ORIGINAL ARTICLES

Comparison of Higher Order Aberrations and Contrast Sensitivity After LASIK, Verisyse Phakic IOL, and Array Multifocal IOL

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ABSTRACT

PURPOSE: To evaluate higher order aberrations and contrast sensitivity after LASIK, implantation of the Verisyse phakic intraocular lens (IOL), and refractive lens exchange with the Array multifocal IOL.

METHODS: In a prospective, non-randomized case series, LASIK was performed in 20 eyes with the Technolas 217z excimer laser (Bausch & Lomb, Rochester, NY), a Verisyse phakic IOL (AMO Inc, Santa Ana, Calif) was implanted in 11 eyes, and refractive lens exchange with implantation of a multifocal IOL (Array IOL, AMO Inc) was performed in 12 eyes. Wavefront error (Zywave aberrometer; Bausch & Lomb) at two pupil sizes (4 and 6 mm) and photopic contrast sensitivity (CVS-1000) was measured preoperatively and 2 months postoperatively in all eyes.

RESULTS: Photopic contrast sensitivity remained unchanged in the LASIK and the Verisyse groups, and decrease was significant in the Array group at three cycles per degree only. Higher order aberrations with a 4-mm pupil were increased in the Array group only. With a 6-mm pupil, they were increased in all groups. Comparing groups, surgically induced higher order aberrations were highest after refractive lens exchange with the Array multifocal IOL and lowest after implantation of the Verisyse IOL.

CONCLUSIONS: Laser in situ keratomileusis, the Verisyse IOL, and the Array IOL increase higher order aberrations at large pupil sizes, but no increase occurs at small pupil sizes with LASIK or the Verisyse IOL. Contrast sensitivity in photopic conditions is normal with LASIK and the Verisyse IOL, but slightly reduced with the Array IOL due to the multifocal optic. [*J Refract Surg*. 2006;22:231-236.]

Refractive surgery changes the optics of the eyes. Part of this, namely the correction of the lower order aberrations defocus and astigmatism, is the desired effect. Another part, the possible induction of higher order aberrations, such as coma, trefoil, and spherical aberration, is undesirable as it will reduce quality of vision.

The purpose of this study was to evaluate quality of vision after three of today's most common refractive surgical procedures. Laser in situ keratomileusis (LASIK), implantation of the Verisyse phakic intraocular lens (IOL), and refractive lens exchange with implantation of a multifocal IOL were selected. As these procedures do not have the same indications, the main purpose of this study was not to directly compare the results but to evaluate the change each of these procedures caused as compared to the preoperative values.

Contrast sensitivity and wavefront measurement were evaluated to assess quality of vision.

PATIENTS AND METHODS

LASIK

Laser in situ keratomileusis was performed in 20 eyes (15 patients) using the Technolas 217z excimer laser with the standard Planoscan software (Bausch & Lomb, Rochester, NY) and the Amadeus microkeratome (AMO Inc, Santa Ana, Calif) with a 140-µm blade holder and either an 8.5- or 9.5-mm suction ring. Flap thickness was not measured intraoperatively. In bilateral cases, bilateral simultaneous LASIK was always performed. All eyes were myopic, with up to −8.00 diopters (D) of myopia (Table 1).

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The authors have no proprietary interest in the materials presented herein.

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TABLE 1

Demographic Data and Preoperative Refraction of Patients Who Underwent LASIK, Verisyse IOL Implantation, and Refractive Lens Exchange With the Array IOL

	LASIK	Verisyse IOL	Array IOL
No. eyes	20	13	14
No. patients	15	8	9
Age (y) (mean±SD, range)	34.8±6.8 (21 to 42)	43.5±9.7 (26 to 53)	51.2±5.7 (44 to 60)
Female (eyes)	12	7	10
Male (eyes)	11	6	4
Mean spherical equivalent (D) (range)	−5.3±2.0 (−2.37 to −8.25)	−9.5±2.2 (−5.3 to −13.7)	−1.55±7.3 (−15.25 to +5.75)
Sphere (range)	−4.8±2.1 (−1.75 to −8.0)	−8.9±2.4 (−4.5 to −13.5)	−1.1±7.1 (−13.5 to +6.0)
Cylinder (range)	−1.0±0.9 (0 to −3.25)	−1.1±0.45 (−0.5 to −2.0)	−0.9±0.8 (−0.25 to −3.5)
Mean BSCVA (range)			
Preoperatively	20/22±0.15 (20/30 to 20/16)	20/30±0.11 (20/40 to 20/25)	20/28±0.23 (20/60 to 20/20)
Postoperatively	20/24±0.19 (20/40 to 20/16)	20/26±0.17 (20/40 to 20/20)	20/27±0.23 (20/60 to 20/20)

BSCVA = best spectacle-corrected visual acuity

Verisyse Phakic IOL

The Verisyse phakic IOL (6-mm optic; AMO Inc) was implanted in 13 eyes (8 patients). Pupils were constricted with pilocarpine 1%, topical anesthesia was performed using oxybuprocaine, lidocaine 1% was injected subconjunctivaly at 12 o'clock, and the conjunctiva was incised along the limbus. After bipolar cautery, a 6-mm frown incision was performed at 12 o'clock, and two side-port incisions of 1.5 mm each at 3 and 9 o'clock were made to facilitate enclavation. Lidocaine 1% was injected at each side port, followed by acetylcholine, to counteract the mydriatic effect of lidocaine, and a high-viscosity viscoelastic (Healon GV, AMO Inc).

The Verisyse IOL was inserted and rotated horizontally using a hook. The haptics were then enclavated using a dual forceps technique: one forceps (IOL holding forceps, AMO Inc) held the IOL while a fold of iris was created using the second forceps (iris enclavation forceps, AMO Inc) passed through the side-port incision. The IOL haptics were then pushed over the branches of the forceps holding the iris fold, thereby enclavating the iris. The iris was always re-grasped beneath the haptics, and the haptics were pushed over the forceps again to ensure a good hold of the haptics by a thick fold of enclavated iris tissue. A peripheral iridectomy was then performed at 12 o'clock, the incision was closed with a single horizontal 10-0 nylon suture, viscoelastic was washed out with balanced salt solution (BSS; Alcon Inc, Ft Worth, Tex), the suture was tied, and the conjunctiva closed with a 10-0 nylon suture.

A patch was applied for the first night. Surgery was performed on one eye at a time, with the second eye operated on at least 1 week later. Inclusion criteria were myopia ⩾−8.0 D, myopia ⩾−5.0 D, corneal thickness <500 µm, anterior chamber depth ⩾3.0 mm, endothelial cell counts ⩾2000 cells/mm^2, no previous ocular surgery, no glaucoma, and no cataract.

Array IOL

Refractive lens exchange with implantation of a multifocal IOL (Array SA40, AMO Inc) was performed in 14 eyes (9 patients). In all eyes, pupils were dilated using topical tropicamide and phenylephrine, and oxybuprocaine drops were used as topical anesthesia. A 3-mm incision was made at the steepest corneal meridian, viscoelastic was injected (Healon GV, AMO Inc), a 5- to 5.5-mm capsulorrhexis was performed using a forceps, followed by hydrodissection and phacoemulsification/aspiration of the nucleus. Viscoelastic was injected again, and the Array IOL was implanted into the capsular bag using an injector (silver series, AMO Inc). Viscoelastic was aspirated and the anterior chamber reformed with BSS. No sutures were used.

A patch was applied for the first night. Surgery was performed on one eye at a time; the second eye was operated on at least 1 week later. Inclusion criteria were myopia of ⩾−5.0 D, hyperopia, patient age at least 40 years, no previous ocular surgery, no glaucoma, and normal pupillary response.

TABLE 2

Comparison of Contrast Sensitivity With Spectacle Correction Pre- and Postoperatively After LASIK, Implantation of the Verisyse Phakic IOL, and Refractive Lens Exchange With the Array Multifocal IOL

	LASIK			Verisyse IOL			Array IOL		
Cycle per degree	Preop	Postop	*P* Value*	Preop	Postop	*P* Value*	Preop	Postop	*P* Value*
3	5.0	4.5	.13	4.8	4.8	.43	4.9†	4.0†	.006†
6	5.6	5.5	.37	5.6	5.4	.50	5.1	4.6	.22
12	5.9	5.9	.32	5.7	5.6	.41	5.4	4.9	.19
18	6.6	6.3	.09	6.4	6.2	.29	5.6	5.4	.63

**P values according to t test.*
†Significant differences.

Follow-up Assessment

All surgeries were performed between May and June 2003 by one surgeon (M.C.K.). The demographics and preoperative refractive status are given in Table 1. All patients were seen preoperatively, 1 day, 1 week, and 2 months postoperatively. Uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), refraction, and intraocular pressure were measured at each visit and a slit-lamp examination was performed. In addition, preoperatively and 2 months postoperatively, contrast sensitivity was measured using the CSV-1000 system with spectacle correction in room light conditions.

As the purpose of this study was to compare pre- and postoperative results, pupil sizes were also measured (Procyon) but were not reported, as pupil size should not affect this intra-individual comparison. Pupils were then dilated using neosynephrine 5% until a pupil size >6 mm was achieved. Aberrometry was then performed using a Hartmann-Shack aberrometer (Zywave, software 4.0.1; Bausch & Lomb Inc). Root-mean-square of total aberrations and higher order aberrations was calculated as well as for selected single aberrations (coma [x, y], trefoil [x, y], and spherical aberration) for both 4- and 6-mm pupil sizes. In the Verisyse group, corneal endothelial cell counts were determined preoperatively and 2 months postoperatively. For statistical evaluation, the Student paired *t* test was used to compare pre- and postoperative values in each group.

RESULTS

Complications

No intra- or postoperative complications occurred in any of the three groups. In the LASIK group, all treatments were centered within ±1.0 mm based on topography. In the Verisyse group, IOLs were centered (±0.5 mm) in reference to the pupil in 10 eyes and decentered upward <1 mm in 3 eyes. In the Array group, all lenses were centered within the capsular bag; no capsular contraction or optic pop-out was observed.

Visual Acuity and Refraction

LASIK. Mean UCVA was 20/22±0.18 (range: 20/30 to 20/16), and 58% saw ≥20/20 and 100% ≥20/40. Eighty-four percent were within ±0.5 D and 100% were within ±1.0 D of emmetropia, respectively.

Verisyse IOL. Mean UCVA was 20/33±0.18 (range: 20/50 to 20/25), and 70% saw ≥20/40. Fifty-four percent were within ±0.5 D and 92% within ±1.0 D of emmetropia, respectively.

Array IOL. Mean UCVA was 20/35±0.23 (range: 20/100 to 20/25), and 79% saw ≥20/40. Fifty-seven percent were within ±0.5 D and 79% within ±1.0 D of emmetropia, respectively.

Mean postoperative BSCVA did not differ from preoperative values (Table 1).

Contrast Sensitivity

Contrast sensitivity remained almost the same in the LASIK and Verisyse groups, but was slightly reduced after surgery in the Array group (Table 2). Decrease was significant at three cycles per degree in the Array group only (Table 2).

Higher Order Aberrations

LASIK. Higher order aberrations after LASIK remained unchanged for a 4-mm pupil but increased significantly with a 6-mm pupil (Table 3). Looking at single Zernike terms, spherical aberration (Z_4^0) and coma (Z_3^1) increased significantly both with a 4- and 6-mm pupil, and this increase was more pronounced with a 6-mm pupil (Table 3).

TABLE 3

Root-Mean-Square of Higher Order Aberrations and Selected Single Zernike Coefficients Pre- and Postoperatively After LASIK, Implantation of the Verisyse Phakic IOL, and Refractive Lens Exchange With the Array Multifocal IOL at 4 mm and 6 mm Pupil Size

	LASIK			Verisyse IOL			Array IOL		
4-mm Pupil	**Preop**	**Postop**	***P* Value***	**Preop**	**Postop**	***P* Value***	**Preop**	**Postop**	***P* Value***
Higher order RMS	**0.178**	**0.175**	**.4**	**0.237**	**0.283**	**.2**	**0.201**	**0.437**	**.001**
Higher order RMS without spherical aberration	**0.161**	**0.157**	**.4**	**0.223**	**0.252**	**.3**	**0.176**	**0.382**	**.001**
Spherical aberration Z_4^0	0.041	0.060	.04	0.069	0.111	.04	0.081	0.198	.001
Coma x Z_3^{-1}	0.069	0.073	.4	0.104	0.181	.04	0.105	0.229	.02
Coma y Z_3^1	0.044	0.063	.05	0.082	0.079	.4	0.032	0.102	.01
Trefoil x Z_3^{-3}	0.061	0.049	.2	0.103	0.082	.2	0.076	0.135	.01
Trefoil y Z_3^3	0.066	0.057	.3	0.071	0.058	.1	0.049	0.084	.1
Secondary astigmatism Z_4^2	0.029	0.025	.3	0.041	0.027	.05	0.019	0.095	.01
Secondary astigmatism Z_4^{-2}	0.021	0.024	.3	0.017	0.024	.2	0.024	0.078	.02
Quadrafoil Z_4^4	0.042	0.041	.5	0.039	0.028	.2	0.039	0.063	.05
Quadrafoil Z_4^{-4}	0.030	0.027	.3	0.039	0.033	.3	0.033	0.052	.1
6-mm Pupil									
Higher order RMS	**0.445**	**0.647**	**.001**	**0.618**	**0.798**	**.06**	**0.661**	**1.245**	**.000**
Higher order RMS without spherical aberration	**0.402**	**0.511**	**.04**	**0.511**	**0.632**	**.1**	**0.500**	**1.103**	**.001**
Spherical aberration Z_4^0	0.151	0.367	.000	0.310	0.440	.04	0.385	0.481	.2
Coma x Z_3^{-1}	0.188	0.212	.2	0.248	0.373	.08	0.310	0.513	.04
Coma y Z_3^1	0.144	0.280	.004	0.151	0.226	.2	0.135	0.285	.04
Trefoil x Z_3^{-3}	0.164	0.169	.4	0.248	0.178	.04	0.191	0.339	.03
Trefoil y Z_3^3	0.106	0.127	.2	0.092	0.157	.04	0.104	0.377	.002
Secondary astigmatism Z_4^2	0.081	0.085	.4	0.102	0.066	.01	0.081	0.249	.008
Secondary astigmatism Z_4^{-2}	0.032	0.053	.1	0.042	0.050	.4	0.066	0.109	.1
Quadrafoil Z_4^4	0.080	0.098	.2	0.082	0.090	.3	0.080	0.317	.02
Quadrafoil Z_4^{-4}	0.045	0.069	.01	0.050	0.080	.2	0.045	0.184	.000

Gray shading indicates significant differences.
**P values according to t test*

Verisyse IOL. Higher order aberrations after implantation of the Verisyse IOL increased moderately both with a 4- and 6-mm pupil, but this increase was not statistically significant (Table 3). Looking at single Zernike terms, spherical aberration (Z_4^0) increased significantly with a 4- and 6-mm pupil, coma (Z_3^1) and secondary astigmatism (Z_4^2) were increased with a 4-mm pupil, and trefoil (Z_3^3) and secondary astigmatism were increased with a 6-mm pupil (Table 3).

Array IOL. Higher order aberrations as well as single Zernike terms increased greatly and significantly after implantation of the Array multifocal IOL with a 4- and 6-mm pupil.

Comparing the three groups, postoperative higher order aberrations were highest in the Array group. A comparison between the LASIK and the Verisyse group was not possible, as the preoperative higher order aberrations were much higher in the Verisyse group, and the increase was small in both groups at both pupil sizes (Table 3).

DISCUSSION

Higher order aberrations were compared at two pupil sizes, 4 and 6 mm, mimicking performance of the optical system of the eye in photopic and mesopic conditions. With a 4-mm pupil, both the LASIK and the Verisyse group did not show a significant increase in higher order aberrations. However, an increase in selected aberrations (eg, spherical aberration and coma) was observed, indicating that both surgical techniques induce some aberrations. With a 6-mm pupil, mimicking mesopic conditions, higher order aberrations were significantly increased in the LASIK group, whereas the increase in the Verisyse group was not significant, although visible. This increase in higher order aberrations was mainly due to spherical aberration, which increased more in the LASIK group than in the Verisyse group. This is confirmed by other studies comparing LASIK and phakic IOLs.[1] In a study comparing LASIK and the Verisyse IOL for the same amounts of myopia (−9.0 to −19.0 D), most patients preferred the quality of vision with the Verisyse IOL,[2] which clearly shows that LASIK should not be performed for such high levels of myopia. The increase in spherical aberration after LASIK is explained by the ablation profile, which leads to a positive asphericity of the cornea, causing spherical aberration. It has been confirmed by other studies[3-5] and has also been shown to be related to the amount of myopia being corrected.[6] It remains to be seen if new aspherical ablation profiles can avoid or at least minimize the increase in spherical aberration after LASIK.

We also found an increase of spherical aberration in the Verisyse group, indicating that the spherical optic of the IOL increases the spherical aberration of the eye. In addition, coma and trefoil were increased in the Verisyse group, most likely due to small amounts of decentrations of the IOL as compared to the center of the pupil, which serves as the reference point for all wavefront measurements, or due to some edge glare phenomena.[7] Our findings are in contrast to those of Brunette et al[8] who reported a decrease in higher order aberrations with the Verisyse IOL.

Higher order aberrations were highest in the Array group, with significant increases with a 4- and 6-mm pupil. Accordingly, coma, trefoil, and secondary astigmatism were also increased in this group. As multifocal optics are designed to distribute the light to different foci, the quality of each image must be somewhat lower than that of a monofocal optic, eg, the optic of an eye after LASIK or after implantation of a Verisyse IOL. Our findings therefore confirm the properties of a multifocal optic. In a normal eye, the cornea also exhibits positive spherical aberration, which is compensated for by negative spherical aberration of the lens.[9] Following refractive lens exchange, as performed in the Array group, removal of the natural lens and replacement by an IOL without negative asphericity[10] explains the increase of spherical aberration in the Array group.

Contrast sensitivity was evaluated in photopic conditions (well-lit room), which equals a smaller pupil size, comparable to the results of higher order aberrations with a 4-mm pupil. One limitation of the study is that we did not actually measure pupil size, but just standardized illumination. Under photopic conditions, we did not see a decrease of contrast sensitivity in the LASIK group or in the Verisyse group. This finding is supported by other studies that reported no decrease in contrast sensitivity after LASIK in photopic conditions, but found a decrease in mesopic conditions.[11,12] In the Array group, we found a decrease of contrast sensitivity even in photopic conditions, which was significant at three cycles per degree. Montes-Mico and Alió[13] compared the Array IOL to a monofocal IOL and also reported a decrease of contrast sensitivity (12 and 18 cycles per degree only) at 1 month, but no significant differences were found at 6, 12, and 18 months.

Comparing the three groups, preoperative contrast sensitivity was highest in the LASIK group and lowest in the Array group, a difference most likely explained by the different age of the groups as contrast sensitivity decreases with increasing age.[14,15]

Comparing higher order aberrations and contrast sensitivity, there was also a correlation that became most apparent in the Array group: increased higher order aberrations with a 4-mm pupil were matched by decreased contrast sensitivity in photopic conditions. The LASIK and Verisyse groups both showed small increases in higher order aberrations with a 4-mm pupil only, again matched by an almost unchanged contrast sensitivity. We did not measure contrast sensitivity in mesopic conditions, but a decrease was reported by others,[11,12] which again matches the increase in higher order aberrations with a 6-mm pupil. Higher order aberrations and contrast sensitivity clearly correlate, but higher order aberrations cannot quantitatively predict contrast sensitivity, as different Zernike terms have a different impact on contrast sensitivity.[16]

Limitations of our study include the small number of patients, different patient ages, and different preoperative refraction of the groups. The Verisyse IOL and the Array IOL also have different incision sizes and slightly different optic sizes, which may affect aberrations differently. As LASIK, the Verisyse IOL, and the Array IOL have different indications, we believe a direct comparison in the same age group and similar refractive errors is not possible. In addition, a difference in wavefront errors may not be clinically meaningful as it might be compensated for by the processing of the visual system.

In conclusion, LASIK, the Verisyse IOL, and the Array IOL increase higher order aberrations at large pupil sizes, but no increase occurs at small pupil sizes with LASIK or the Verisyse IOL. Contrast sensitivity in photopic conditions is normal with LASIK and the Verisyse IOL, but slightly reduced with the Array IOL due to the multifocal optic. With some simplification, LASIK is indicated in younger patients with lower refractive errors whereas phakic implants are indicated in the same age group but for higher refractive errors. The Array IOL is indicated in presbyopic patients, preferably in hyperopes and high myopes.

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