ORIGINAL ARTICLE

Correlating Optical Bench Performance With Clinical Defocus Curves in Varifocal and Trifocal Intraocular Lenses

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ABSTRACT

PURPOSE: To investigate the correlations existing between a trifocal intraocular lens (IOL) and a varifocal IOL using the "ex vivo" optical bench through-focus image quality analysis and the clinical visual performance in real patients by study of the defocus curves.

METHODS: This prospective, consecutive, nonrandomized, comparative study included a total of 64 eyes of 42 patients. Three groups of eyes were differentiated according to the IOL implanted: 22 eyes implanted with the varifocal Lentis Mplus LS-313 IOL (Oculentis GmbH, Berlin, Germany); 22 eyes implanted with the trifocal FineVision IOL (Physiol, Liege, Belgium), and 20 eyes implanted with the monofocal Acrysof SA60AT IOL (Alcon Laboratories, Inc., Fort Worth, TX). Visual outcomes and defocus curve were evaluated postoperatively. Optical bench through-focus performance was quantified by computing an image quality metric and the cross-correlation coefficient between an unaberrated reference image and captured retinal images from a model eye with a 3.0-mm artificial pupil.

RESULTS: Statistically significant differences among defocus curves of different IOLs were detected for the levels of defocus from -4.00 to -1.00 diopters (D) ($P < .01$). Significant correlations were found between the optical bench image quality metric results and logMAR visual acuity scale in all groups (Lentis Mplus group: $r = -0.97$, $P < .01$; FineVision group: $r = -0.82$, $P < .01$; Acrysof group: $r = -0.99$, $P < .01$). Linear predicting models were obtained.

CONCLUSIONS: Significant correlations were found between logMAR visual acuity and image quality metric for the multifocal and monofocal IOLs analyzed. This finding enables surgeons to predict visual outcomes from the optical bench analysis.

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Several multifocal intraocular lens (IOL) designs are available for restoring distance and near vision simultaneously.[1] Different studies have confirmed the efficacy of multifocal IOLs to provide good functional vision without the use of corrective lenses.[1,2-6] However, optical side effects such as decreased contrast sensitivity, glare disability, or halos have also been reported.[7-10]

Recently, two new multifocal IOL technologies have been introduced into clinical practice: the varifocal IOL and the trifocal multifocal IOL. The Lentis Mplus (Oculentis GmbH, Berlin, Germany) varifocal IOL includes an inferior surface-embedded segment with the optical power required for near vision and seamless transitions between the near and far vision zones.[11,12] The FineVision (Physiol, Liege, Belgium)[13] trifocal IOL combines two diffractive apodized profiles that can provide three foci for distance, near, and intermediate vision.[14] Previous studies[15,16] have clinically evaluated the optical image quality of these models. These studies had some restrictions, such as pupil diameters, corneal aberrations, and ocular axis misalignments. The optical bench analysis allows assessment of the differences between IOL optics independently of factors noted previously.

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Some investigators[17-20] have studied the optical quality of these new technologies in an optical bench and several reports[11-14,21-24] have shown their clinical defocus curve. However, no studies have compared the relationship between the subjective information provided by the clinical defocus curve and the objective information of these multifocal IOL models using the through-focus optical performance analysis obtained in an optical bench. Establishing such a relationship will contextualize optical bench studies, enabling clinicians and vision scientists to meaningfully interpret previous findings. The importance of this was emphasized when the American Academy of Ophthalmology and the U.S. Food and Drug Administration sponsored a symposium with industry to encourage the development and standardization of optical and clinical testing methods to clarify the performance of multifocal, extended depth of focus, and accommodating IOLs (March 28, 2014).

The aim of this study was to correlate and compare the through-focus optical performance obtained in an optical bench with the clinical visual performance using the defocus curve measured in pseudophakic patients following the implantation of varifocal, trifocal, or monofocal IOLs.

PATIENTS AND METHODS

PATIENTS

This prospective, consecutive, nonrandomized clinical study included a total of 64 eyes of 42 patients with ages ranging between 36 and 84 years. All patients underwent cataract surgery followed by IOL implantation in the capsular bag. According to the IOL implanted, three groups of eyes were differentiated: 22 eyes implanted with the varifocal Lentis Mplus LS-313 IOL (the Lentis Mplus group); 22 eyes implanted with the FineVision trifocal IOL (the FineVision group); and 20 eyes implanted with the monofocal Acrysof SA60AT IOL (Alcon Laboratories, Inc., Fort Worth, TX) (the Acrysof group). 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 ethical committee. The inclusion criteria used in this study were patients with incipient or moderate cataract reporting a significant reduction in visual quality and no other ocular comorbidity that might influence the visual outcome. The exclusion criteria were patients with active ocular diseases and topographic astigmatism greater than 2.00 diopters (D). Patients with previous ocular surgeries, corneal irregularities, or corneal opacities were excluded.

IOLS

Lentis Mplus LS-313 IOL. This IOL is a refractive varifocal IOL composed of an aspheric distance vision zone combined with a 3.00-D posterior sector-shaped near-vision zone allowing seamless varifocal transition between the zones. The light lost with this IOL is between 5% and 7%.

FineVision IOL. This IOL is a trifocal, single-piece, foldable aspheric IOL with two interspersed diffractive structures, one with +1.75-D addition for intermediate vision and another with +3.50-D addition for near vision. The theoretical light distribution for a 20-D diffractive Fine Vision IOL is 42% for far focus, 15% for intermediate focus, and 29% for near focus with 14% lost energy at 3-mm pupil diameter.[25]

Monofocal IOL. The AcrySof SA60AT monofocal IOL was used as the control group. This is a foldable, single-piece, monofocal, spherical IOL with an overall diameter of 13 mm and biconvex optics.

IOL OPTICAL BENCH TESTING SYSTEM

Figure A (available in the online version of this article)[19] shows a schematic outline of the optical bench metrology system, which was developed at Flaum Eye Institute, University of Rochester, to measure the optical properties of IOLs in vitro. An artificial pupil was placed in the pupil plane and imaged onto the artificial corneal surface using the relay optics. The artificial pupil was set to 3-mm diameter for this study. A pupil camera imaged the artificial pupil, the alignment reference, and an IOL in a model eye simultaneously and was used to accurately determine pupil diameter and IOL alignment. The model eye consisted of an artificial cornea and a wet cell. As per the recommendation of the International Organization for Standardization (ISO) 11979-2, an aspheric (spherical aberration-free) doublet was used as an artificial cornea. The power of the artificial cornea was 40 D (EdmundOptics, Inc., Barrington, NJ). The IOL was submerged in a wet cell with the front and back surfaces of the latter covered by optical flat windows. The IOL was mounted onto a stage with three-axis translation, allowing precise alignment within the wet cell. The air space between the artificial cornea and the wet cell was set to 4 mm so that the ratio of entrance pupil diameter to beam size at the IOL was in accordance with that found in the Gullstrand model eye. The IOL power of IOLs analyzed in the optical bench was 20.0 D.

To quantify the image quality of the IOLs, through-focus images of a resolution target were captured. The resolution target consisted of tumbling Sloan letter E’s corresponding to 20/40, 20/30, 20/25, 20/20, and 20/15 Snellen letter sizes and was displayed by a computer projector (PG-M20X; Sharp Corp., Blacktown, Australia) in white light. This target was placed in a plane conjugate to the IOL image plane (retinal plane). The retinal image formed by the model eye was magnified by a microscope objective onto a 5-megapixel charge-coupled device to improve sampling resolution. Near vision was simulated using a Badal optometer to change the object vergence at the model eye. Simulated object distances ranged from +1.00 D (beyond infinity) to -5.00 D (near vision) in 0.125-D increments.[19,20]

SURGICAL TECHNIQUE

All surgeries were performed by the same surgeon (JLA) using a standard technique of sutureless micro-incision phacoemulsification. The incision was placed on the steepest corneal meridian studied by the corneal topography and the size in all cases was 1.8 to 2 mm. All IOLs were implanted into the capsular bag.

PREOPERATIVE AND POSTOPERATIVE EXAMINATIONS

Preoperatively, all patients had a full ophthalmologic examination. The distance visual acuity was measured using Snellen charts at 4 m under standard illumination of 500 lux and the near visual acuity with Radner Reading Charts (Spanish validated version)[26,27] at 40 cm under illumination of 500 lux.

Postoperatively, patients were evaluated during the follow-up at 1 day, 1 month, and 6 months after surgery. The follow-up was performed in an unmasked way by two optometrists (ABP and ES) specialized and certified in good clinical practice. The postoperative examination protocol at 6 months was identical to the preoperative protocol, with the additional measurement of the defocus curve. The defocus curves were obtained in monocular distance vision and with the best distance refractive correction by adding plus lenses in 0.50-D steps and recording the visual acuity achieved by the patient with each type of blur. The defocus range evaluated was between -4.00 and +1.00 D. Following this, the procedure was repeated but with negative lenses. Visual acuity has been reported in logMAR. In addition, the postoperative pupil size was measured in photopic light conditions using the corneal topographer.

DATA ANALYSIS

To assess through-focus image quality of the resolution target through different IOLs, an image quality metric (IQM) based on cross-correlation coefficients was computed using a custom-made Matlab program (version 2009; Mathworks, Inc., Natick, MA), as described elsewhere.[19,20,28] The analysis procedure consisted of first registering each captured image with an unaberrated reference image to avoid errors in alignment. Subsequently, the cross-correlation coefficient between the unaberrated reference image and the captured image was computed to quantify their similarity, defining the IQM. Cross-correlation coefficient values range from -1 to +1, where +1 corresponds to a perfect match between the captured and reference images. Therefore, an IQM value of +1 refers to ideal retinal image quality, and values less than +1 correspond to poorer retinal image quality (eg, due to optical imperfections). The distance (0.00 D) image was chosen to maximize the cross-IQM of an image for a 3-mm pupil, and defocus points for the rest of the images were shifted accordingly.[19] To compare and graph the data of the clinical defocus curve and the cross-correlation coefficients, we used the clinical convention of negative dioptric values to represent near target vergences.

To compare the clinical defocus curve for a given IOL, IQM was plotted as a function of the logMAR visual acuity at the corresponding target vergence. Thus, each IOL resulted in its own IQM versus logMAR visual acuity curve, on which a linear regression was performed to quantify the strength of the correlation (R^2).

The statistical analysis was performed using the SPSS statistics software package version 15.0 for Windows (SPSS, Inc., Chicago, IL). The Wilcoxon rank sum test was applied to assess the significance of differences between preoperative and postoperative data, whereas the Kruskal–Wallis test was used to compare the analyzed parameters between groups. For post-hoc analysis, the Mann–Whitney test with Bonferroni's adjustment was used to avoid the experimental error rate in these cases. For all statistical tests, the same level of significance was used ($P < .05$).

RESULTS

Preoperatively, no statistically significant differences between groups were found in age, spherical equivalent, keratometry, axial length, or power of the implanted IOL ($P \geq .10$) (**Table 1**). During follow-up, decentration and IOL tilt were evaluated using the slit lamp and no significant IOL tilt or decentration were found in any patient.

OPTICAL DEFOCUS CURVES FROM OPTICAL BENCH TESTING

Figure 1 represents the focus image quality quantified using the IQM described above.

As shown, the multifocal Lentis Mplus IOL pattern shows improved IQM for near target vergences compared to the monofocal IOL. The IQMs for this IOL were 0.81, 0.76, and 0.73 at distance (0.00 D), intermediate (-1.50 D), and near (-3.00 D), respectively.

The IQMs for the trifocal FineVision IOL were 0.80, 0.72, and 0.69 at distance (0.00 D), intermediate (-1.50 D), and near (-3.00 D), respectively. This IOL pattern shows improved cross-correlation coefficients for near target vergences compared to the Acrysof monofocal IOL.

TABLE 1

Preoperative Conditions of Patients in the Three Groups, Mean ± SD (Range)

Characteristic	Lentis Mplus	FineVision	Acrysof	P^a
Age (years)	61.92 ± 7.5 (51 to 79)	65.18 ± 8.6 (54 to 82)	68.50 ± 9.67 (46 to 84)	.10
UDVA (logMAR)	0.57 ± 0.50 (0.04 to 2.00)	0.66 ± 0.31 (0.24 to 1.30)	1.46 ± 0.76 (0.10 to 1.90)	< .01
SE (D)	-0.44 ± 3.33 (-7.38 to +5.13)	-0.56 ± 3.22 (-9.38 to +2.88)	-1.22 ± 4.92 (-7.88 to 11.75)	.61
CDVA (logMAR)	0.13 ± 0.21 (0.00 to 0.82)	0.17 ± 0.18 (0.00 to 0.59)	0.23 ± 0.22 (0.00 to 0.82)	.20
Km (D)	43.70 ± 1.11 (42.21 to 47.04)	44.19 ± 2.16 (39.88 to 47.78)	43.27 ± 2.33 (35.03 to 46.27)	.55
Axial length (mm)	23.13 ± 0.96 (21.47 to 25.37)	23.60 ± 1.36 (21.67 to 26.27)	24.02 ± 2.00 (19.23 to 27.98)	.17
IOL power (D)	21.30 ± 2.97 (16.00 to 27.00)	20.57 ± 4.14 (12.00 to 27.00)	20.55 ± 6.06 (12.00 to 40.00)	.79

SD = standard deviation; UDVA = uncorrected distance visual acuity; SE = spherical equivalent; D = diopters; CDVA = corrected visual acuity; Km = mean keratometry; IOL = intraocular lens

The Lentis Mplus LS-313 IOL is manufactured by Oculentis GmbH, Berlin, Germany; the FineVision IOL by Physiol, Liege, Belgium; and the Acrysof SA60AT IOL by Alcon Laboratories, Inc., Fort Worth, TX.

[a]Comparison between groups.

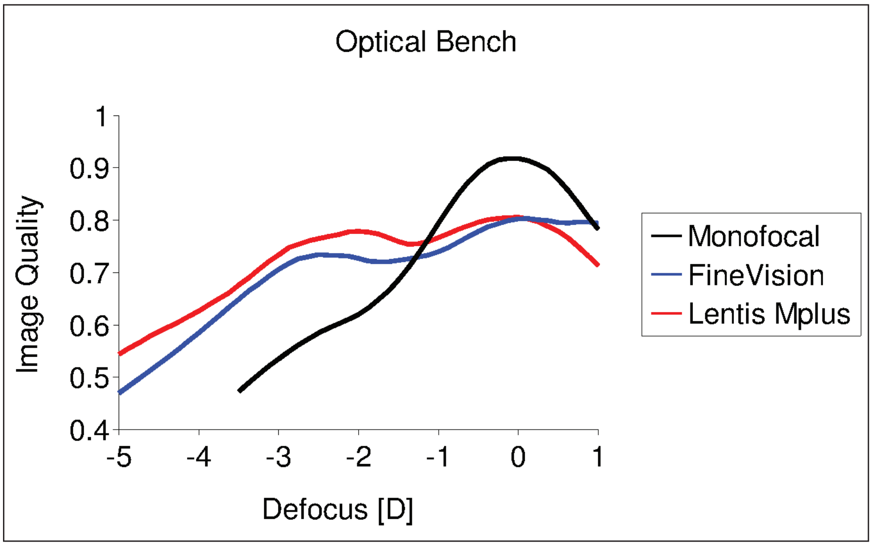

Figure 1. Cross-correlation coefficients for 3.0-mm pupils in the three intraocular lens (IOL) designs analyzed: the Lentis Mplus LS-313 (Oculentis GmbH, Berlin, Germany) (red line), the FineVision (Physiol, Liege, Belgium) (blue line), and the AcrySof SA60AT (Alcon Laboratories, Inc., Fort Worth, TX) (black line).

The Acrysof monofocal IOL provided higher IQM for far vision and lower IQM for near vision than the multifocal IOLs. At distance, intermediate, and near vision, the IQM was 0.92, 0.69, and 0.54, respectively.

VISUAL AND REFRACTIVE OUTCOMES

Table 2 summarizes the visual and refractive outcomes at 6 months postoperatively for groups of eyes analyzed. A statistically significant improvement in the uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) was observed after surgery in all groups of eyes. **Table 2** shows a comparative analysis among groups of the postoperative visual and refractive outcomes at 6 months after surgery.

Statistically significant differences between groups were detected in UDVA, CDVA, uncorrected near (UNVA) and distance corrected near (DCNVA) visual acuities at 6 months postoperatively (**Table 2**).

Comparisons Between Lentis Mplus and FineVision Groups. Statistically significant differences were found only in CDVA ($P < .01$) with better CDVA for the Lentis Mplus group. No statistically significant differences were observed between multifocal IOLs in UDVA, UNVA, or DCNVA ($P \geq .06$) (**Table 2**).

Comparisons Between Lentis Mplus and Acrysof Groups. No statistically significant differences were detected in distance visual acuities between groups. Statistically significant differences were found in near visual acuities with better outcomes for the multifocal group (**Table 2**).

Comparisons Between FineVision and Acrysof Groups. Statistically significant differences between groups were observed in UDVA, CDVA, UNVA, and DCNVA ($P < .01$), with better outcomes for distance vision in the Acrysof monofocal group and with better near visual acuities for the trifocal FineVision group (**Table 2**).

TABLE 2

Postoperative Visual and Refractive Outcomes at 6 Months After Cataract Surgery, Mean ± SD (Range)

Characteristic	Lentis Mplus	FineVision	Acrysof	P^a
UDVA (logMAR)	0.15 ± 0.10 (0.00 to 0.30)	0.21 ± 0.13 (0.01 to 0.52)	0.11 ± 0.10 (0.00 to 0.32)	.02
SE (D)	+0.06 ± 0.43 (-1.25 to +0.50)	-0.26 ± 0.43 (-1.00 to +0.75)	-0.45 ± 0.47 (-1.50 to 0.00)	< .01
CDVA (logMAR)	0.00 ± 0.04 (-0.18 to 0.05)	0.04 ± 0.05 (0.00 to 0.15)	0.01 ± 0.02 (0.00 to 0.05)	< .01
UNVA (logMAR)	0.15 ± 0.10 (0.00 to 0.30)	0.24 ± 0.19 (0.00 to 0.62)	0.56 ± 0.12 (0.30 to 0.80)	< .01
DCNVA (logMAR)	0.12 ± 0.07 (0.00 to 0.22)	0.19 ± 0.13 (0.00 to 0.52)	0.60 ± 0.09 (0.50 to 0.80)	< .01
Pupil size (mm)	3.18 ± 0.41 (2.33 to 3.87)	3.22 ± 0.50 (2.25 to 4.23)	3.47 ± 0.47 (2.67 to 4.72)	.22

SD = standard deviation; UDVA = uncorrected distance visual acuity; SE = spherical equivalent; D = diopters; CDVA = corrected visual acuity; UNVA = uncorrected near visual acuity; DCNVA = distance corrected near visual acuity

The Lentis Mplus LS-313 IOL is manufactured by Oculentis GmbH, Berlin, Germany; the FineVision IOL by Physiol, Liege, Belgium; and the Acrysof SA60AT IOL by Alcon Laboratories, Inc., Fort Worth, TX.

[a]Comparison between groups.

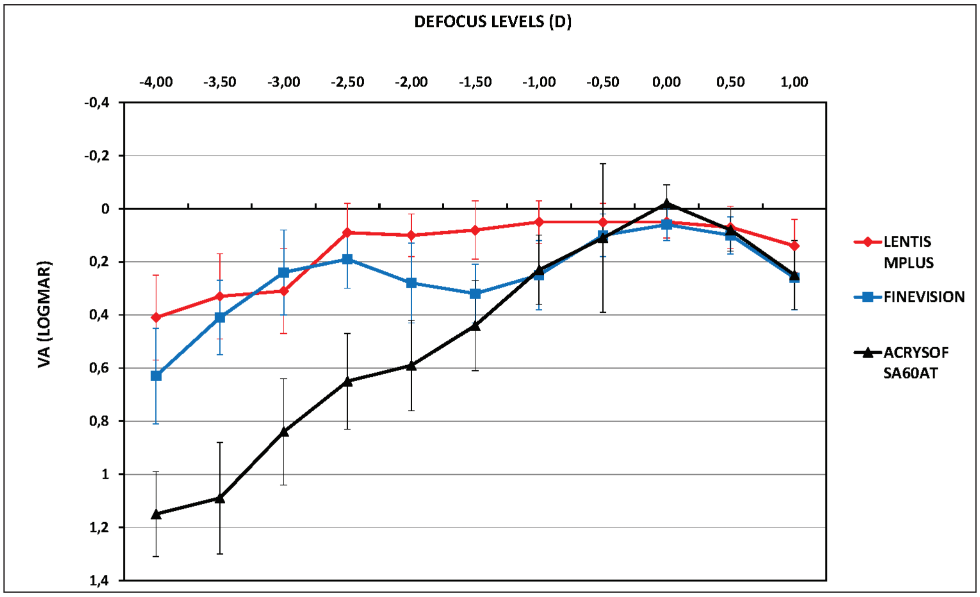

Figure 2. Mean defocus curve in the three groups of eyes analyzed: eyes implanted with the Lentis Mplus LS-313 (Oculentis GmbH, Berlin, Germany) (red line), eyes implanted with the FineVision (Physiol, Liege, Belgium) (blue line), and eyes implanted with the AcrySof SA60AT (Alcon Laboratories, Inc., Fort Worth, TX) (black line).

No statistically significant differences were detected in the photopic pupil size among groups (**Table 2**).

CLINICAL DEFOCUS CURVES

Figure 2 shows the mean defocus curve for groups of patients analyzed in the current study. The statistical analysis of the results of the defocus curve revealed significant differences among groups for all defocus levels ($P < .01$) except for the range of -0.50 to +1.00 D of defocus levels ($P \geq .06$). When pairs of IOLs were compared we observed the following.

Comparisons Between Lentis Mplus and FineVision Groups. Statistically significant differences were found for defocus levels of -4.00, -3.50, -3.00, -2.50, -2.00, -1.50, and -1.00 D ($P < .01$) with better visual acuities for the Lentis Mplus group.

Comparisons Between Lentis Mplus and Acrysof Groups. Statistically significant differences were observed for defocus levels of -4.00, -3.50, -3.00, -2.50, -2.00, -1.50, and -1.00 D ($P < .01$) with higher visual acuities values for the Lentis Mplus group.

Comparisons Between FineVision and Acrysof Groups. Statistically significant differences were detected for defocus levels of -4.00, -3.50, -3.00, -2.50, -2.00, and -1.50 D ($P \leq .01$) with higher visual acuities values for the FineVision group.

CORRELATION BETWEEN RETINAL IMAGE QUALITY AND VISUAL ACUITY

Significant and strong correlations were found between the IQM and logMAR visual acuity scale among groups (Lentis Mplus group: $r = -0.97$, $P < .01$; FineVision group: $r = -0.82$, $P < .01$; Acrysof group: $r =$

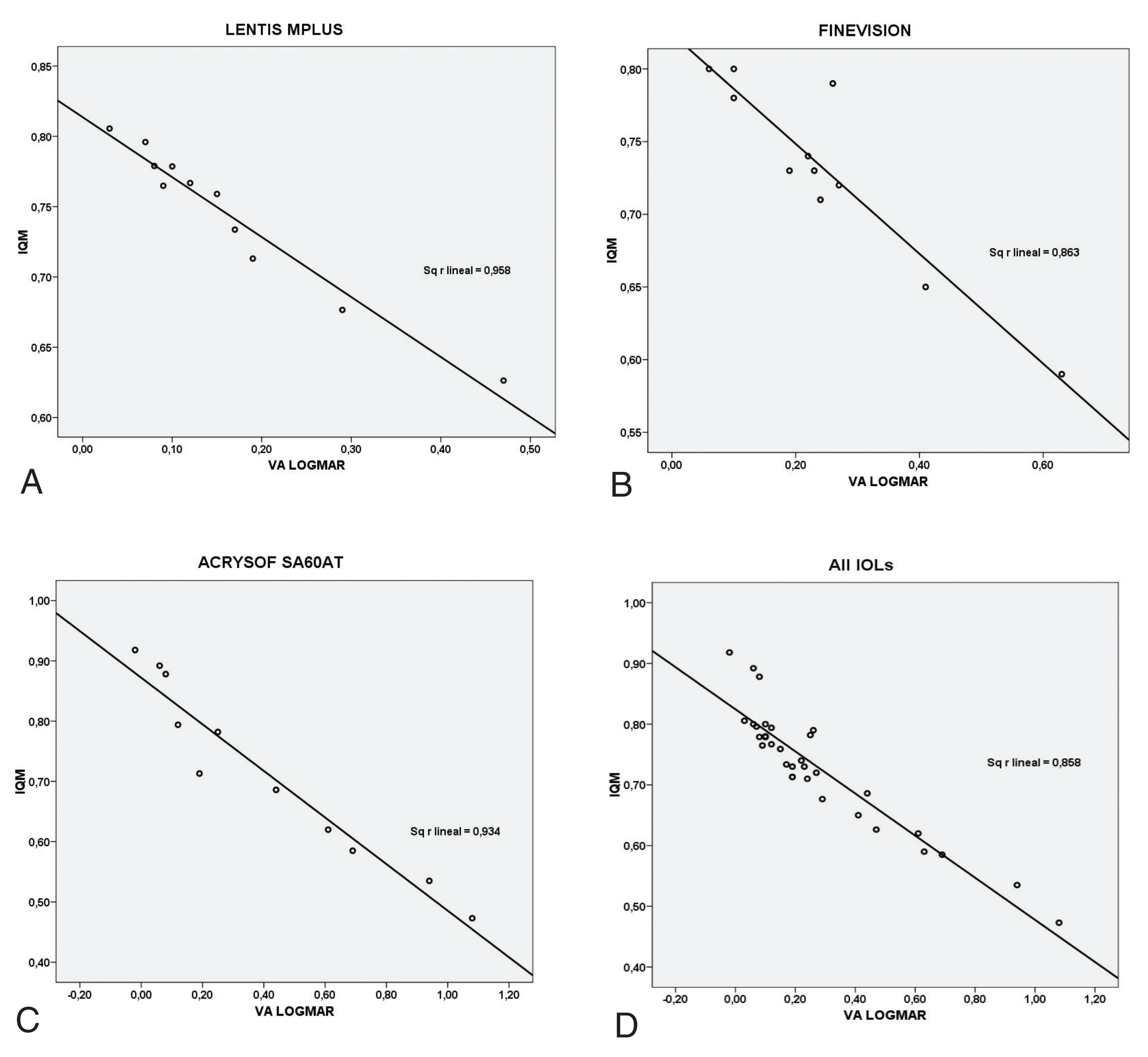

Figure 3. Scattergram plot showing the relationship between logMAR visual acuity (VA) scale and image quality metric (IQM) for (A) the Lentis Mplus LS-313 (Oculentis GmbH, Berlin, Germany): linear model $VA_A = -2.247$ IQM -1.835 ($R^2 = 0.954$); (B) the FineVision (Physiol, Liege, Belgium): linear model $VA_B = -2.282$ IQM -1.914 ($R^2 = 0.848$); (C) the AcrySof SA60AT (Alcon Laboratories, Inc., Fort Worth, TX): linear model $VA_C = -2.417$ IQM -2.134 ($R^2 = 0.927$); and (D) all three groups: linear model $VA_{all} = -2.473$ IQM -2.077 ($R^2 = 0.853$).

-0.99, $P < .01$). For this relationship, a linear predicting model with predictability (R^2) 0.954 was found for the Lentis Mplus group (**Figure 3A**), 0.848 for the FineVision group (**Figure 3B**), and 0.927 for the Acrysof group (**Figure 3C**). When we analyzed the three groups as one group, significant and strong correlation was detected ($r = -0.90$, $P < .01$) with R^2 of 0.853 (**Figure 3D**).

DISCUSSION

The results from this study demonstrate a high correlation between optical bench determined image quality and clinically determined visual acuity. To the best of our knowledge, such a correlation study has not been previously reported despite the obvious advantage that a strong correlation enables us to predict the clinical outcomes of new IOL optical profiles, avoiding unnecessary cumbersome clinical investigations and clinical failures due to inadequate optical designs.

First we compared the visual acuity outcomes in patients with a varifocal IOL, a trifocal IOL, or a monofocal IOL. As expected, a significant improvement in distance visual outcomes was achieved after surgery in the three groups analyzed. This was consistent with previous findings reported by other studies using the same IOLs.[12-14,21-24,29] Statistically significant differences were found in the postoperative visual outcomes between the evaluated groups with better results for eyes implanted with the varifocal group for near visual acuity and monofocal group for distance visual acuity. This could be due to loss of energy for far focus due to the different light distribution in multifocal IOLs.

Clinical defocus curves also showed significant differences between groups in this study. Better results were observed for the range of defocus levels of -4.00 to -1.00 D with the varifocal IOL than the other two groups. As shown in **Figure 2**, we found these differences particularly in the defocus levels that corresponded to intermediate vision (-2.00 to -1.00 D) despite the trifocal IOL being developed to improve the intermediate visual acuity provided by other multifocal IOLs. In this study, we obtained better visual acuities with the varifocal IOL in defocus levels at intermediate distances. This may be due to the gradual transition zone between both areas of the IOL and the induction of higher-order aberrations, such as the coma aberration, providing a larger depth of focus.[30-32]

To understand the optical performance of multifocal IOLs, an objective evaluation of through-focus image quality is required. Despite other image quality metrics available, such as the Strehl ratio and modulation transfer function, we used cross-correlation coefficients as an image quality metric calculated from the captured images through a monofocal IOL, a varifocal IOL, and a trifocal IOL. This technique was originally derived from digital image correlations, which use tracking and image registration techniques to measure deformations of digital images.[33] An advantage of this method is that it provides a single-value metric that can be correlated with visual performance. Furthermore, previous studies have also found strong correlations between visual performance and image quality metrics based on the correlation coefficient.[34,35]

A high correlation between logMAR visual acuity and IQM was found for all IOLs ($R^2 = 0.853$). However, it should be noted that they have different physical meaning and units. The logMAR visual acuity is an angular measure of resolution for a high contrast target such as an optotype. This corresponds to the highest resolvable spatial frequency of the visual system, and is determined by the eye's optical quality, retinal sampling, and subsequent neural processing. Alternatively, instead of focusing on a single spatial frequency, the IQM described in this study is an analysis of the full spatial frequency spectrum available in the retinal image. Furthermore, the IQM values depend on the spectrum of the retinal image, and are therefore specific to the resolution target used in this study. To define the relationship between logMAR visual acuity and IQM, four linear models have been calculated. Using these linear models, the visual acuity for each defocus levels on the defocus curve can be predicted from through-focus measurements using an optical bench for each IOL. These predictions may be useful for surgeons to select the most adequate multifocal IOL depending on the patient's visual requirement.

A limitation of this study was the use of a spherical monofocal IOL in comparison to two aspheric IOLs, because the amount of spherical aberration in the monofocal IOL will depend on the dioptric power of the IOL for the spherical but not the aspheric models, which could impact the defocus curves. However, the impact is relatively small because spherical aberration within the small pupil size is reduced substantially even if the magnitude of spherical aberration for a large aperture of the IOL varies between different IOL powers.

We found significant correlations between logMAR visual acuity and cross-correlation coefficients representing the image quality using an optical bench system for three models of IOLs. Such a correlation between the image quality in an optical bench system and the visual acuity allows predicting the expected visual outcome from the optical bench analysis.

AUTHOR CONTRIBUTIONS

Study concept and design (ABP-P, JLA, SM); data collection (ABP-P, JLA, LZ, ES, GY); analysis and interpretation of data (ABP-P, LZ, GY); writing the manuscript (ABP-P, LZ, ES); critical revision of the manuscript (JLA, SM, GY); statistical expertise (ABP-P); administrative, technical, or material support (JLA, ES); supervision (JLA, SM, LZ, GY)

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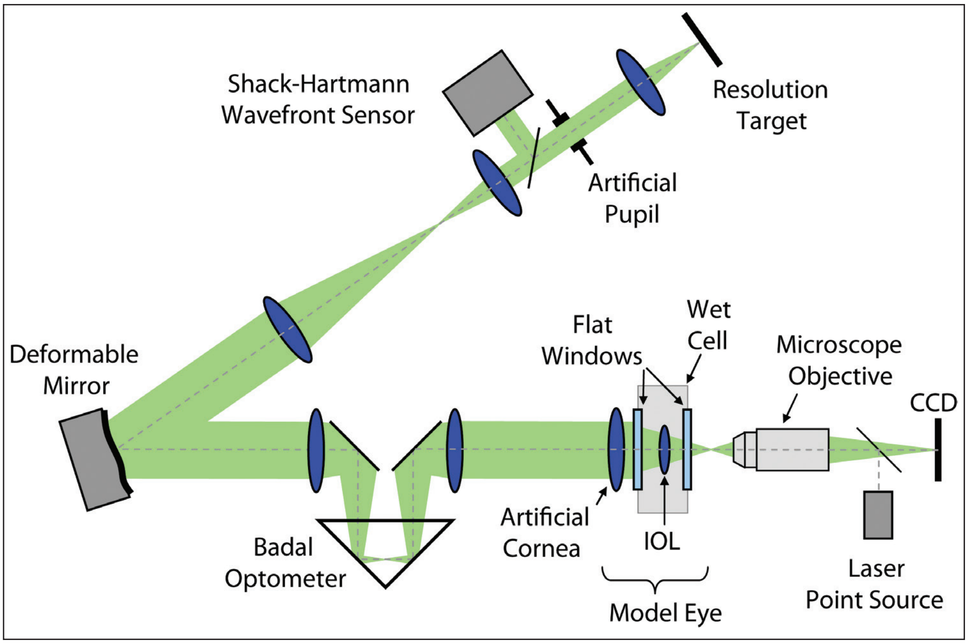

Figure A. Diagram of an optical bench metrology system. IOL = intraocular lens; CCD = charge-coupled device