Postoperative Wavefront Analysis and Contrast Sensitivity of a Multifocal Apodized Diffractive IOL (ReSTOR) and Three Monofocal IOLs

Karolinne Maia Rocha, MD; Maria Regina Chalita, MD; Carlos Eduardo B. Souza, MD; Eduardo S. Soriano, MD; Lincoln L. Freitas, MD; Cristina Muccioli, MD; Rubens Belfort, Jr, MD, PhD

ABSTRACT

PURPOSE: To compare visual acuity, total and high order wavefront aberrations (coma, spherical aberration, and other terms of high order aberration), and contrast sensitivity in 105 eyes implanted with 4 different types of intraocular lenses (IOLs) (1 multifocal apodized diffractive IOL and 3 monofocal IOLs).

METHODS: A prospective study comparing four types of IOLs (Alcon ReSTOR [50 eyes], Alcon Acrysof MA30AC [20 eyes], Alcon Acrysof SA60AT [20 eyes], and Mediphacos Acqua IOL [15 eyes]) was carried out. All eyes were targeted for emmetropia. Complete ophthalmological examination, including uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), contrast sensitivity (Pelli-Robson chart), and wavefront analysis, was performed 2 months postoperatively.

RESULTS: All eyes in all groups had BSCVA ⩾20/32 postoperatively. Mean total aberration root-mean-square (RMS) values were: 0.72±0.25 µm (ReSTOR), 0.94±0.26 µm (MA30), 0.84±0.23 µm (SA60), and 2.04±0.77 µm (Acqua). Mean higher order aberration values were: 0.35±0.15 µm (ReSTOR), 0.41±0.12 µm (MA30), 0.43±0.13 µm (SA60), and 0.85±0.50 µm (Acqua). The Acqua IOL showed statistically significant more total and higher order aberrations when compared with the other IOLs ($P<.05$). The ReSTOR IOL showed statistically significant less induction of spherical aberration when compared to the monofocal IOLs ($P<.05$). Mean contrast sensitivity values were: 1.64±0.08 (ReSTOR), 1.72±0.08 (MA30), 1.70±0.07 (SA60), and 1.65±0.11 (Acqua).

CONCLUSIONS: Different types of IOLs resulted in measurably different postoperative higher order aberration patterns. The multifocal apodized diffractive IOL (ReSTOR) induced significantly less spherical aberration compared to the monofocal IOLs. Contrast sensitivity revealed better values with MA30 and SA60 IOLs when compared to ReSTOR. The integration of wavefront technology in evaluating pseudophakic patients represents a step towards better understanding and analyzing postoperative visual quality. [*J Refract Surg*. 2005;21:S808-S812.]

Cataract surgery and intraocular lens (IOL) implantation is becoming more of a refractive procedure, where results are not only measured by means of visual acuity, but also by quality of vision.

Contrast sensitivity and wavefront analysis effectively represent the optical quality of vision. With wavefront technology, the aberrations (low and high order aberrations) present in an optical system can be measured. High order optical aberrations, such as spherical aberration and coma, have an impact on contrast sensitivity and functional vision. Highly aberrated eyes have a poor contrast and poor quality of vision that cannot be corrected with eyeglasses or contact lenses.[1-3]

The IOL materials and designs have been extensively improved to provide the best quality of vision after cataract removal. Some IOLs are designed to compensate for the spherical aberration of the cornea, which in turn would improve contrast sensitivity at low and mid spatial frequencies.[3-5] Recently, new IOLs have been developed to lessen patient's spectacle dependence, such as diffractive multifocal and pseudoaccommodative IOLs, but the optical performance by means of wavefront analysis and contrast sensitivity of these IOLs has not yet been described.

This prospective study aims to compare visual acuity, total and high order wavefront aberrations (coma, spherical aberration and other terms of higher order aberrations), and contrast sensitivity in 105 eyes implanted with 4 different IOL types (1 multifocal apodized diffractive IOL and 3 monofocal IOLs).

PATIENTS AND METHODS

A prospective study comparing four types of IOLs—Alcon ReSTOR (50 eyes), Acrysof MA30AC (20 eyes), Acrysof SA60AT (20 eyes) (Alcon Laboratories Inc, Ft Worth, Tex), and Mediphacos Acqua (15 eyes) (Mediphacos, Belo Horizonte, Brazil)—was carried out at the Federal University of Sao Paulo, Brazil. Patients who underwent clear corneal phacoemulsification and IOL implantation were followed prospectively

From the Ophthalmology Department, Federal University of Sao Paulo, Brazil.

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

Correspondence: Maria Regina Chalita, MD, SQSW 101 BLOCO I apt 507, Brasilia – DF, 70670-109 Brazil. E-mail: mrchalita@pobox.com

from February to September 2004. Inclusion criteria were corneal astigmatism <1 diopter, no ocular-associated diseases, and potential acuity meter >0.2 logMAR units. Patients with ocular disease, such as dry eye, corneal opacities, glaucoma, retinal abnormalities, surgical complications, or IOL tilt, were excluded.

All surgeries were performed by two experienced surgeons (E.S.S., L.L.F.). The eyes were selected to receive different IOL types. Surgeon E.S.S. performed 65 surgeries (including all ReSTOR cases and 5 cases of each remaining IOL) and surgeon L.L.F. performed 40 surgeries (15 MA30 cases, 15 SA60 cases, and 10 Acqua cases). Continuous curvilinear capsulorrhexis with an approximate 5.0-mm diameter was created. The IOLs were implanted in the capsular bag.

Patients were examined 1, 7, 15, and 30 days after surgery, and the final follow-up examination was at 2 months postoperatively. At that time, complete ophthalmological examination including uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA) (ETDRS chart), microscopy, applanation tonometry, fundus examination, contrast sensitivity (Pelli-Robson chart; Clement Clarke International, London, UK), and wavefront analysis with the LADARWave aberrometer (Alcon Laboratories) were performed. The Pelli-Robson contrast sensitivity test was performed using a 1-m distance (corresponding to a spatial frequency of approximately 1 cycle per degree) and a luminance of approximately 85 cd/m^2 (Gossen-Starlite).[6] Absolute values of log contrast sensitivity were obtained for each eye. The wavefront maps were analyzed using a 5-mm pupil diameter and up to the 6th order of Zernike coefficients.

Statistical analysis was performed using Kruskal-Wallis test and analysis of variance test; $P \leqslant .05$ was considered statistically significant. The Kruskal-Wallis tests were followed with the Dunn pairwise multiple comparisons among the four groups to identify which groups were significantly different.

RESULTS

Sixty-seven patients (35 men [52%] and 32 women [48%]) (105 eyes) were enrolled in this study. Average patient age was 62.25 years (range: 50 to 77 years). Mean patient age in each group was: 64 years, ReSTOR; 60 years, MA30; 61 years, SA60; and 64 years, Acqua.

All eyes in all groups had BSCVA of ≥20/32 postoperatively. Best spectacle-corrected visual acuity was ≥20/25 in 90% of eyes in the ReSTOR group, 85% of eyes in the MA30 group, 100% of eyes in the SA60 group, and 85% of eyes in the Acqua group (Table 1). The induced astigmatism was not statistically significant (P>.05). No significant differences were noted between the groups in age, corneal curvature, axial length, IOL power, or mean follow-up. The IOL centration was not measured by any specific method, but was observed under slit-lamp examination.

TABLE 1

Postoperative BSCVA in all IOL Groups 2 Months Postoperatively

	n (%)			
Postoperative BSCVA	ReSTOR (n=50)	MA30 (n=20)	SA60 (n=20)	Acqua (n=15)
20/10	0 (0)	0 (0)	1 (5)	0 (0)
20/16	9 (18)	6 (30)	7 (35)	0 (0)
20/20	25 (50)	8 (40)	10 (50)	6 (40)
20/25	11 (22)	3 (15)	2 (10)	6 (40)
20/30	0 (0)	0 (0)	0 (0)	3 (20)
20/32	5 (10)	3 (15)	0 (0)	0 (0)

BSCVA = best spectacle-corrected visual acuity

Postoperative wavefront analysis revealed mean total aberration root-mean-square (RMS) values of 0.72±0.25 µm (ReSTOR), 0.94±0.26 µm (MA30), 0.84±0.23 µm (SA60), and 2.04±0.77 µm (Acqua). Mean higher order aberration values were 0.35±0.15 µm (ReSTOR), 0.41±0.12 µm (MA30), 0.43±0.13 µm (SA60), and 0.85±0.50 µm (Acqua) (Table 2). No statistically significant difference was found between MA30, SA60, and ReSTOR IOLs when looking at total and higher order aberration RMS values; however, these three IOLs showed significantly less total and higher order aberration values when compared to the Acqua group (P<.001).

The ReSTOR, MA30, and SA60 IOLs showed statistically significant less defocus (P<.001) and astigmatism (P=.048) measured with the wavefront sensor than the Acqua IOL (Table 3).

When analyzing each higher order aberration separately, coma values were 0.13±0.09 µm (ReSTOR), 0.17±0.08 µm (MA30), 0.15±0.07 µm (SA60), and 0.23±0.11 µm (Acqua), and the difference between the ReSTOR and Acqua group was statistically significant (P=.012), with the ReSTOR IOL inducing less coma-like aberrations (Table 3).

The ReSTOR IOL obtained statistically significant less spherical aberration when compared to all of the monofocal IOLs tested (ReSTOR 0.09±0.05 µm; MA30 0.23±0.08 µm; SA60 0.25±0.08 µm) (P<.001), whereas the Acqua IOL showed the highest values (0.37±0.04 µm) (P<.001) (Table 3).

Mean contrast sensitivity values, measured by Pelli-Robson test, were 1.64±0.08 (ReSTOR), 1.72±0.08 (MA30), 1.70±0.07 (SA60), and 1.65±0.11 (Acqua).

TABLE 2

Mean and Median of Total Aberrations and Higher Order Aberrations for All IOL Groups

Total RMS	ReSTOR (n=50)	MA30 (n=20)	SA60 (n=20)	Acqua (n=15)
Mean±SD	0.72±0.25	0.94±0.26	0.84±0.23	2.04±0.77
Median	0.70	0.92	0.87	1.74
Min - Max	0.25 - 1.32	0.40 - 1.31	0.41 - 1.22	1.20 - 3.30
Kruskal-Wallis test	$P<.001$*			
Higher order aberration RMS				
Mean±SD	0.35±0.15	0.41±0.12	0.43±0.12	0.85±0.50
Median	0.33	0.39	0.42	0.67
Min - Max	0.19 - 0.92	0.23 - 0.61	0.24 - 0.69	0.40 - 1.94
Kruskal-Wallis test	$P<.001$*			

The MA30 and SA60 IOL groups were not statistically significantly different, whereas the ReSTOR group presented the worst contrast sensitivity values (P=.002) (Table 4).

DISCUSSION

Studies demonstrated that during life the crystalline lens compensates for the cornea positive spherical aberration, compensating for the total aberration of the eye. The aging lens changes its balance with the cornea, with a reduction in the negative spherical aberration of the crystalline lens.[1,7-10] Intraocular lens implantation increases spherical aberration and wavefront variances, as conventional monofocal IOLs are either plane-convex or biconvex and they can only introduce positive spherical aberration.[11,12] Some pseudophakic patients complain about glare, halos, and starburst that could be attributed to spherical aberration.[11,13] The IOL decentration and tilt creates an asymmetrical high order aberration, related to coma and secondary astigmatism.[2]

Wavefront technology was first described to evaluate low and high order aberrations in normal, phakic eyes. However, this technology can also be used to measure pseudophakic eyes.[14,15] When the pupil diameter analyzed is smaller than the IOL optical zone, the Hartmann-Shack spot patterns can be appropriately measured and analyzed.

The multifocal IOL (ReSTOR), with an apodized diffractive surface based on the Huygens-Fresnel principle, induced statistically significant less spherical aberration when compared to the monofocal IOLs (ReSTOR 0.09±0.05 µm; MA30 0.23±0.08 µm; SA60 0.25±0.08 µm; Acqua 0.37±0.04 µm) ($P<.05$). The apodized diffractive surface behaved as an aspherical surface, showing less spherical aberration. The ReSTOR showed lower mean total aberration RMS values (ReSTOR, 0.72±0.25 µm; MA30, 0.94±0.26 µm; SA60, 0.84±0.23 µm; Acqua, 2.04±0.77 µm) and lower mean high order aberration values (ReSTOR, 0.35±0.15 µm; MA30, 0.41±0.12 µm; SA60, 0.43±0.13 µm; and Acqua, 0.85±0.50 µm). No statistically significant difference was found between MA30 and SA60 IOLs.

It has been demonstrated that the Tecnis Z9000 IOL (Advanced Medical Optics, Santa Ana, Calif), with a modified prolate anterior surface design, induced less spherical aberration.[1-5,12] Bellucci et al[3] compared five types of IOLs—the Tecnis Z9000 showed lower spherical aberration, although no difference was found in coma, and little difference was found in high order aberration between the other IOLs (Acrysof SA60AT and MA60BN [Alcon Laboratories], Sensar AR40e, and CeeOn 911Edge [AMO, Santa Ana, Calif]). Taketani et al[16] found no significant differences between a hydrophilic acrylic IOL (Hydroview) and a hydrophobic acrylic IOL (Acrysof MA30BA [Alcon Laboratories]) in coma or total high order aberration; however, the Acrysof IOL induced higher spherical aberration (0.696±0.287 vs 0.441±0.147) at a 6-mm pupil diameter.

The use of contrast sensitivity tests with letters as optotypes, such as the Pelli-Robson test, is reliable, repeatable and easy to apply.[16-19] In our study including pseudophakic patients, the implanted ReSTOR IOL and Mediphacos Acqua IOL showed worse mean contrast sensitivity values (ReSTOR, 1.64±0.08; Acqua, 1.65±0.11; MA30 1.72±0.08; and SA60 1.70±0.07). Mäntyjärvi and Laitinen[6] studied normal values for the Pelli-Robson test at a 1-m distance in a group of

TABLE 3

Individual Analysis of Low Order (Defocus and Astigmatism) and High Order (Coma, Spherical Aberration, and Other Terms) Aberrations for All IOL Groups

Aberrations	ReSTOR (n=50)	MA30 (n=20)	SA60 (n=20)	Acqua (n=15)
Defocus				
Mean±SD	0.36±0.23	0.68±0.28	0.46±0.29	1.72±0.82
Median	0.35	0.75	0.42	1.36
Min - Max	0.00 - 1.11	0.22 - 1.12	0.07 - 1.07	0.89 - 2.99
Kruskal-Wallis test		$P<.001$ *		
Astigmatism				
Mean±SD	0.43±0.24	0.43±0.27	0.46±0.23	0.77±0.43
Median	0.41	0.43	0.46	0.78
Min – Max	0.01 - 1.10	0.10 - 1.02	0.08 - 0.86	0.31 - 1.81
Kruskal-Wallis test		$P=.048$ *		
Coma				
Mean±SD	0.14±0.09	0.17±0.08	0.15±0.07	0.23±0.11
Median	0.12	0.15	0.15	0.22
Min - Max	0.00 - 0.53	0.07 - 0.37	0.06 - 0.30	0.10 - 0.39
Kruskal-Wallis test		$P=.012$ *		
Spherical Aberration				
Mean±SD	0.09±0.05	0.23±0.08	0.25±0.08	0.37±0.04
Median	0.09	0.21	0.27	0.36
Min – Max	−0.04 - 0.20	0.11 - 0.38	0.12 - 0.37	0.32 - 0.43
Kruskal-Wallis test		$P<.001$ *		
Other				
Mean±SD	0.29±0.14	0.26±0.11	0.29±0.14	0.54±0.31
Median	0.28	0.23	0.23	0.46
Min – Max	0.10 - 0.90	0.14 - 0.49	0.10 - 0.58	0.19 - 1.15
Kruskal-Wallis test		$P=.005$ *		

**Statistically significant.*

patients aged 60 to 75 years, showing a mean value of 1.72±0.08. Rubin et al[20] studied contrast sensitivity in multifocal IOL implants and found similar results when compared to our study (1.65±0.08). Elliott and Whitaker[21] published normal values for the Pelli-Robson test in phakic individuals in different age groups and found worse contrast than what we report (1.50 for individuals aged >50 years). It is also important to point out that Montés-Micó and Alió[17] observed an increase in contrast sensitivity over time in patients with multifocal IOLs, suggesting adaptation of the patient over time that could, in turn, improve the contrast sensitivity measurement if performed after 6 months of implantation. This could be why, despite having less aberrations, the ReSTOR group did not show a better contrast sensitivity performance when compared to the other IOL groups. Longer follow-up with contrast sensitivity re-test will be necessary to clarify this.

With the advent of wavefront technology, it has been possible to quantify total ocular aberrations and to better understand the potential benefits of a customized IOL to correct the aberrations of the cornea. The compensation for the corneal aberrations should enhance visual performance by greatly improving retinal image quality and optimizing surgical results. By this means, using one IOL type that induces less aberrations could potentially improve visual quality.

The multifocal apodized diffractive IOL (ReSTOR) induced significantly less spherical aberration than all other monofocal IOLs. The integration of wavefront

TABLE 4

Postoperative Contrast Sensitivity Measured With Pelli-Robson Chart for All IOL Types

	n (%)			
Contrast Sensitivity	ReSTOR (n=50)	MA30 (n=20)	SA60 (n=20)	Acqua (n=15)
1.50	7 (14)	0 (0)	0 (0)	4 (26.7)
1.65	39 (78)	11 (55)	13 (65)	7 (46.7)
1.80	3 (6)	9 (45)	7 (35)	4 (26.7)
1.95	1 (2)	0 (0)	0 (0)	0 (0)
Kruskal-Wallis test	*P*=.002*			

technology in pseudophakic patients represents a step towards better understanding and analyzing postoperative visual quality.

REFERENCES

1. Packer M, Fine IH, Hoffman RS. Wavefront technology in cataract surgery. *Curr Opin Ophthalmol*. 2004;15:56-60.
2. Altmann GE. Wavefront-customized intraocular lenses. *Curr Opin Ophthalmol*. 2004;15:358-364.
3. Bellucci R, Morselli S, Piers P. Comparison of wavefront aberrations and optical quality of eyes implanted with five different intraocular lenses. *J Refract Surg*. 2004;20:297-306.
4. Mester U, Dillinger P, Anterist N. Impact of a modified optic design on visual function: clinical comparative study. *J Cataract Refract Surg*. 2003;29:652-660.
5. Holladay JT, Piers PA, Koranyi G, van der Mooren M, Norrby NE. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. *J Refract Surg*. 2002;18:683-691.
6. Mäntyjärvi M, Laitinen T. Normal values for the Pelli-Robson contrast sensitivity test. *J Cataract Refract Surg*. 2001;27:261-266.
7. Amano S, Amano Y, Yamagami S, Miyai T, Miyata K, Samejima T, Oshika T. Age-related changes in corneal and ocular higher-order wavefront aberrations. *Am J Ophthalmol*. 2004;137:988-992.
8. Sachdev N, Ormonde SE, Sherwin T, McGhee CN. Higher-order aberrations of lenticular opacities. *J Cataract Refract Surg*. 2004;30:1642-1648.
9. Kelly JE, Mihashi T, Howland HC. Compensation of corneal horizontal/vertical astigmatism, lateral coma, and spherical aberration by internal optics of the eye. *J Vis*. 2004;4:262-271.
10. Roorda A, Glasser A. Wave aberrations of the isolated crystalline lens. *J Vis*. 2004;4:250-261.
11. Miller JM, Anwaruddin R, Straub J, Schwiegerling J. Higher order aberrations in normal, dilated, intraocular lens, and laser in situ keratomileusis corneas. *J Refract Surg*. 2002;18:S579-S583.
12. Werner L, Mamalis N. Wavefront corrections of intraocular lenses. *Ophthalmol Clin North Am*. 2004;17:233-245.
13. Chalita MR, Krueger RR. Correlation of aberrations with visual acuity and symptoms. *Ophthalmol Clin North Am*. 2004;17:135-142.
14. Vilarrodona L, Barrett GD, Johnson B. High-order aberrations in pseudophakia with different intraocular lenses. *J Cataract Refract Surg*. 2004;30:571-575.
15. Uchio E, Ohno S, Kusakawa T. Spherical aberration and glare disability with intraocular lenses of different optical design. *J Cataract Refract Surg*. 1995;21:690-696.
16. Taketani F, Matsuura T, Yukawa E, Hara Y. High-order aberrations with Hydroview H60M and AcrySof MA30BA intraocular lenses. Comparative study. *J Cataract Refract Surg*. 2004;30:844-848.
17. Montés-Micó R, Alió JL. Distance and near contrast sensitivity function after multifocal intraocular lens implantation. *J Cataract Refract Surg*. 2003;29:703-711.
18. Nio YK, Jansonius NM, Geraghty E, Norrby S, Kooijman AC. Effect of intraocular lens implantation on visual acuity, contrast sensitivity, and depth of focus. *J Cataract Refract Surg*. 2003;29:2073-2081.
19. Aggarwal A, Khurana AK, Nada M. Contrast sensitivity function in pseudophakics and aphakics. *Acta Ophthalmol Scand*. 1999;77:441-443.
20. Rubin GS, Adamsons IA, Stark WJ. Comparison of acuity, contrast sensitivity, and disability glare before and after cataract surgery. *Arch Ophthalmol*. 1993;111:56-61.
21. Elliott DE, Whitaker D. Clinical contrast sensitivity chart evaluation. *Ophthalmic Physiol Opt*. 1992;12:275-280.