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Influence of isofocal intraocular lenses on objective refraction based on autorefraction and aberrometry

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Abstract

Purpose To evaluate and compare the objective refractions obtained by autorefraction and aberrometry under different lighting conditions with an isofocal intraocular lens (Isopure, BVI medical, Liége, Belgium) compared to a monofocal control lens (Micropure, BVI medical, Liége, Belgium) with the same platform and material.

Methods Prospective, comparative and randomized study on patients undergoing cataract surgery and bilateral isofocal or monofocal IOL implantation. A total of 44 subjects were randomly assigned to either the isofocal group ($n=22$) or the Micropure ($n=22$). Manifest refraction (MR) was always performed under the same lighting conditions for all the patients. For objective refraction the autorefractor KR8800 and the aberrometer OPD-Scan III (Nidek Inc., Tokyo, Japan.) were used. For each eye included in the study, six result sets were collected: MR, AR (autorefraction measured with the autorefractor), WF-P and WF-M (Zernike-coefficients-based objective refraction, photopic and mesopic pupil size), OPD-C and OPD-M (autorefraction measured with the aberrometer in photopic and mesopic conditions).

Results The mean sphere for MR was 0.03 ± 0.32D for the Isopure group and 0.24 ± 0.22D for the monofocal group ($p=0.013$). For the Isopure group, Friedman analysis showed statistically significant differences for sphere measured with WF-P ($p=0.035$), WF-M ($p=0.018$) and OPD-M ($p=0.000$), and SE measured with OPD-M ($\mathrm{p}=0.004$). In the Micropure lens group, the Friedman analysis showed differences for all values studied ($p<0.05$). Correlation coefficients showed that AR is the objective method with the strongest correlation values for all components of refraction for both groups.

Conclusion The modification of the surfaces of the isofocal lens does not have a negative impact on the refraction obtained by AR compared to a standard monofocal intraocular lens.

Keywords Isofocal · Intraocular lens · Objective refraction · Subjective refraction · Aberrometry · Autorefraction

Key messages

What is known:

- Objective refraction is a good starting point to estimate the refraction in patients with intraocular lens implanted.

What this paper adds:

- Intraocular lenses based on an isofocal concept have a good correlation between manifest refraction and objective refraction obtained by autorefractor and aberrometry.
- The objective refraction obtained with autorefractometer based on 30 the Scheiner double-pinhole principle are better than results obtained with an aberrometer when the lens under evaluation has an isofocal design to enhance the depth of focus.

Introduction

Manifest refraction (MR) is considered the gold-standard method to achieve the patient's refraction, both for spectacle prescription and after cataract surgery [1, 2]

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Automated refraction (AR) after intraocular lens (IOL) implantation is a proper starting point to estimate the subjective refraction and to verify if this is within the range calculated previously. While it has been noted that in monofocal lenses there is a good correlation between AR and manifest refraction [3], the same may not occur with multifocal refractive IOLs [4, 5] or with diffractive optic [6, 7], where the results obtained for the sphere by autorefraction tend to yield more negative values [6].

The latest innovation in the optical development of IOLs are Enhanced Depth of Focus (EDOF) lenses. Through different strategies in which monofocal lenses are modified, such as the induction of certain amounts of spherical aberration (SA), an increase in depth of focus can be achieved. This depth of focus extension leads to an increased visual acuity especially at intermediate distances while having less drawbacks to the occurrence of photic side effects as with multifocal lenses [8].

One of the latest lenses of this type to come onto the market is the Isopure lens (BVI medical, Liége, Belgium). This is the only lens currently on the market that employs isofocal technology. This lens is based onto a 100% aspherical refractive mechanism. The optic design, based on the patented isofocal concept [9], displays polynomial complex surface design parameters to extend the depth of focus compared to standard monofocal IOLs. On the optical bench, Isopure tends to achieve around 1.00D of EDOF, 50% more with respect to standard aspheric monofocal IOL [8, 10]. Due to the novelty of its design, it is a lens for which many of its clinical results are unknown. Therefore, this study aims to compare the subjective (manifest refraction) and objective refractions, obtained by autorefraction and aberrometry under different lighting conditions with the isofocal intraocular lens compared to a monofocal control lens, the Micropure lens (BVI medical, Liége, Belgium) with the same platform and material.

Material and methods

Study design and patient population

This is a prospective, comparative, randomized study on patients undergoing cataract surgery and bilateral isofocal IOL or monofocal IOL implantation at Miranza IOA, Madrid, Spain. Since no previous studies were found with this intraocular lens, the sample size was calculated with a refractive advanced monofocal IOL accepting an alpha risk of 0.05 and a beta risk of 0.2 in a two-sided test. 22 subjects were necessary to recognize as statistically significant a difference greater than or equal to 0.25 units. The standard deviation was assumed to be 0.39 based on the results obtained from the spherical equivalent (SE) of the manifest refraction with that advanced monofocal lens [11]. A drop-out rate of 10% was anticipated.

All patients provided written informed consent before enrollment. This study was approved by the clinical research ethics committee of the Hospital Clinico San Carlos de Madrid (Madrid, Spain) under code number 20/030-R_P and was performed in accordance with the Declaration of Helsinki. Inclusion criteria were patients over 50 years old with healthy eyes, lens power calculated within the available range (10–30 D), regular corneal astigmatism less than 1.0D and clear intraocular media (other than cataract). Exclusion criteria were previous ocular pathologies such as uveitis, glaucoma, AMD, or intraocular or corneal surgery, regular corneal astigmatism above 1D or irregular astigmatism, and the presence of pupil abnormalities.

Surgical procedure

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All surgeries were carried out by the same surgeon (FP) under topical anaesthesia. A 2.2 mm corneal incision and a paracentesis were made with a surgical knife. Anterior capsulotomy and nuclear fragmentation were performed with a femtosecond laser with optical coherence tomography image control (CATALYS Precision System, Abbott Medical Optics, Inc.) and for lens phacoemulsification, a commercial microsurgical system (Centurion Vision System, Alcon Laboratories, Inc.) was used.

Two ophthalmic viscosurgical devices were used throughout the entire procedure: the cohesive sodium hyaluronate 1.0% (Healon, Johnson & Johnson, Santa Ana, CA) and the dispersive sodium hyaluronate 1.2% (Amvisc, Bausch & Lomb, Inc., Rochester, NY). Isopure or Micropure IOL were then implanted into the capsular bag with a single-use injection system (123 system, BVI medical, Liége, Belgium). All surgeries were supported by the assisted cataract surgery system (CALLISTO Eye from the Cataract Suite Markerless, Carl Zeiss Meditiec AG). Once the procedure was completed, patients were treated with a combination of antibiotics, corticosteroids, and antiinflammatory eyedrops (moxifloxacin, dexamethasone, and bromfenac).

All lenses were calculated using the Barrett Universal II Formula taking into account a lens factor (LF) of 2.09 to achieve emmetropia.

Intraocular lenses

Isopure lens is an enhanced depth of focus lens based on an isofocal concept, a patented polynomial technology. It has an aspheric, 100% refractive optic that features a complex polynomial surface to extend the depth of focus compared to standard monofocal intraocular lenses. It is a pre-loaded lens made of a hydrophobic glistening free material and it has a filter for blue and ultraviolet light. The lens has an optic diameter of 6.00 mm and a total diameter of 11.00 mm, its refractive index is 1.52 and its Abbe number is 42. The lens has a smooth aspheric surface (described by the radius of curvature, and 5 conic constants (1 constant and 4 coefficients) per surface) [9], aiming at providing optimal vision at far and intermediate distances.

Micropure lens is a biconvex aspheric monofocal lens with -0.11microns of SA to partly compensate the positive SA of the average human cornea. It has the same material and platform as the Isopure lens.

Optical bench measurements, when comparing Isopure to Micropure lens, show that the depth of focus is increased from 48 to 86% for corneal spherical aberrations ranging from 0 to 0.28 microns at 6 mm diameter according to the manufacturer [12].

Postoperative Eye Examinations

Subjective refraction

Patients were examined 1 day, 1 week, 1 month and 3 months after surgery, although the data reported in this paper were taken at three months visit, as this is when refraction is considered reliable.

All refraction assessments were carried out by the same optometrist (LP). MR was always performed under the same lighting conditions (85 lx) for all the patients using the ETDRS (Early Treatment Diabetic Retinopathy Study) acuity chart and a trial frame. The starting point for the subjective refraction was an automated objective refractor (Topcon KR8800, Topcon Inc, Tokyo, Japan) with fogging ensuring a VA under 20/40. Once the best visual acuity was obtained, MR was fine-tuned, both spherical and cylindrical components, with cross-cylinders in steps of 0.25D.

After obtaining the MR, a + 0.50 D sphere was added to that value to ensure a worsening in the far vision visual acuity. This procedure helps to ensure that subjective refraction has been properly obtained for the far focus of the IOL and not for an "intermediate focus" since the almost theoretical, depth of focus of such IOLs can provide good far distance VA with a slightly more positive refraction. This procedure can be identified with the measurement of just two points of the defocus curve, corresponding with the 0.00 D and + 0.50 D defocus, in which VA must be worse than for 0.00 D defocus if the refraction has been correctly measured.

Objective refraction

For objective refraction two instruments were used. The first one was the autorefractor KR8800 (Nidek Inc., Tokyo, Japan.) that determines both objective refraction and corneal keratometry. This device is based on the Scheiner principle, in which images from two light sources are focused in the pupil plane to simulate Scheiner pinhole apertures. The measurements were repeated three times and the mean was used for statistical analysis.

The second device was the aberrometer OPD-Scan III (Nidek Inc., Tokyo, Japan.). It combines a wavefront aberrometer, an autorefractor, an autokeratometer and a pupillometer. The autorefractor relies on the principle of scanning-slit retinoscopy, where an automated measurement is performed, and refraction is calculated based on wavefront phase differences.

Since the aberrometer calculates all Zernike coefficients, objective refraction in vector notation can be calculated using low-order coefficients Z_0^2, Z_2^{+2}, $Z_{2.}^{-2}$ according to the expressions described by Garzon et al. [6]

For each eye included in the study, 6 result sets were collected: MR (manifest refraction), AR (autorefraction measured with the autorefractor with a 2 mm pupil), WF-P (Zernike-coefficients-based objective refraction, photopic pupil size), WF-M (Zernike-coefficients-based objective refraction, mesopic pupil size), OPD-C (autorefraction measured with the aberrometer in the central pupil/photopic conditions), and OPD-M (autorefraction measured with the aberrometer under mesopic conditions). This terminology has been used by other authors in previous publications [6, 7, 13].

Statistical analysis

The refraction values obtained in clinical spherocylindrical notation were converted into vectorial notation for statistical analysis.

SPSS for Windows v.25 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Descriptive statistics were calculated for all variables as mean ± standard deviation and range. The normality of all the data was evaluated using the Shapiro–Wilk test. For each group, Friedman's test was used to look for differences across the 6 assessment methods used for each of the refraction vector components. When such differences were found, the Wilcoxon test was used to identify between those differences.

The Spearman/Pearson correlation coefficient was calculated as a function of the sample (non-parametric/parametric) to study the correlation between methods as well as the Bland–Altman plots. A significance level of $p\text{-value} < 0.05$ was considered.

Results

The study comprised 44 right eyes (22 eyes per group) of 44 patients. The mean age was 71.3 ± 6.9 years for the Isopure group and 70.1 ± 6.5 years for the Micropure group

($p = 0.451$). There were no statistical significant differences when the axial length (23.15 ± 0.79 mm for Isopure and 23.49 ± 1.06 mm for Micropure), the anterior chamber depth (3.00 ± 0.36 mm for Isopure and 3.17 ± 0.33 mm for Micropure) or the IOL power implanted (22.41 ± 2.23 D for Isopure and 21.18 ± 2.29 D for Micropure group) were compared.

Under photopic conditions, the mean pupil size was 2.82 ± 0.42 mm and 3.97 ± 0.56 mm for the Isopure and Micropure group, respectively ($p = 0.002$). Under mesopic conditions, the mean pupil size was 3.36 ± 0.65 mm and 4.48 ± 0.92 mm for the Isopure and Micropure group, respectively ($p = 0.124$). These results of measured pupil mean values were obtained by measuring WF-P and OPD-C (photopic pupil mean size), WF-M and OPD-M (mesopic pupil mean size).

Table 1 shows descriptive statistics for manifest refraction and visual acuities for both groups. All lenses were calculated for emmetropia, with a mean SE of -0.08 ± +0.34D for the Isopure group and 0.05 ± 0.23D for the Micropure group.

Table 2 shows descriptive statistics for all the objective refraction and methods considered while Fig. 1 shows the difference between manifest refraction and each of the five objective methods for both lenses.

For the Isopure group, Friedman analysis showed statistically significant differences for sphere and SE values ($p = 0.000$). For the sphere, differences were found with WF-P ($p = 0.035$), WF-M ($p = 0.018$) and OPD-M ($p = 0.000$), which yielded the biggest difference with manifest refraction (0.68 ± 0.61D). Differences in spherical equivalent were found only with OPD-M ($p = 0.004$). Regarding the astigmatism components, no differences were found.

In the Micropure lens group, the Friedman analysis showed differences for all values studied ($p < 0.05$). The differences in the sphere were found with the AR ($p = 0.010$) and OPD-M ($p = 0.018$) while the differences in the SE were found with WF-P, WF-M and OPD-M ($p = 0.000$), being this method the one with the biggest difference (-0.26 ± 0.47D). The differences with the J0 astigmatism component were found with all the objective methods except for OPD-M ($p < 0.05$), while with the J45 component the differences were only with OPD-C ($p = 0.022$).

Table 3 shows all the average differences obtained between manifest refraction and all objective methods in both groups.

Figures 2 and 3 show the Bland–Altman plots for the sphere and spherical equivalent for both lenses. In each graph, the vertical axis represents the difference between each objective method and the subjective results of the manifest refraction, while the horizontal axis indicates the corresponding manifest refraction value. The manifest refraction value was considered instead of the average value of all

Table 1 Descriptive statistics obtained after surgery for subjective refraction and visual acuity in both groups

	Group	Subjective refraction (D)					Visual acuity (logMAR)		Pupil size (mm)	
		Sph	Cyl	M	J0	J45	UDVA	CDVA	Photopic pupil size	Mesopic pupil size
Mean ± SD	ISOPURE	0.03 ± 0.32	−0.23 ± 0.27	−0.08 ± 0.34	−0.04 ± 0.13	0.01 ± 0.12	0.04 ± 0.13	0.00 ± 0.06	2.82 ± 0.42	3.97 ± 0.56
	MICROPURE	0.24 ± 0.22	−0.38 ± 0.33	0.05 ± 0.23	−0.10 ± 0.18	0.02 ± 0.14	0.01 ± 0.06	−0.04 ± 0.04	3.36 ± 0.65	4.48 ± 0.92
Min	ISOPURE	−0.75	−0.75	−0.75	−0.37	−0.25	−0.08	−0.08	2.03	2.91
	MICROPURE	0.00	−1.00	−0.38	−0.38	−0.38	−0.08	−0.10	2.41	3.16
Max	ISOPURE	0.75	0.00	0.75	0.19	0.25	0.36	0.10	3.63	5.16
	MICROPURE	0.75	0.00	0.50	0.35	0.32	0.14	0.00	4.43	5.99
p-value		**0.013**	0.122	0.095	0.076	0.355	0.868	**0.019**	**0.002**	0.124

CDVA corrected distance visual acuity; *Cyl* cylinder; *D* diopters; *J0* vertical Jackson cross-cylinder, axes at 180 degrees and 90 degrees; *J45* oblique Jackson cross-cylinder, axes at 45 degrees and 135 degrees; *LogMAR* logarithm of the minimun angle of resolution; *M* spherical equivalent; *max* maximum; *min* minimum; *mm* milimeters; *SD* standard deviation; *Sph* sphere; *UDVA* uncorrected distance visual acuity. Statistically significant values appear in boldface

Table 2 Descriptive statistics for the objective refractions obtained with all the evaluated methods

		Objective Methods				
Parameter	Group	AR	WF-P	WF-M	OPD-C	OPD-M
Sph (D)	ISOPURE	0.16 ± 0.53	0.43 ± 0.90	0.22 ± 0.45	–0.06 ± 0.48	0.72 ± 0.57
	MICROPURE	0.39 ± 0.35	0.37 ± 0.65	0.21 ± 0.36	0.27 ± 0.39	–0.02 ± 0.46
Cyl (D)	ISOPURE	–0.41 ± 0.33	–1.17 ± 0.97	–0.64 ± 0.76	–0.39 ± 0.47	–0.70 ± 0.40
	MICROPURE	–0.75 ± 0.37	–1.39 ± 0.62	–0.78 ± 0.35	–0.66 ± 0.41	–0.60 ± 0.55
M (D)	ISOPURE	–0.05 ± 0.55	–0.16 ± 0.98	–0.11 ± 0.51	–0.25 ± 0.48	0.37 ± 0.59
	MICROPURE	0.01 ± 0.29	–0.33 ± 0.49	–0.18 ± 0.27	–0.06 ± 0.32	–0.32 ± 0.33
J0 (D)	ISOPURE	–0.05 ± 0.19	–0.13 ± 0.60	–0.09 ± 0.43	–0.06 ± 0.22	–0.08 ± 0.25
	MICROPURE	–0.24 ± 0.26	–0.47 ± 0.43	–0.26 ± 0.24	–0.22 ± 0.24	–0.22 ± 0.28
J45 (D)	ISOPURE	0.03 ± 0.18	0.03 ± 0.47	0.03 ± 0.24	–0.01 ± 0.21	0.12 ± 0.29
	MICROPURE	0.01 ± 0.24	–0.05 ± 0.43	–0.02 ± 0.25	–0.03 ± 0.21	0.06 ± 0.19

AR autorefraction; *Cyl* cylinder; *J0* vertical Jackson cross-cylinder, axes at 180 degrees and 90 degrees; *J45* oblique Jackson cross-cylinder, axes at 45 degrees and 135 degrees; *OPD-C* autorefraction measured with the 3-dimension wavefront topography aberrometer system in the central pupil/photopic conditions; *OPD-M* autorefraction measured with the 3-dimension wavefront topography aberrometer system under mesopic conditions; *M* spherical equivalent; *Sph* sphere; *WF-M* wavefront mesopic; *WF-P* wavefront photopic

methods as this is considered the gold standard for obtaining refraction.

Table 4 shows the correlation coefficients of each component measured with each objective method with respect to the manifest refraction. As can be seen, autorefraction is the objective method with the strongest correlation values for all components of refraction for both types of lenses.

Discussion

Post-surgical refraction is one of the methods that allow us to know if one of the most demanded post-surgical objectives has been achieved, such as emmetropia and the elimination of the use of glasses for different tasks depending on the type of lens implanted.

Although manifest refraction is still the gold standard for determining the refractive status of the eye, it requires time and training to perform correctly, especially when not using monofocal intraocular lenses. There are other techniques that also allow us to know it more quickly and require less training, such as autorefraction or aberrometry [6].

To our knowledge, this is the first study that assesses the refraction obtained with different objective methods in an intraocular lens based on isofocal technology and compares it with a monofocal control. Both lenses have the same platform and material. It has been published that lenses with the same optical design but different materials show different behaviours when compared using objective refraction methods. Comparing two lenses of identical material allows us to associate the changes that may occur only to the optical design [7].

The optic of Isopure is based on complex polynomial design parameters for the two anterior and posterior surfaces with high order terms (up to 10th order) while Micropure is limited to a second order parameter and to the posterior optic, the anterior optic being spherical.

It is the only lens available with this novel design, so it is necessary to know how it behaves in terms of autorefraction in order to guide the optometrist or ophthalmologist in the refraction and analysis of postoperative data based on objective methods.

All lenses included were calculated to emmetropia using the target close to zero. Despite differences statistically significant between lenses ($p = 0.013$) have been observed, with both models the target was lower than 0.25D.

Several studies show the relevance of knowing the differences that can be found between objective and subjective refraction values with IOLs that allow vision at different distances. Muñoz et al. [14] studied the bifocal refractive lens ReZoom (Abbott Medical Optics, Santa Ana, CA, USA). They showed more negative values with autorefraction than those obtained at manifest refraction, both for sphere and SE, -0.84 ± 0.62D and -1.00 ± 0.61D respectively. The authors concluded that these differences were due to the existence of 5 concentric refractive zones that could interfere with the autorefractometer measurement. Unlike the lens evaluated by Muñoz et al., the Isopure lens has a single focus, and although the focus is elongated it does not contain different zones or rings in the optic. With the Isopure lens a mean difference of 0.13 ± 0.38D was obtained, which was not statistically significant. Ota et al. [15] evaluated the results obtained with a diffractive EDOF intraocular lens (Symfony ZXR00V, Johnson & Johnson Vision, Santa Ana, CA, USA) through autorefraction and manifest refraction, with more negative values for sphere and SE, with a mean difference of -0.71 ± 0.24D and -0.84 ± 0.24D respectively, similar values to those obtained by Muñoz et al. [14], despite the lenses

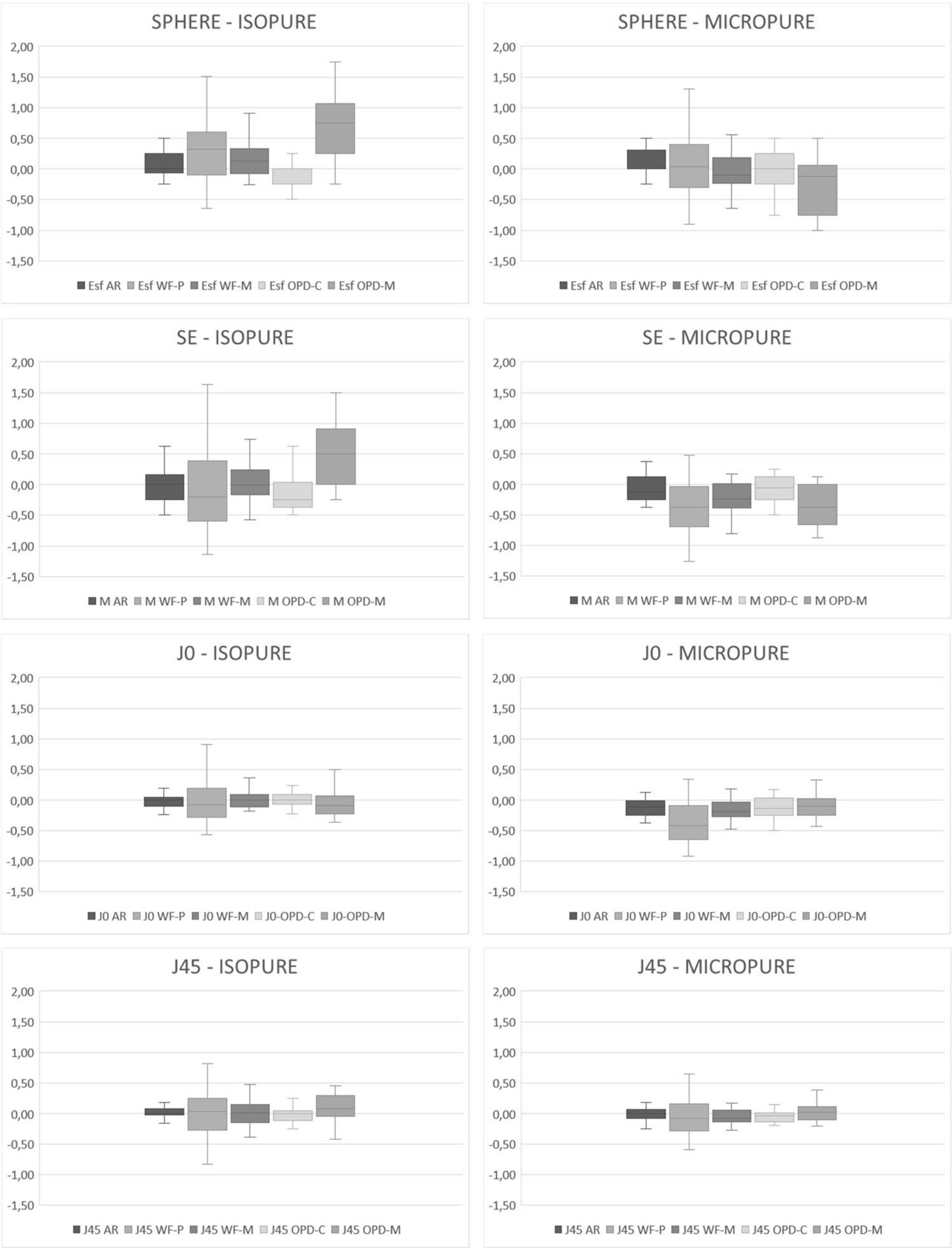

Fig. 1 Differences between objective refraction and subjective refraction for sphere, SE, and J0 and J45 (vector components of astigmatism), and for each of the 5 objective refraction scenarios under assessment for both lenses. AR = autorefraction; J0 = vertical Jackson cross-cylinder, axes at 180 degrees and 90 degrees; J45 = oblique Jackson cross-cylinder, axes at 45 degrees and 135 degrees; OPD-C = autorefraction measured with the 3-dimension wavefront topography aberrometer system in the central pupil/photopic conditions; OPD-M = autorefraction measured with the 3-dimension wavefront topography aberrometer system under mesopic conditions; SE = spherical equivalent; Sph = sphere; WF-M = wavefront mesopic; WF-P = wavefront photopic)

have different technology. In the case of the diffractive lens [15], the authors hypothesized that this difference could be caused by the chromatic difference induced by the diffraction of the lens when measuring objective refraction with light between 800 and 850 nm, and so the difference would be inherent to the lens design. In our case, when evaluating the Isopure lens, which can be considered refractive as the ReZoom lens and with elongated focus as the Symfony lens, values much closer to emmetropia were obtained. Although there was a slight tendency towards hypermetropia it was less than a quarter of a dioptre (0.13 ± 0.38D), and not statistically significant.

The study by Garzón et al. [13] compared subjective refraction with objective refractive values, both with an autorefractometer and an aberrometer, using a methodology similar to that applied in our study. In their study they evaluated an advanced monofocal refractive lens, the Tecnis Eyhance (ICB00, Johnson & Johnson Vision, Santa Ana, CA, USA) versus the standard monofocal lens Tecnis One (ZCB00, Johnson & Johnson Vision, Santa Ana, CA, USA). Like the lenses in our study, these lenses share the same material and platform, differing only in the optic design. For the Eyhance lens, statistically significant differences were obtained for the sphere only between the manifest refraction

Table 3 Mean differences for both groups of patients between objective and subjective methods under study

Objective-Subjective refraction differences						
Parameter	Group	AR	WF-P	WF-M	OPD-C	OPD-M
Sph (D)	ISOPURE	0.13 ± 0.38	**0.39 ± 0.76**	**0.18 ± 0.33**	–0.09 ± 0.36	**0.68 ± 0.61**
	MICROPURE	**0.15 ± 0.23**	0.13 ± 0.58	–0.03 ± 0.32	0.03 ± 0.33	**–0.26 ± 0.47**
M (D)	ISOPURE	0.03 ± 0.36	–0.08 ± 0.90	–0.03 ± 0.54	–0.17 ± 0.38	**0.45 ± 0.62**
	MICROPURE	–0.04 ± 0.22	**–0.38 ± 0.41**	**–0.24 ± 0.25**	–0.11 ± 0.28	**–0.38 ± 0.33**
J0 (D)	ISOPURE	–0.01 ± 0.10	–0.09 ± 0.57	–0.06 ± 0.42	–0.03 ± 0.22	–0.05 ± 0.20
	MICROPURE	**–0.13 ± 0.14**	**–0.37 ± 0.34**	**–0.16 ± 0.18**	**–0.12 ± 0.17**	–0.12 ± 0.30
J45 (D)	ISOPURE	0.02 ± 0.11	0.02 ± 0.41	0.02 ± 0.20	–0.02 ± 0.17	0.11 ± 0.28
	MICROPURE	–0.01 ± 0.12	–0.08 ± 0.32	–0.04 ± 0.16	**–0.05 ± 0.10**	0.04 ± 0.19

AR autorefraction; *Cyl* cylinder; *J0* vertical Jackson cross-cylinder, axes at 180 degrees and 90 degrees; *J45* oblique Jackson cross-cylinder, axes at 45 degrees and 135 degrees; *OPD-C* autorefraction measured with the 3-dimension wavefront topography aberrometer system in the central pupil/photopic conditions; *OPD-M* autorefraction measured with the 3-dimension wavefront topography aberrometer system under mesopic conditions; *M* spherical equivalent; *Sph* sphere; *WF-M* wavefront mesopic; *WF-P* wavefront photopic. Statistically significant values appear in boldface

and the OPD-C, while for the SE the differences were found with the AR and the OPD-C. According to the authors, the Eyhance lens, which is based on the modification of the anterior surface to induce spherical aberration, showed pupil-dependent behaviour as the larger the pupil size the more negative the refraction value, while the monofocal lens did not show that pupil dependence. Our data show statistically significant differences between both Isopure and the

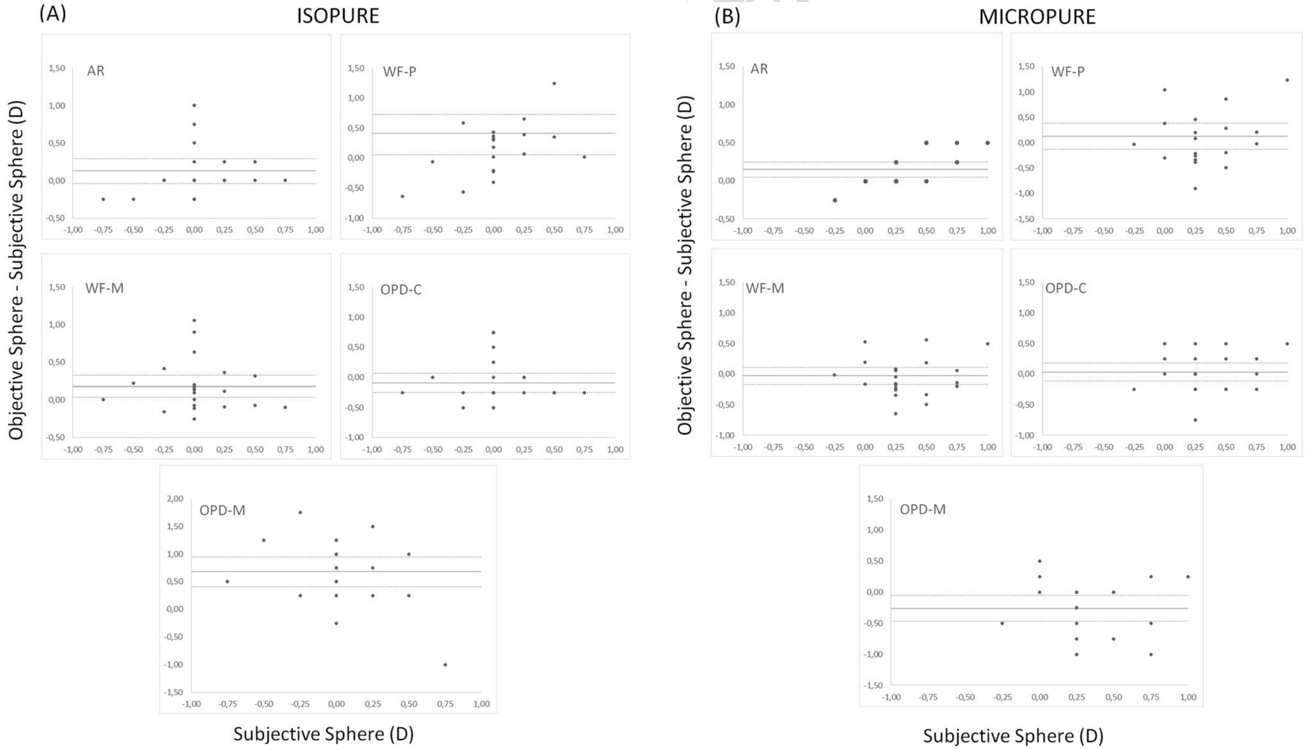

Fig. 2 **a** Bland–Altman plots for the subjective sphere showing the objective–subjective refraction difference sphere value for each of the five objective-refraction approaches (AR: autorefractor; WF-P: wavefront photopic; WF-M: wavefront mesopic; OPD-C: OPD photopic; OPD-M: OPD mesopic) for the group implanted with Isopure lens. The mean pupil size for photopic conditions was 2.82 ± 0.42 mm and 3.36 ± 0.65 mm for mesopic conditions. **b** Bland–Altman plots for the subjective sphere showing the objective–subjective refraction difference sphere value for each of the five objective-refraction approaches (AR: autorefractor; WF-P: wavefront photopic; WF-M: wavefront mesopic; OPD-C: OPD photopic; OPD-M: OPD mesopic) for the group implanted with Micropure lens. The mean pupil size for photopic conditions was 3.97 ± 0.56 mm and 4.48 ± 0.92 mm for mesopic conditions

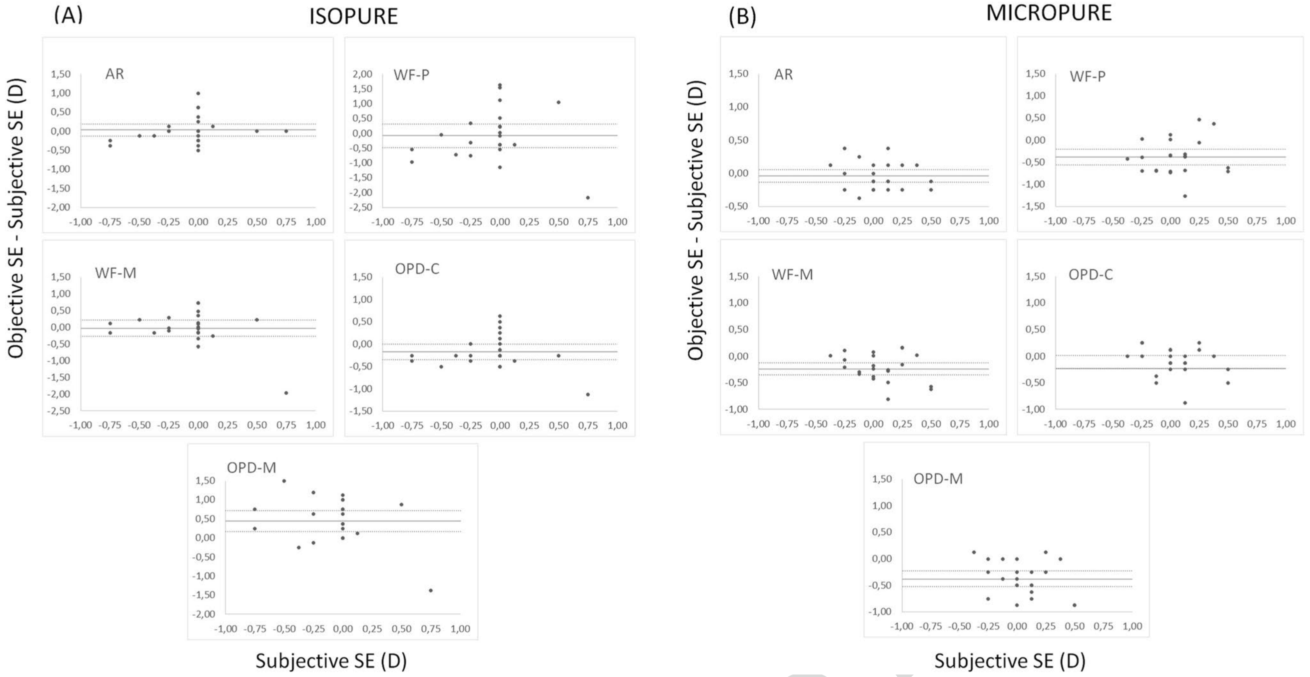

Fig. 3 **a** Bland–Altman plots for the subjective spherical equivalent (SE) showing the objective–subjective refraction difference M value for each of the five objective refraction approaches (AR: autorefractor; WF-P: wavefront photopic; WF-M: wavefront mesopic; OPD-C: OPD photopic; OPD-M: OPD mesopic) for the group implanted with Isopure lens. The mean pupil size for photopic conditions was 2.82 ± 0.42 mm and 3.36 ± 0.65 mm for mesopic conditions. **b** Bland–Altman plots for the subjective spherical equivalent (SE) showing the objective–subjective refraction difference M value for each of the five objective refraction approaches (AR: autorefractor; WF-P: wavefront photopic; WF-M: wavefront mesopic; OPD-C: OPD photopic; OPD-M: OPD mesopic) for the group implanted with Micropure lens. The mean pupil size for photopic conditions was 3.97 ± 0.56 mm and 4.48 ± 0.92 mm for mesopic conditions

control lens in the measurement of the sphere and the SE with the OPD-M. For the Isopure lens, the sphere showed a mean difference from the manifest refraction of 0.68 ± 0.61D and the SE of 0.45 ± 0.62D, while the differences with the control lens were -0.26 ± 0.47D and -0.38 ± 0.33D respectively. These are significant differences of more than 0.75D for the two variables. The results agree, as far as monofocal lenses are concerned, with those of Garzón et al. [13], which seems to indicate a trend towards negative values of this device versus subjective refraction in aspheric monofocal lenses. Where agreement was found between the results of the Eyhance model and the Isopure model was that in both

Table 4 Correlation coefficients for each method and for each of the refractive components for both lenses

Correlation coefficients						
Parameter	Group	AR	WF-P	WF-M	OPD-C	OPD-M
Sph (D)	ISOPURE	**0.668**	**0.611**	**0.636**	**0.667**	0.174
	MICROPURE	**0.715**	0.387	0.375	**0.465**	0.023
M (D)	ISOPURE	**0.740**	**0.445**	0.404	**0.637**	0.212
	MICROPURE	**0.675**	**0.566**	**0.509**	**0.518**	0.355
J0 (D)	ISOPURE	**0.782**	**0.501**	**0.499**	**0.510**	**0.546**
	MICROPURE	**0.871**	**0.680**	**0.653**	**0.702**	0.245
J45 (D)	ISOPURE	**0.829**	**0.474**	**0.483**	**0.545**	**0.425**
	MICROPURE	**0.907**	**0.902**	**0.901**	**0.907**	**0.654**

AR autorefraction; *Cyl* cylinder; *J0* vertical Jackson cross-cylinder, axes at 180 degrees and 90 degrees; *J45* oblique Jackson cross-cylinder, axes at 45 degrees and 135 degrees; *OPD-C* autorefraction measured with the 3-dimension wavefront topography aberrometer system in the central pupil/photopic conditions; *OPD-M* autorefraction measured with the 3-dimension wavefront topography aberrometer system under mesopic conditions; *M* spherical equivalent; *Sph* sphere; *WF-4* wavefront 4.0 mm; *WF-M* wavefront mesopic; *WF-P* wavefront photopic. Statistically significant values appear in boldface cases, in both sphere and cylinder values, the values were more positive in the autorefraction measurements with the aberrometric system in mesopic conditions than in photopic conditions. The two lenses, although using different technology to obtain the focus elongation, show a more negative spherical aberration in the centre than in the periphery, which could be one of the reasons for this pupil-dependent variation [13, 16].

Regarding the measurements derived from the Zernike coefficients, both with the Isopure lens and with the control lens, a similar behaviour was observed, with more positive sphere values under photopic conditions than under mesopic ones, while the cylinder values were more negative under photopic conditions. This trend agrees with that reported by Hou [17] in his study with monofocal intraocular lenses evaluating the autorefraction derived from the wavefront.

On the other hand, for the Isopure lens, none of the astigmatism components showed statistically significant differences with the manifest refraction when evaluated with the objective methods. For the Micropure lens, statistically significant differences were found in the J0 component for all objective methods except OPD-M. For the J45 component, the difference was found only with the OPD-C. In any case, these differences were not clinically relevant as they were around a quarter of a dioptre or even less.

The correlation coefficients of all spherical and cylindrical refractive components in the present study were better with the autorefractometer than with any of the other methods analysed for both the isofocal and monofocal models. As in the study by Garzón et al. [13], with the advanced monofocal IOL, the Eyhance model, the correlation was higher for the cylinder than for the sphere for both models. The OPD-M measurement showed the lowest correlation for all parameters evaluated for both lenses. These results indicate that the traditional method, which obtains the refractive power in a single pupillary zone [17], and which is still the most widely used clinically, is still the most effective, especially in lenses with complex optical designs such as the Isopure lens.

Based on the results obtained in this study, we can conclude that the modification of the anterior and posterior surfaces of the Isopure lens with high order terms to enhance the depth of focus does not have a negative impact on the refraction obtained by AR, as no statistically significant differences are observed between measurements and there is good correlation between the measurements obtained. Therefore, objective evaluation techniques such as AR and OPD-C can be a good starting point for refraction in this type of lens.

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Declarations

Ethics approval and consent to participate Informed consent for participation was obtained from each patient. The study was approved by Ethics Committee Hospital Clínico San Carlos (C.I. 20/030-R_P, Madrid, Spain.

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Conflict of interest On behalf of all authors, I declare no conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. As corresponding author, I confirm that the manuscript has been read and approved for submission by all the named authors.

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