recorded with the pupil under cycloplegia with a minimum diameter of 5.0 mm obtained using phenylephrine 10.0%. All measurements correspond to a 5.0 mm pupil. Patients were evaluated 1 and 7 days and 1, 3, and 6 months postoperatively. One and 7 days after surgery, only UDVA, UNVA, intraocular pressure (IOP), and the integrity of the anterior segment were evaluated. The postoperative examination protocol at 1, 3, and 6 months was identical to the preoperative protocol. The postoperative protocol also included visual acuity at 40 cm. Three months after surgery, defocus curves were obtained to characterize the far, near, and intermediate visual function. Defocus curves were obtained using ETDRS charts at 4 m with monocular and binocular vision for each patient; the measurements were performed using distance correction. Lenses from +4.5 to 0.0 D in 0.5 D steps were placed in front of each eye, and the value of visual acuity was recorded. Afterward, measurements were taken using negative lenses up to −4.5 D. This information was represented in a 2-dimensional graphic using Cartesian coordinates (spherical blur in the x-axis and visual acuity in the y-axis). Comparisons of intermediate vision were performed at 66 cm, and comparisons of near vision were performed at 33 cm.

All patients completed a test provided by the manufacturer of the trifocal IOL to evaluate the subjective degree of satisfaction for different tasks. This test is not validated to evaluate the quality of life of the patient before or after IOL implantation. However, it was thought it would be interesting to analyze these results, at least with the purpose of finding correlations between the scores and several visual variables. A clinician registered the scores to the following question: Describe, using a number, the quality of vision for these different tasks. Tasks evaluated were television, theater/concerts, at home, driving at daytime, driving at night (distance vision), cooking, newspaper, computer, and housework (intermediate and near vision). The possible scores were excellent (1), very good (2), good (3), not completely satisfied (4), dissatisfied (5), and very dissatisfied (6).

Surgical Technique

All surgeries were performed by the same experienced surgeon (P.M.) using a standard technique of sutureless



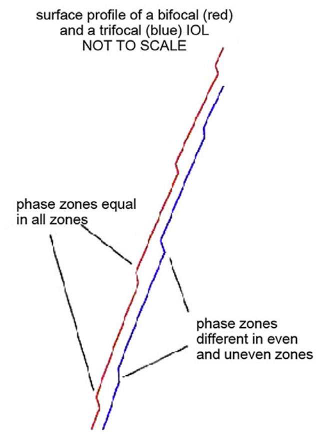


Figure 2. Diffractive design of the trifocal IOL (IOL = intraocular lens).

microcoaxial phacoemulsification. In all cases, topical anesthesia drops were applied before the surgical procedure. The microincision was 1.6 mm, and it was placed temporally. After capsulorhexis creation and phacoemulsification (Infinity Vision System, Alcon Laboratories, Inc.), the trifocal IOL was implanted in the capsular bag through the 1.6 mm incision with a single-use Bluemixs 180 injector (Carl Zeiss Meditec). Postoperative topical therapy included tobramycin and dexamethasone (Tobradex).

Intraocular Lens

The AT Lisa tri 839MP is a preloaded IOL with a single-piece diffractive multifocal design. It has a 6.0 mm biconvex optic and an overall length of 11.0 mm (Figure 1). It is a foldable hydrophilic acrylate IOL with a water content of 25% and hydrophobic surface properties. Its smooth diffractive structure is designed to reduce unwanted diffraction to increase optical quality. The surface is divided into main zones and phase zones. The diffractive structure has a soft transition of the phase zones between the main zones (Figure 2). The adjusted phase zones were designed to reduce disturbing light phenomena (eg, scattered light, halos) to improve retinal image quality and visual performance. This trifocal IOL consists of different phase zones in even and uneven zones. The optic does not have sharp angles with the goal of providing excellent optical image quality with reduced light scattering. Diffractive rings cover the entire optic diameter. The optic of the IOL consists of a central 4.34 mm trifocal zone and a peripheral bifocal zone from 4.34 to 6.00 mm. The fewer rings on the optic surface are intended to reduce the risk for visual disturbances. The aspheric optic corrects spherical aberrations of the typical cornea; the asphericity of the IOL is -0.18 μm.

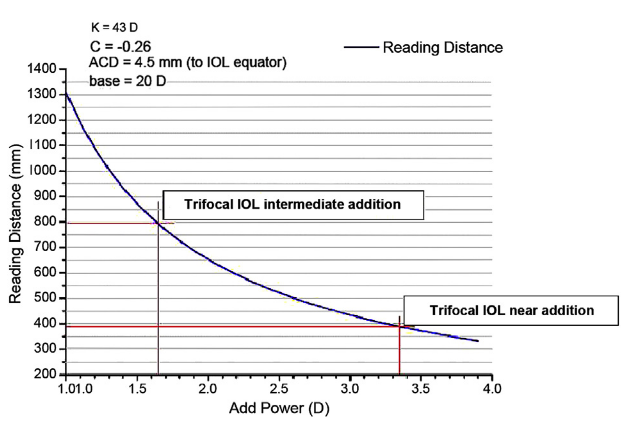


Figure 3. Relationship between reading distance and addition (ACD = anterior chamber depth; Add = addition; C = cylinder; IOL = intraocular lens; K = keratometry; IOL = intraocular lens).

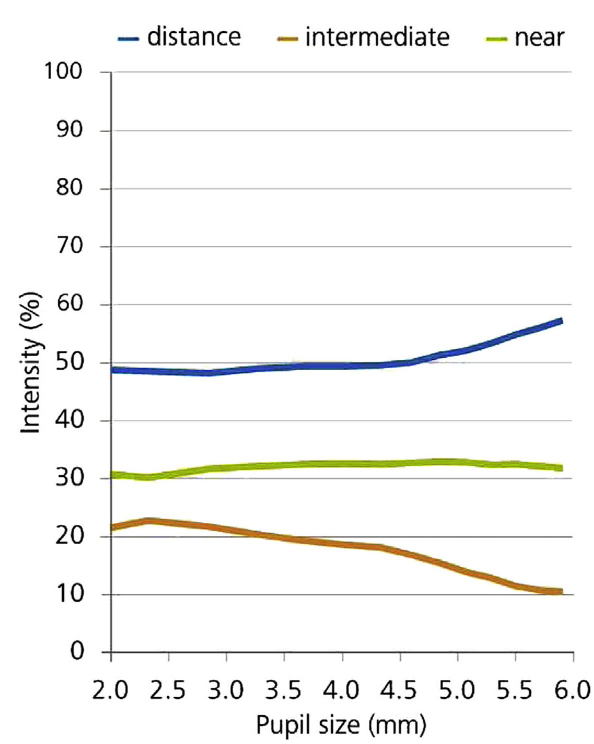


Figure 4. Dependence of light-intensity distribution for far, intermediate, and near distances as a function of pupil size.

Table 1. Keratometric changes over time.

Variable (D)	Preoperative	Postoperative 1 Month	Postoperative 3 Months	Postoperative 6 Months	P Value*
K2					
Mean ± SD	43.55 ± 1.23	43.60 ± 1.23	43.59 ± 1.26	43.54 ± 1.21	.769
Range	40.27, 46.49	40.51, 46.55	40.11, 46.68	40.76, 46.62	
K1					
Mean ± SD	42.99 ± 1.28	43.00 ± 1.34	43.06 ± 1.29	42.99 ± 1.32	.970
Range	39.62, 45.86	39.76, 45.96	39.85, 45.92	39.52, 45.86	
K2 − K1					
Mean ± SD	0.56 ± 0.23	0.58 ± 0.28	0.54 ± 0.26	0.54 ± 0.31	.611
Range	0.16, 1.13	0.11, 1.43	0.05, 1.15	0.00, 1.32	

K1 = flattest meridian; K2 = steepest meridian; K2 − K1 = corneal cylinder
*Preoperative versus 6 months postoperative

This IOL has a trifocal anterior surface and provides an addition of 3.33 D for near and of 1.66 D for intermediate at the IOL plane (Figure 3). Its design allocates 50.0% of light to distance, 20.0% to intermediate, and 30.0% to near (Figure 4); its overall efficiency of global light transmittance is 85.7%. The IOL is not dependent on pupil diameters up to 4.5 mm and provides adequate visual performance under all lighting conditions. It has a 4-haptic design with an angulation of 0 degree and a 360-degree square edge to prevent posterior capsule opacification formation. It has spherical powers of 0.00 D to +32.00 D in 0.50 D increments and is implanted with a single-use injector through an incision smaller than 1.8 mm.

Statistical Analysis

Statistical analysis of the data was performed using SPSS for Windows software (version 19.0, SPSS, Inc.). Normality of the samples was studied with the Kolmogorov-Smirnov test and homoscedasticity with the Levene test. When parametric statistical analysis was possible, the Student *t* test for paired data was applied to assess the significance of differences between preoperative data and postoperative data; the Wilcoxon rank-sum test was applied when parametric statistical analysis was not possible. To compare several independent samples, analysis of variance or the Kruskal-Wallis test was applied depending on the normality or non-normality of the samples. To compare several related samples, the Friedman test was applied.

The level of statistical significance was always the same ($P<.05$). Correlation coefficients (Pearson or Spearman depending on whether normality could be assumed) were used to assess the correlation between variables.

RESULTS

The study enrolled 60 eyes of 30 patients. The mean patient age was 57.9 years ± 7.8 (SD) (range 42 to 76 years).

Keratometry

Table 1 shows the keratometry results. There were no significant differences in the flattest meridian (K1) or the steepest meridian (K2) between preoperatively and 6 months postoperatively ($P=.970$ and $P=.769$, respectively; Wilcoxon rank-sum test). There was no significant change in corneal cylinder (K2 − K1) between preoperatively and 6 months postoperatively ($P=.611$, Student *t* test for paired samples).

Refraction

Table 2 shows the refractive results in all patients over time. There were significant reductions in sphere, cylinder, and spherical equivalent (SE) ($P=.009$, $P<.001$, and $P=.010$, respectively; Wilcoxon rank-sum test).

The preoperative refractive status of the patients according to the type of ametropia was as follows: 42 eyes with hyperopic astigmatism (mean SE 1.78 ± 1.09 D; range +0.38 to +5.00), 5 eyes with mixed astigmatism (mean SE −0.08 ± 0.11 D; range −0.25 to 0.00 D), and 13 eyes with myopic astigmatism (mean SE −4.88 ± 3.83 D; range −12.25 to −0.25 D).

Postoperatively, the spherical equivalent decreased significantly to −0.12 ± 0.40 (−0.75 to +1.00) ($P<.001$, Wilcoxon rank-sum test) in hyperopic patients and to −0.13 ± 0.38 (−1.00 to +0.50) ($P=.003$ Wilcoxon rank-sum test) in myopic patients. In mixed astigmatism patients, the SE was −0.15 ± 0.35 (−0.50 to 0.25); no significant change was detected ($P=.680$, Wilcoxon rank-sum test).

Three months after surgery, the SE ranged from −0.63 to −1.00 D in 8 eyes (13.33%), from −0.50 to 0.00 D in 34 eyes (56.67%), and from +0.13 to +0.50 D in 18 eyes (30.00%).

Visual Acuity

Table 3 and Figure 5 show the visual acuities over time. There was a statistically significant improvement between preoperatively and 6 months

Table 2. Refractive changes over time.

Variable (D)	Preoperative	Postoperative 1 Month	3 Months	6 Months	P Value*
Sphere					
Mean ± SD	0.42 ± 3.38	−0.12 ± 0.40	0.00 ± 0.36	0.02 ± 0.38	.009
Range	−12.00, 5.25	−0.75, 1.00	−0.75, 0.75	−0.75, 1.00	
Cylinder					
Mean ± SD	−0.47 ± 0.31	−0.33 ± 0.21	−0.28 ± 0.19	−0.28 ± 0.24	<.001
Range	−1.25, 0.00	−0.75, 0.00	−0.75, 0.00	−1.00, 0.00	
SE					
Mean ± SD	0.18 ± 3.35	−0.28 ± 0.41	−0.14 ± 0.36	−0.12 ± 0.39	.010
Range	−12.25, 5.00	−1.00, 1.00	−1.00, 0.50	−1.00, 1.00	

SE = spherical equivalent
*Preoperative versus 6 months postoperative

postoperatively in the following variables: UDVA, CDVA, UIVA, distance-corrected intermediate visual acuity, UNVA, and distance-corrected near visual acuity.

The CNVA was slightly better 6 months after surgery, although no significant improvement was detected. The CIVA also improved slightly; the change was at the limit of significance.

Table 3. Changes in visual acuity over time.

LogMAR Acuity	Preoperative	Postoperative 1 Month	3 Months	6 Months	P Value*
UDVA					
Mean ± SD	0.53 ± 0.47	−0.03 ± 0.08	−0.04 ± 0.10	−0.03 ± 0.09	<.001
Range	0.00, 1.80	−0.20, 0.20	−0.20, 0.20	−0.20, 0.20	
CDVA					
Mean ± SD	0.02 ± 0.21	−0.05 ± 0.07	−0.06 ± 0.09	−0.05 ± 0.08	.012
Range	−0.30, 0.30	−0.20, 0.20	−0.20, 0.20	−0.20, 0.20	
UNVA (33 cm)					
Mean ± SD	0.92 ± 0.26	0.22 ± 0.13	0.19 ± 0.11	0.20 ± 0.12	<.001
Range	0.10, 1.40	−0.10, 0.50	0.00, 0.50	0.00, 0.50	
CNVA (33 cm)					
Mean ± SD	0.17 ± 0.19	0.20 ± 0.11	0.14 ± 0.10	0.13 ± 0.10	.230
Range	−0.20, 0.70	0.00, 0.50	−0.10, 0.30	0.00, 0.40	
DCNVA (33 cm)					
Mean ± SD	0.68 ± 0.19	0.20 ± 0.11	0.17 ± 0.10	0.17 ± 0.11	<.001
Range	0.10, 0.90	0.00, 1.00	0.00, 0.40	0.00, 0.40	
UIVA (66 cm)					
Mean ± SD	0.76 ± 0.27	0.08 ± 0.11	0.11 ± 0.10	0.08 ± 0.10	<.001
Range	0.00, 1.40	−0.10, 1.30	−0.10, 0.30	−0.10, 0.40	
CIVA (66 cm)					
Mean ± SD	0.13 ± 0.23	0.07 ± 0.10	0.08 ± 0.10	0.06 ± 0.11	.050
Range	−0.20, 0.50	−0.10, 0.30	−0.10, 0.30	−0.10, 0.40	
DCIVA (66 cm)					
Mean ± SD	0.43 ± 0.26	0.07 ± 0.10	0.10 ± 0.09	0.08 ± 0.10	<.001
Range	0.00, 0.90	−0.10, 0.30	−0.10, 0.30	−0.10, 0.40	

CDVA = corrected distance visual acuity; CIVA = corrected intermediate visual acuity; CNVA = corrected near visual acuity; DCIVA = distance-corrected intermediate visual acuity; DCNVA = distance-corrected near visual acuity; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity
*Preoperative versus 6 months postoperative (Wilcoxon test)

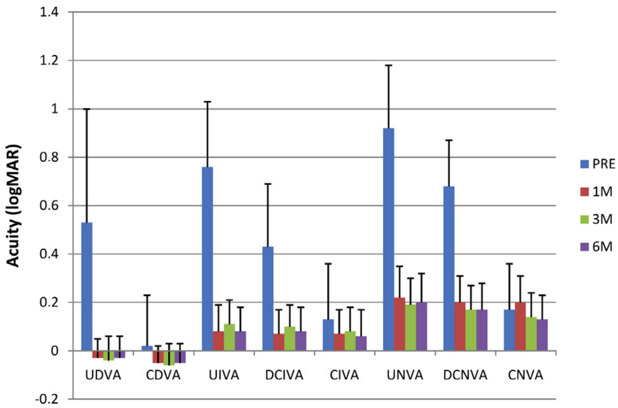


Figure 5. Visual outcomes for distance, intermediate (66 cm), and near (33 cm) distance during the follow-up. All variables were measured with and without correction (CDVA = corrected distance visual acuity; CIVA = corrected intermediate visual acuity; CNVA = corrected near visual acuity; DCIVA = distance-corrected intermediate visual acuity; DCNVA = distance-corrected near visual acuity; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity).

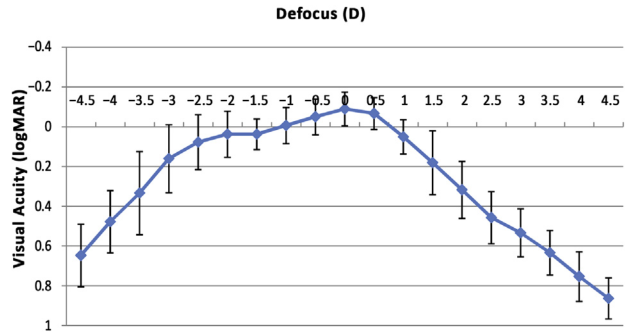


Figure 6. Defocus curve.

Defocus Curve

Figure 6 shows the mean visual acuities (logMAR) and their standard deviations for different values of the defocus. In this study, the visual acuity values achieved ranged from −0.09 ± 0.09 logMAR (for 0.0 D) to 0.16 ± 0.17 logMAR (for −3.0 D). The defocus curve remained stable along this interval, providing continuous and acceptable visual acuity at all distances. There were no statistically significant differences in visual acuity in the defocus range between +0.5 D and −0.5 D (P=.180, Kruskal-Wallis test). The intermediate-vision values were stable, with no significant differences in visual acuity in the range from −2.0 to −1.0 D (50 cm to 1 m) (P=.343, Kruskal-Wallis test).

Contrast Sensitivity Curve

Figure 7 shows the contrast sensitivity curve 6 months after surgery. From 1 month to 6 months postoperatively, there was a slight but statistically significant improvement in contrast sensitivity. The mean contrast sensitivity at low spatial frequencies (1.5 cpd) changed from 1.57 ± 0.13 log units to 1.62 ± 0.15 log units (P=.034, Wilcoxon rank-sum test); For medium-high frequencies (12 cpd), the contrast sensitivity changed from 1.35 ± 0.15 log units to 1.40 ± 0.16 log units (P=.019, Wilcoxon rank-sum test) and for high frequencies (18 cpd), from 0.73 ± 0.22 log units to 0.85 ± 0.25 log units (P=.001 Wilcoxon rank-sum test). There was no significant improvement in contrast sensitivity at 3 cpd or 6 cpd (P=.209 and P=.455, respectively; Wilcoxon rank-sum test) between 1 month and 6 months postoperatively. The best levels of contrast sensitivity were achieved at medium (6 cpd) spatial frequencies (P<.001 Kruskal-Wallis test).

Aberrometry

No significant differences were found between preoperative and postoperative corneal aberrations.

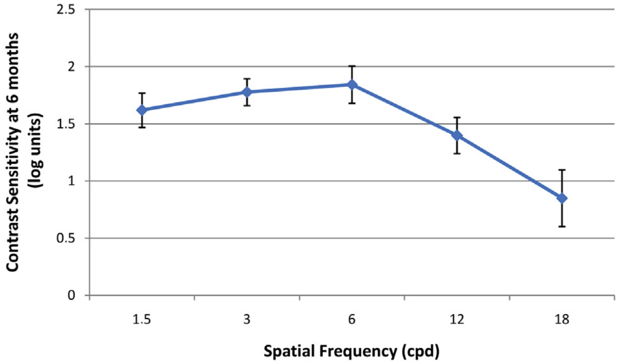


Figure 7. Contrast sensitivity curve under photopic conditions. Contrast sensitivity at different spatial frequencies (cpd = cycles per degree).

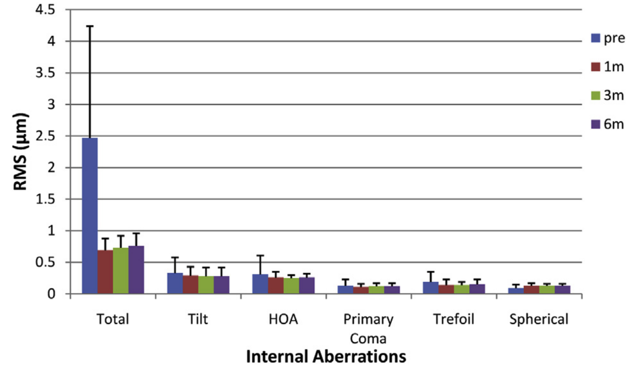


Figure 8. Changes in internal aberrations during the follow-up (HOA = higher-order aberration; RMS = root mean square).

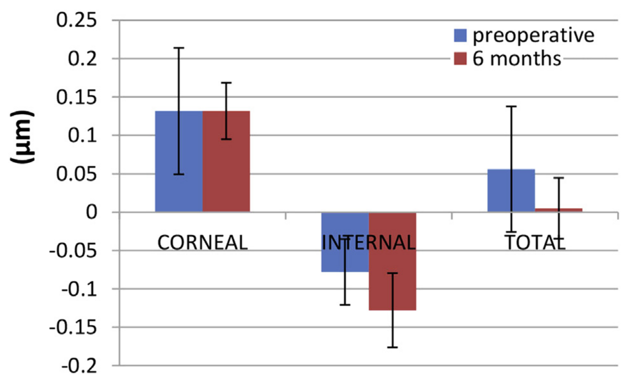


Figure 9. Changes in spherical aberration (Z4 coefficient) at corneal, internal, and ocular levels.

The lowest P value (.310, Wilcoxon rank-sum test) was for the change in corneal trefoil aberration.

For ocular aberrations, there was a significant decrease after the surgery in RMS total aberrations (from 2.16 $\pm$ 1.89 µm to 0.60 $\pm$ 0.18 µm) and RMS spherical aberration (from 0.11 $\pm$ 0.13 µm to 0.04 $\pm$ 0.03 µm) (both $P<.001$, Wilcoxon rank-sum test). The mean RMS higher-order aberrations (HOAs) changed from 0.33 $\pm$ 0.16 µm to 0.29 $\pm$ 0.10 µm; the difference was not statistically significant ($P=.075$, Wilcoxon rank-sum test).

There was a significant decrease in the mean total internal aberrations between preoperatively and 6 months postoperatively (from 2.47 µm to 0.76 µm) ($P<.001$, Wilcoxon rank-sum test). The RMS spherical aberration increased significantly (from 0.09 $\pm$ 0.06 µm to 0.13 $\pm$ 0.03 µm) ($P<.001$, Wilcoxon rank-sum test) (Figure 8). The Z(4,0) coefficient was more negative postoperatively and compensated better for corneal spherical aberration. This effect resulted in lower ocular spherical aberration values (Figure 9).

Using the Friedman test for several related samples, there were no significant changes in internal aberrations between 1, 3, and 6 months in the following: total internal ($P=.144$), tilt ($P=.682$), HOAs ($P=.583$), primary coma ($P=.247$), trefoil ($P=.190$), and spherical aberration ($P=.805$). Thus, the patients' visual function was restored from the first month after surgery and then remained stable.

There was a statistically significant improvement in the ocular Strehl ratio (from 0.11 $\pm$ 0.03 preoperatively to 0.14 $\pm$ 0.04 6 months postoperatively) ($P=.019$, Wilcoxon rank-sum test).

Complications

No serious complications, such as posterior capsule rupture, endophthalmitis, or corneal decompensation, occurred during the follow-up. Two patients had increased IOP immediately after surgery; it was treated by tapered administration of topical timolol twice per day.

Table 4. Scores for different visual tasks.

Task	Score*
Television	
Mean $\pm$ SD	1.13 $\pm$ 0.35
Range	1, 2
Theater/concert	
Mean $\pm$ SD	1.23 $\pm$ 0.43
Range	1, 2
Driving at daytime	
Mean $\pm$ SD	1.33 $\pm$ 0.48
Range	1, 2
At home	
Mean $\pm$ SD	1.17 $\pm$ 0.38
Range	1, 2
Driving at night	
Mean $\pm$ SD	2.57 $\pm$ 0.77
Range	1, 4
Cooking	
Mean $\pm$ SD	1.13 $\pm$ 0.35
Range	1, 2
Newspaper	
Mean $\pm$ SD	1.67 $\pm$ 0.71
Range	1, 3
Computer	
Mean $\pm$ SD	1.67 $\pm$ 0.80
Range	1, 4
Homework	
Mean $\pm$ SD	1.10 $\pm$ 0.31
Range	1, 2
Overall	
Mean $\pm$ SD	1.43 $\pm$ 0.57
Range	1, 2

*Excellent (1); very good (2); good (3); not completely satisfied (4); dissatisfied (5); very dissatisfied (6)

Patient Satisfaction

Table 4 shows the results of the subjective evaluation of patient satisfaction. The overall scores were highly correlated with the scores for the variable related to the household tasks (r = 0.512, $P<.001$). Overall scores were also strongly correlated with the scores obtained for reading a newspaper (r = 0.480, $P<.001$) and driving at night (r = 0.473, $P<.001$). Thus, these 3 questions had an important weight in the overall score assigned by each patient. Table 5 shows the most representative correlations between the scores and visual outcomes.

DISCUSSION

Multifocal IOLs were designed to improve vision at different distances by increasing the depth of field in

Table 5. Most significant correlations between visual and refractive variables and scores to questions about degree of satisfaction with different visual tasks.

Variable	Overall	At Home	Reading Newspaper	Driving at Night	Cooking
CS at 3 cpd					
r value	—	—	—	—	−0.300
P value	—	—	—	—	.020
CS at 6 cpd					
r value	—	—	—	—	−0.362
P value	—	—	—	—	.004
CS at 12 cpd					
r value	−0.254	−0.274	−0.256	—	−0.345
P value	.050	.034	.049	—	.007
CS at 18 cpd					
r value	−0.255	—	−0.357	—	−0.345
P value	.050	—	.005	—	.007
SE					
r value	—	—	—	—	0.348
P value	—	—	—	—	.006
HOA					
r value	—	—	—	0.291	—
P value	—	—	—	.024	—
Strehl ratio					
r value	—	—	—	−0.246	—
P value	—	—	—	.058	—
UNVA (33 cm)					
r value	—	0.317	0.297	—	—
P value	—	.014	.021	—	—
CNVA (33 cm)					
r value	—	—	0.278	—	—
P value	—	—	.031	—	—

CS = contrast sensitivity; CNVA = corrected near visual acuity; HOA = higher-order aberration; SE = spherical equivalent; UNVA = uncorrected near visual acuity

the eye.[26] The approach is different depending on the particular IOL model; however, the principal goal is to provide the best levels of spectacle independence.[17] The most frequently used designs up to now have been refractive, diffractive, or a combination. More recently, accommodating IOL models are being tested and new technologies are being developed. Although IOLs have greatly improved in recent years, one of their weakest points is their inability to provide good levels of vision at intermediate distance; the introduction of trifocal models could help improve intermediate vision.

Although other multifocal IOLs present a clearly bimodal defocus curve, in the case of AT Lisa tri 839MP IOL, the curve remains almost constant in the interval from −1.5 D to −0.5 D, corresponding to distances from 67 cm to 2 m. The mean change in visual acuity in this range was less than 0.1 logMAR unit (from 0.04 to −0.05 logMAR). Moreover, variations along the defocus curve were slight and continuous. The trifocal design, with the inclusion of a third focus for intermediate vision, seems to be the explanation for this behavior.

Our UDVA results were notable, with a mean value of −0.03 ± 0.09 logMAR. The mean UNVA at 33 cm was 0.20 ± 0.12 logMAR and at 40 cm, 0.24 ± 0.10 logMAR; we believe these values are sufficient to obtain a high level of spectacle independence.

In the present study, there was an improvement in UDVA, UIVA, UNVA, CDVA, DCIVA, and CNVA (all P value $<.001$ except for CDVA [$P = .012$]). Therefore, the trifocal IOL we tested was very effective. These results are consistent with the refractive values obtained. All were within the interval of −1.00 to +1.00 D of SE 6 months after surgery. In a recent study of another trifocal model (Finevision, PhysIOL S.A), Sheppard et al.[25] report a mean monocular UDVA and CDVA of 0.19 ± 0.09 and 0.08 ± 0.08, respectively. These results are consistent with those presented by Voskresenskaya et al.[23] for the MIOL-Record 3 model (Reper). Our results for both variables (mean −0.03 ± 0.09 for UDVA and −0.05 ± 0.08 for CDVA) seem to be better than, although very similar to, those published by Lesieur[22] and for the Finevision IOL (mean 0.00 ± 0.01 for UDVA and 0.00 ± 0.00 for CDVA). The mean age of the patients in the present study (57.9 ± 7.8 years) was comparable to the age of the patients in the Lesieur study[22] (59.3 ± 4.1 years) but lower than that of patients in the Sheppard et al. study[25] (69.8 ± 10.0 years). This difference in age could partially explain the difference in the visual results between the studies.

With respect to the keratometric outcomes, as mentioned, the trifocal IOL used in this study is foldable. The IOLs were inserted through a small incision (1.6 mm). These facts are congruent with no significant keratometric changes.

Regarding internal aberrations, there was a significant decrease in total aberrations and a significant increase in the RMS spherical aberration postoperatively. The internal spherical aberration changed postoperatively to more negative values, which resulted in lower ocular spherical aberration RMS values. The explanation for this seems to be related to the age of the patients. As Artal et al. report,[27] the internal spherical aberration in the young eye is normally negative and tends to compensate for the usual positive aberration of the cornea. However, changes occur with age, causing the internal spherical aberration to reach less negative values; the effect is a decrease in the compensation for ocular spherical aberration.

Therefore, the aberrometric analysis showed that the AT Lisa tri IOL induced negative internal spherical aberration values and that the internal spherical aberration was more negative (mean 0.04 μm) than that induced by the crystalline lens in our presbyopic population. The final result was good compensation between corneal and internal spherical aberrations, leading to low ocular spherical aberration values.

The significant decrease in total ocular aberrations was consistent with a significant improvement in optical quality, which can be evaluated using the Strehl ratio. The mean ocular Strehl ratio changed significantly, from 0.11 $\pm$ 0.03 to 0.14 $\pm$ 0.04. However, photic phenomena, such as halos and glare, have been reported by patients in previous studies of diffractive multifocal IOLs.[20,21] In our study, patients were asked specifically about this in a questionnaire provided by the trifocal IOL's manufacturer. Three patients (10%) reported significant halos, and 3 reported glare. Three other patients reported color distortion (1 of them occasionally) for greens but said this was not disturbing and was a temporary phenomenon. During the follow-up, the patients reporting severe halos said there was a significant improvement over time and that, overall, they were satisfied with the outcomes of the surgery. All patients reported that the final result, as a whole, was excellent or very good (1 or 2 points). Moreover, all reported that they were comfortable performing intermediate-distance tasks.

The contrast sensitivity curve showed the patients had high sensitivity to medium spatial frequencies, although this decreased rapidly at higher frequencies. However, these results are approximately within the normal range for normal subjects aged between 50 years and 60 years.[28] The results of the patient satisfaction questionnaire in our study showed the importance of contrast sensitivity at medium to high spatial frequencies for different visual tasks. The correlation was negative because the higher the contrast sensitivity, the lower the score (ie, better results correspond to lower scores). The positive correlation between HOA with the score for the question regarding driving at night explains the negative effect of HOA on retinal image quality and its significant importance at night, when the pupil size increases. Specifically, primary spherical aberration (4th order) has been identified to be an important source of alterations in the quality of vision at night.[29]

The main advantage of multifocal IOLs is the capability of generating different foci to achieve acceptable levels of vision at far and near.[30] In addition, others have shown the advantages of multifocal IOLs over monofocal IOLs.[11] However, better intermediate vision results are still necessary. In conclusion, we believe that the excellent visual results obtained at different distances with the trifocal design indicate an emerging technique in the field of the diffractive IOLs.

WHAT WAS KNOWN

- Multifocal IOLs can improve near and distance uncorrected visual acuity and therefore reduce spectacle dependence. Different designs have their own advantages and disadvantages.
- Several new technologies are being developed; however, improvement in intermediate vision remains under study in the field of multifocal IOLs.

WHAT THIS PAPER ADDS

- Analysis of the defocus curve showed that this trifocal diffractive model can efficiently improve intermediate vision as well as near vision. Internal aberrations analysis showed that this IOL model accurately compensates for the spherical aberration induced by the cornea in presbyopic patients.

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