Optical Quality One Month After Verisyse and Veriflex Phakic IOL Implantation and Zeiss MEL 80 LASIK for Myopia From 5.00 to 16.50 Diopters

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ABSTRACT

PURPOSE: To evaluate the eye's optical quality after phakic intraocular lens (IOL) implantation and LASIK for moderate to high myopia.

METHODS: The retinal image quality of 45 patients was evaluated after undergoing one of three surgical procedures (9 patients with Verisyse IOL [AMO] implants, 11 patients with Veriflex IOL [AMO] implants, and 25 patients who underwent LASIK). Patients were aged <40 years, had at least 5.00 diopters of myopia, and had preoperative best spectacle-corrected visual acuity and postoperative uncorrected visual acuity better than 20/30. The eye's optical quality was measured using the Optical Quality Analysis System (OQAS, Visiometrics S.L.), which is an instrument based on the double-pass technique. Measurements were performed before surgery and 1 day and 1 month after surgery.

RESULTS: Optical quality worsened noticeably 1 day after surgery with the Verisyse IOL with a 50% to 60% loss, most likely due to the large incision and the presence of sutures in most eyes. The LASIK technique and Veriflex IOL implant did not cause as remarkable a decrease in optical quality (20% to 25% loss). One month after surgery, the optical quality of patients with IOL implants was high, although some surgically induced astigmatism remained, especially in the Verisyse patients. Conversely, LASIK patients had slightly lower optical quality, with optical parameters that represented 90% of their initial value.

CONCLUSIONS: Verisyse and Veriflex phakic IOL implantation and LASIK are both safe and effective in correcting moderate to high myopia, but they involve different processes of optical quality recovery. One day after surgery, the Verisyse IOL implantation significantly reduced the eye's optical quality, mainly due to the larger incision required and the higher number of sutures used. This reduction was not as remarkable with the other two techniques. However, 1 month after surgery, patients with IOL implants recovered more optical quality than LASIK patients. [*J Refract Surg.* 2009;25:689-698.]
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In recent years, refractive surgery has revolutionized the correction of various types of refractive errors. At present, two of the most common surgical techniques for correcting moderate to high myopia are the implantation of phakic intraocular lenses (IOL)[1-5] and LASIK.[6-10]

Follow-up examination after one of these procedures generally includes subjective tests such as a standard visual acuity evaluation and contrast sensitivity.[11-17] Due to recent advances in commercial ophthalmic instruments, new tools for objective evaluation of optical quality have become common in clinical practice. These instruments include aberrometers, usually based on the Hartmann-Shack wavefront sensor,[18,19] and newer devices based on the double-pass technique.[20]

In the past decade, aberrometers have become widely used for determining ocular aberrations. These sensors are used in clinical ophthalmology (mostly refractive surgery) and vision research, including studies of aberrations in normal young eyes[21] and in the elderly population,[22] and in patients who have undergone surgeries such as LASIK[23,24] and implantation of phakic monofocal[25] or multifocal[17] IOLs.

With the double-pass technique, the image of a point source object is recorded after reflection on the retina and a double pass through the ocular media. This technique was proposed half a century ago as a means of estimating retinal image quality.[26] The method incorporated various technical innovations[20] and was shown to provide accurate estimates of the eye's image quality. Recently, a double-pass instrument for the

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TABLE 1

Mean Preoperative Degree of Myopia For Eyes That Underwent LASIK and Implantation of Verisyse and Veriflex IOLs

	Mean±Standard Deviation (Range) (D)		
	Sphere	Cylinder	Spherical Equivalent Refraction
Verisyse IOL	8.55±2.07 (5.00 to 11.25)	1.53±1.10 (0.00 to 3.50)	9.32±1.85 (5.00 to 11.88)
Veriflex IOL	7.68±2.74 (4.00 to 15.50)	1.05±0.85 (0.00 to 2.75)	7.99±2.91 (5.00 to 16.38)
LASIK	5.87±1.07 (4.25 to 9.00)	0.84±0.74 (0.00 to 3.00)	6.29±1.21 (5.00 to 9.50)

clinical ophthalmology practice appeared on the market.[27] The double-pass technique has been widely used to investigate retinal image quality in various situations such as in the normal population as a function of age,[28] in contact lens wearers,[29,30] and in patients implanted with monofocal[31] and multifocal[32] IOLs.

Researchers have compared results obtained with the double-pass technique and a Hartmann-Shack wavefront sensor for different patients under similar conditions.[33-35] The double-pass technique can characterize an eye's optical quality including the effect of monochromatic higher order aberrations and, especially, intraocular scattering. Wavefront sensors can also estimate scatter,[33,34] although it is not yet possible to combine the information on aberrations and scatter using this approach. Furthermore, wavefront sensors may overestimate[35] retinal image quality in eyes where higher order aberrations and scattered light are prominent. Intraocular scattering has a large impact on the vision of patients who have ocular conditions such as cataracts and elderly eyes or who have undergone refractive surgery.

In this study, we evaluate optical quality in moderate to high myopic patients after phakic IOL implantation or LASIK using the Optical Quality Analysis System (OQAS; Visiometrics S.L., Terrassa, Barcelona, Spain), which is based on the double-pass technique. The results are useful in the objective evaluation of vision quality variation in patients who have undergone one of these common refractive surgeries. We also evaluate the safety and efficacy indexes of the different techniques analyzed.

PATIENTS AND METHODS

We evaluated the retinal image quality of 45 patients who underwent phakic IOL implantation or LASIK at Barcelona's Instituto de Microcirugía Ocular (IMO). The same surgical procedure was performed in both eyes of each patient.

Two types of anterior monofocal phakic IOLs were evaluated in the study: Verisyse[1,3-5,36] (Abbott Medical Optics Inc [AMO], Santa Ana, Calif) and Veriflex[37] (AMO). Of the 45 patients analyzed, 9 were implanted with the Verisyse IOL (6-mm posterior biplanar corneal incision centered at 12 o'clock) and 11 were implanted with the Veriflex IOL (3-mm posterior corneal incision centered at 12 o'clock). The incision was sutured with 5 interrupted 10.0 nylon sutures for the Verisyse and 1 single interrupted 10.0 nylon suture for the Veriflex. Four weeks after the intervention, we began to consider removing the sutures depending on the astigmatism for the Verisyse IOL and always for the Veriflex IOL.

Twenty-five patients underwent LASIK surgery. The LASIK technique was performed using a MEL 80 excimer laser system (Carl Zeiss Meditec, Jena, Germany) with Aberration Smart Ablation (ASA) optimized profile treatment and 6.2-mm optical zone and standard 8.2-mm transition zone. This profile corresponds to a wavefront optimized treatment that mainly takes into account final asphericity to reduce the induction of spherical aberration, mostly in myopic treatments. The profile used was the same on all eyes. An Amadeus microkeratome (Ziemer Group AG, Port, Switzerland) with a 140-µm plate and 9-mm diameter was used to create a flap. All patients were managed by the same surgeon (J.L.G.).

Postoperative medication was the same for all eyes. Four times per day, a combination of steroids and broad spectrum antibiotic (Tobradex; Alcon Cusí, Barcelona, Spain) with a B blocker (cusimolol 0.5%, Alcon Cusí) were prescribed with a similar combination as ointment at bedtime (De icol ointment, Alcon Cusí) for 2 weeks and then tapered over 10 days. Artificial tears were prescribed at least 5 times per day for 2 months.

All patients provided written informed consent before surgery and before any additional examinations in accordance with the Declaration of Helsinki. Patients were aged <40 years and had moderate to high myopia of at least 5.00 diopters (D) spherical equivalent. Table 1 shows mean preoperative refractive error for the patients analyzed. Standard deviation associated with the mean spherical, cylindrical, and spherical equivalent refractive error, as well as the correspond-

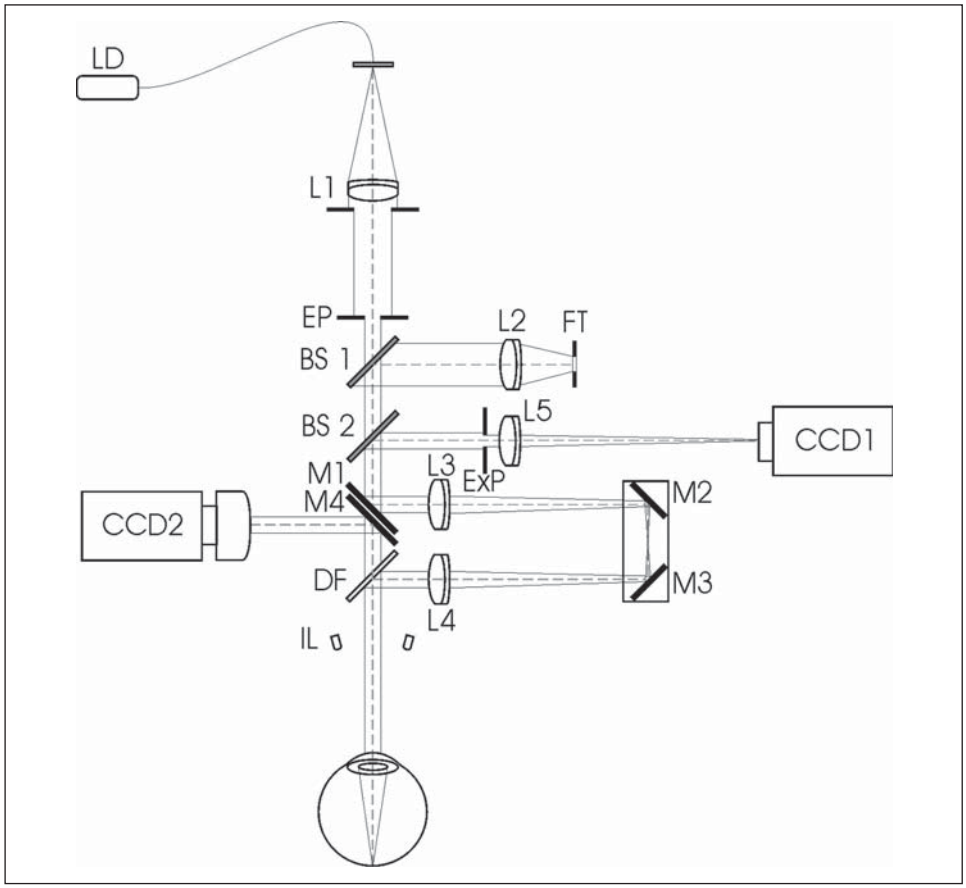

Figure 1. The double-pass experimental setup (Optical Quality Analysis System [OQAS, Visiometrics S.L.]). LD = laser diode; L1, L2, L3, L4, and L5 = lenses; EP = entrance pupil; ExP = exit pupil; BS1 and BS2 = beam splitter 1 and 2; FT = fixation test; CCD1 and CCD2 = CCD cameras 1 and 2; M1, M2, M3, and M4 = mirrors; DF = dicroic filter; IL = infrared LEDs

ing ranges, are also shown for each group (Verisyse, Veriflex, and LASIK). Participation in the study was restricted to patients whose degree of myopia had been stable for the past year and who had preoperative best spectacle-corrected visual acuity (BSCVA) and postoperative uncorrected visual acuity (UCVA) better than 20/30. No postoperative complications (decentering, tilt, inflammation, etc) were noted in the LASIK or phakic IOL groups.

We evaluated the patients' optical quality with the OQAS at three different intervals—before surgery and 1 day and 1 month after surgery. We obtained the comparison at 1 month, when routine follow-up was available, assuming that subsequent changes of the optical quality would be relatively minor, as our experience supports. Although they are early results, they describe the achieved optical quality recovery with the analyzed techniques, and therefore the results can be useful in daily clinical practice. Artificial tears were instilled immediately before each double-pass measurement. The patient's refractive error was corrected during these measurements; spherical refractive error was automatically corrected by the double-pass system, and astigmatism was corrected with an external lens. The outcome of the OQAS strongly depends on the uncorrected refractive error as this factor directly affects the optical quality of the retinal image. Therefore, it is very important to correct the refractive error completely while performing measurements with this instrument.

Figure 1 shows a schematic diagram of this double-pass system. The asymmetric configuration makes it possible to capture asymmetries in retinal images that would be lost in a conventional double-pass system. The instrument[27,35] records the retinal image corresponding to a point source object in near-infrared light, consisting of a laser diode (λ = 780 nm) coupled to an optical fiber, after reflection on the retina and a double pass through the ocular media. Near-infrared light was used as it is more comfortable for the patient and provides retinal image quality estimates that are comparable to those obtained with visible light.[38] A motorized optometer, consisting of two lenses (L3, L4) with a 100-mm focal length and two mirrors (M2, M3), was used to measure the patient's defocus correction. An infrared video camera (CCD1) with a pixel size of 8.4 µm recorded the double-pass images after the light was reflected on the retina and on a beam splitter (BS2). Pupil alignment was controlled with an additional camera (CCD2). A fixation test (FT) helps the patient keep the eye aligned with the system during the measurements. The entrance pupil had a fixed diameter of 2 mm. The instrument had an artificial and variable exit pupil, controlled by a diaphragm wheel, whose image was formed on the patient's natural pupil plane. In this study, optical quality measurements were performed using a standard pupil diameter of 4 mm.

The instrument's software provides qualitative and quantitative information about the eye's optical quality. The double-pass digital image was recorded in two- and three-dimension and provided qualitative

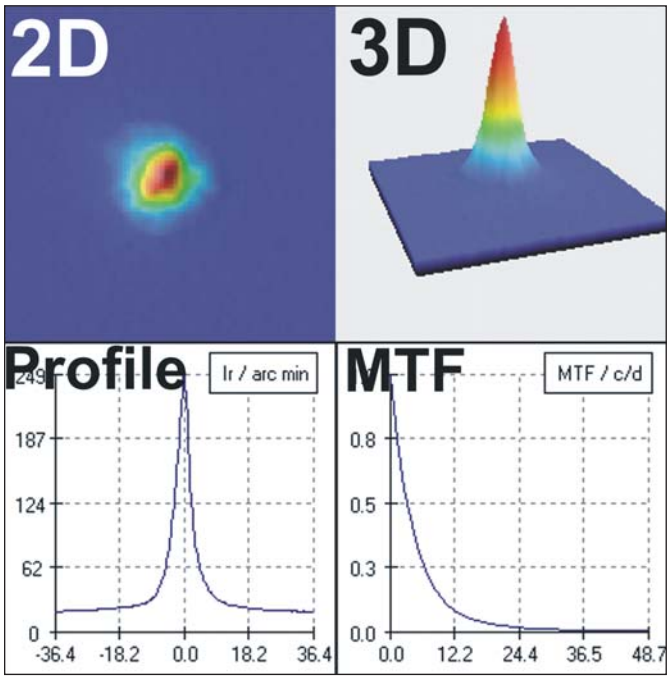

Figure 2. Information provided by the Optical Quality Analysis System (OQAS, Visiometrics S.L.) double-pass image (two-dimensional [2D], three-dimensional [3D]), profile (Ir/arc min = intensity/arc minute), and modulation transfer function (MTF) (c/d = cycles/degree).

information about retinal image quality (Fig 2). The pseudocolored images represent the different energy levels of the retinal image through intuitive color coding. In the three-dimensional representation, the z-axis represents the energy level that corresponds to each point of the acquired image.

Quantitative information about retinal image quality can be obtained from the profile of the recorded spot, ie, the point spread function (PSF). However, the parameter most commonly used to characterize the quality of an optical system, and therefore also used to characterize the eye's optical quality, is the modulation transfer function (MTF). This function represents the loss of contrast produced by the eye's optics as a function of spatial frequency. The MTF can be directly computed based on the recorded double-pass retinal image.

The obtained MTF contains information about the eye's optical quality regarding the monochromatic aberrations and scattered light. This function does not take into account the eye's chromatic aberrations, which were not evaluated in this study. To simplify this information and make it easier to compare quality associated with different images, the double-pass system used determines the retinal image quality in terms of a parameter based on the Strehl ratio, which is computed as the ratio between the areas under the MTF curve of the measured eye and the aberration-free eye.

Moreover, the system also provides three parameters known as OQAS values (OV). The OVs are related to the MTF values corresponding to three different spatial frequencies that describe visual quality for three contrast conditions: 100% (OV 100%), 20% (OV 20%), and 9% (OV 9%). These contrast values are commonly used in ophthalmology practice. Specifically, OV 100% cor-

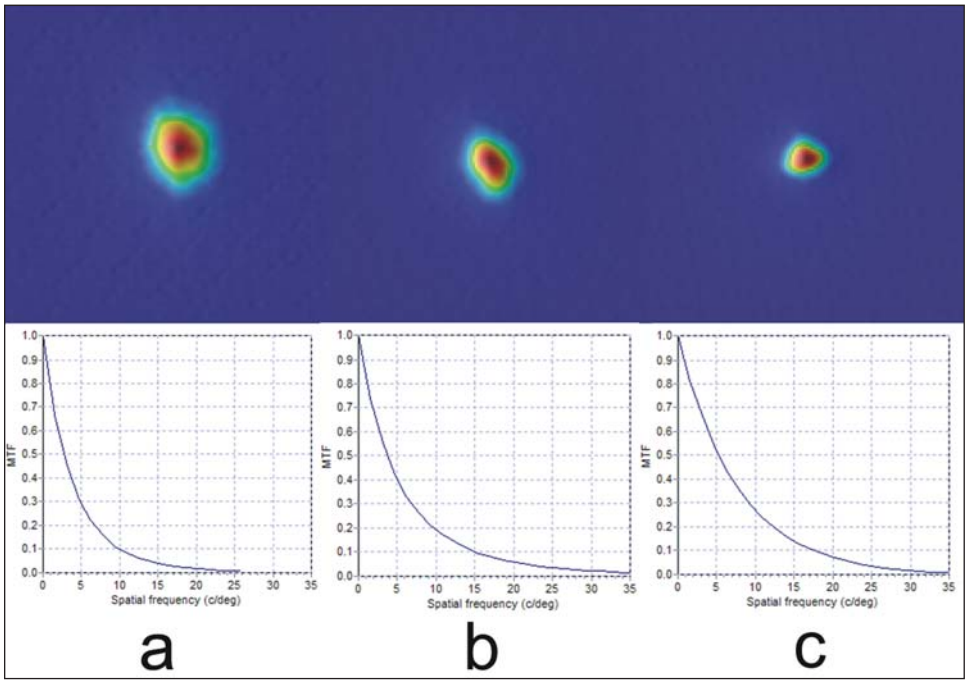

Figure 3. Double-pass images for emmetropic eyes with Strehl parameter **A)** 0.139, **B)** 0.167, and **C)** 0.193. Optical Quality Analysis System (OQAS) value 100% (OV 100%) **A)** 0.8, **B)** 1, and **C)** 1.2, respectively. OV 100% is an optical quality parameter provided by the OQAS system related to the modulation transfer function cut-off frequency.

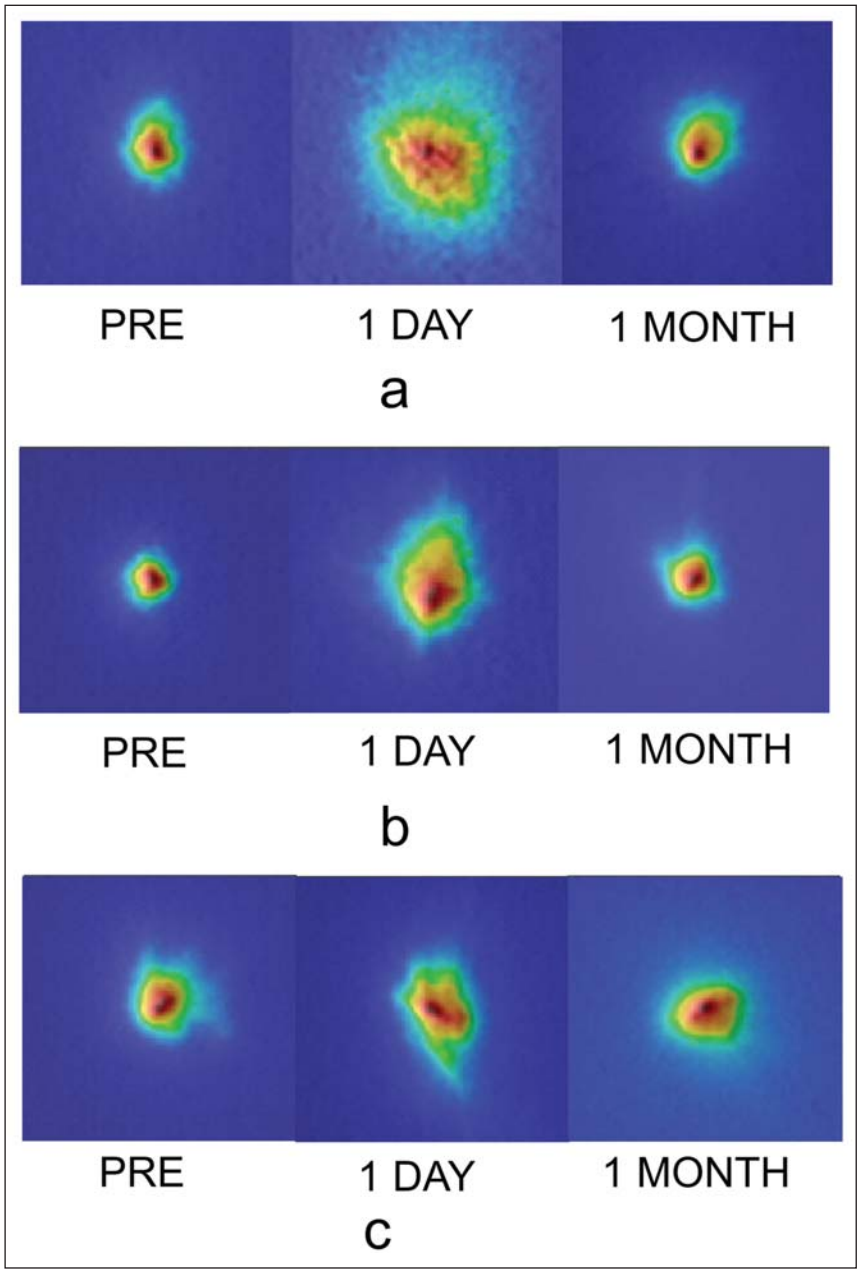

Figure 4. Optical Quality Analysis System (OQAS, Visiometrics S.L.) images recorded preoperatively and 1 day and 1 month after surgery for a **A)** Verisyse IOL patient, **B)** Veriflex IOL patient, and **C)** LASIK patient. PRE = preoperative

responds to the MTF cut-off frequency although it has a different normalization factor. Figure 3 shows three representative double-pass images for emmetropic eyes with Strehl parameter of 0.139, 0.167, and 0.193; and OV 100% values of 0.8, 1, and 1.2, respectively.

Best spectacle-corrected visual acuity and UCVA, assessed with a standard Snellen test, were also reported at each stage.

Statistical analysis of the results was performed using SPSS 8.0 for Windows (SPSS Inc, Chicago, Ill). The analyzed optical quality parameters (OVs, Strehl ratio, and BSCVA) of the three groups were statistically compared preoperatively and 1 day and 1 month after surgery using the paired sample *t* test. A *P* value $<.05$ was considered statistically significant.

RESULTS

Figure 4 shows some specific examples of results obtained in this study and the double-pass images recorded with a 4-mm pupil for representative patients of the three groups (Verisyse IOL, Veriflex IOL, and LASIK) preoperatively and 1 day and 1 month after surgery.

Table 2 shows mean postoperative spherical, cylindrical, and spherical equivalent refractive errors for the three groups. Standard deviations and ranges for each group are also listed.

Figure 5 shows the mean MTF measured preoperatively and 1 day and 1 month after surgery for the 9 Verisyse IOL patients, 11 Veriflex IOL patients, and 25 LASIK patients.

Table 3 shows the mean and standard deviation of OV 100%, OV 20%, and OV 9%, as well as the Strehl parameter, BSCVA (logMAR), and UCVA (logMAR) at the same time intervals for each group.

For the Verisyse IOL patients, the changes observed 1 day after surgery in OV 100%, OV 20%, and OV 9% compared with original mean values were statistically significant (*P*=.001, *P*=.001, *P*=.001, respectively, by paired sample *t* test). The same behavior is found for the Strehl ratio and BSCVA (*P*=.001 and *P*=.001, respectively, by paired sample *t* test). One month later, the OVs, Strehl parameter, and BSCVA almost recover to their original values, and the variations were not statistically significant using the paired sample *t* test (*P*=.775 [OV 100%], *P*=.705 [OV 20%], *P*=.515 [OV 9%], *P*=.299 [Strehl], and *P*=.180 [BSCVA]).

For the Veriflex IOL patients, the differences in the optical quality parameters 1 day after surgery are not as remarkable as with the Verisyse IOL, although the changes are statistically significant by paired sample *t* test (*P*=.001 [OV 100%], *P*=.001 [OV 20%], *P*=.001

TABLE 2

Mean 1-Month Postoperative Refractive Error of Eyes That Underwent LASIK and Implantation of Verisyse and Veriflex IOLs For Myopia

	Mean±Standard Deviation (Range) (D)		
	Sphere	Cylinder	Spherical Equivalent Refraction
Verisyse IOL	0.02±0.65 (−1.75 to 1.00)	−1.05±0.60 (−2.00 to −0.50)	−0.69±0.91 (−2.63 to 1.25)
Veriflex IOL	0.25±0.52 (−0.50 to 1.25)	−0.61±0.79 (−2.50 to 0.00)	−0.14±0.47 (−1.00 to 0.63)
LASIK	−0.26±0.42 (−1.75 to 0.50)	−0.40±0.42 (−1.25 to 0.00)	−0.46±0.47 (−1.75 to 0.38)

[OV 9%], *P*=.004 [Strehl], *P*=.005 [BSCVA]). After 1 month, the averaged parameters became almost identical to their preoperative values, and the changes found were not statistically significant by paired sample *t* test (*P*=.455 [OV 100%], *P*=.740 [OV 20%], *P*=.966 [OV 9%], *P*=.643 [Strehl], *P*=.362 [BSCVA]).

For the LASIK patients, the changes found 1 day after surgery compared with original values were statistically significant by paired sample *t* test (*P*=.001 [OV 100%], *P*=.001 [OV 20%], *P*=.001 [OV 9%], *P*=.001 ([Strehl]), *P*=.001 [BSCVA]). One month later, the changes remained statistically significant with respect to preoperative values using the paired sample *t* test (*P*=.001 [OV 100%], *P*=.007 [OV 20%], *P*=.020 [OV 9%], *P*=.015 [Strehl], *P*=.018 [BSCVA]).

To quantify the optical quality variations obtained with the different surgical procedures, the ratio between each OV and the Strehl parameter 1 day and 1 month after surgery and the same OV or Strehl parameter preoperatively were computed. Ratios were also calculated for related visual acuity values: the ratio between BSCVA 1 day and 1 month after surgery and preoperative BSCVA (ie, safety index), and the ratio between UCVA 1 day and 1 month after surgery and preoperative BSCVA (ie, efficacy index). Table 4 shows the mean and standard deviation of OV 100%, OV 20%, and OV 9% ratios as well as the Strehl parameter ratio, safety index, and efficacy index for all patients. Figure 6 shows the ratios between the MTF curves 1 month after surgery and the same curves for the Verisyse IOL, Veriflex IOL, and LASIK groups preoperatively.

DISCUSSION

Figure 4 shows three representative examples of results obtained from double-pass retinal images, which define the eye's optical quality. The spot corresponding to the retinal image recorded 1 day after surgery is very large in the patient with the Verisyse IOL implantation (see Fig 4A), and smaller for the patients with the Veriflex IOL and LASIK (see Figs 4B, 4C). The spots recorded 1 month after surgery are similar to preoperative in the case of the IOL implants but only slightly larger than that for the LASIK case. In the retinal image obtained with LASIK, some intraocular scattering (diffused light affecting optical quality) can be observed at the edges of the image.

An analysis of the treatments evaluated in this study shows that IOL implantation and LASIK are highly effective in correcting moderate to high myopia. Table 2 shows that patients' postoperative spherical refractive errors at 1 month are small. Only surgically induced astigmatism is still noticeable 1 month after surgery, especially in patients with the polymethylmethacrylate Verisyse IOL, due to the larger incision required and the presence of sutures in most eyes (sutures were removed during the 3-month postoperative period in the Verisyse eyes).

Figure 5 illustrates that the techniques show different MTF behaviors over time. The worsening of the eye's optical quality 1 day after surgery is more noticeable with the Verisyse IOL than with the Veriflex IOL or LASIK. At this stage, the MTF profile is much lower for Verisyse implantation than for the other two procedures (see Fig 5). This can be explained by the larger incision and number of sutures required in the implantation of the Verisyse lens, which have a greater impact on the eye structure. This is in agreement with the results of a previous study,[39] which analyzed the same two IOLs and found that Veriflex patients had a better and faster visual recovery, mainly due to the greater surgically induced astigmatism of the Verisyse IOL.

One month after surgery, the mean MTF profiles for the IOL implants approach their preoperative values, whereas the profile for LASIK remains slightly lower (see Fig 5).

The same behavior is seen for the OVs and Strehl parameter (Table 3). Although the three groups have slightly different averaged optical parameters preoperatively, it can be stated that all present an acceptable vision quality. For the Verisyse IOL patients (Table 3), the OVs are very low 1 day after surgery (ie, the optical quality is greatly reduced). The mean OVs drop

sharply just after surgery, suggesting poor vision quality. The same observation occurs with the mean Strehl parameter. This sharp decline is probably due to surgically induced astigmatism caused by the larger incision required and the sutures used with this technique. One month later, however, the OVs, Strehl parameter, and BSCVA almost recover to their original values, whereas UCVA remained slightly lower as some residual astigmatism was still present. The surgically induced astigmatism usually disappears a few months later.

For the Veriflex IOL patients (Table 3), the reduction in optical quality 1 day after surgery is not as remarkable. The surgically induced astigmatism with the Veriflex IOL is not as large as with the Verisyse IOL because the incision is smaller. After 1 month, all the parameters became almost identical to their preoperative values, although the UCVA parameter could improve over time due to decreasing surgically induced astigmatism.

With LASIK (Table 3), the results obtained 1 day after surgery are similar to those obtained with the Veriflex IOL (ie, the reduction in optical quality is not remarkable). One month later, the OVs, Strehl parameter, and BSCVA remained slightly lower than the preoperative values, and the changes found were statistically significant. This is probably due to the fact that LASIK surgery changes irregular astigmatism. The patients' visual quality is therefore likely to keep improving throughout the following year,[40] especially in dry eyes. In this case, the UCVA parameter was slightly better than in the other two groups, most likely due to the surgically induced astigmatism, which was not present in the LASIK surgery.

In all groups, the OV results were similar for the various contrast values analyzed. OV 20% and OV 9% correlate well to the OV 100% value. Furthermore, the objectively measured parameters (OV and Strehl parameter) were generally in agreement with the measured visual acuity values. The corrected and uncorrected visual acuity values were similar in most patients. The largest differences were obtained for patients with the Verisyse IOLs, specifically 1 day after surgery. As mentioned above, this

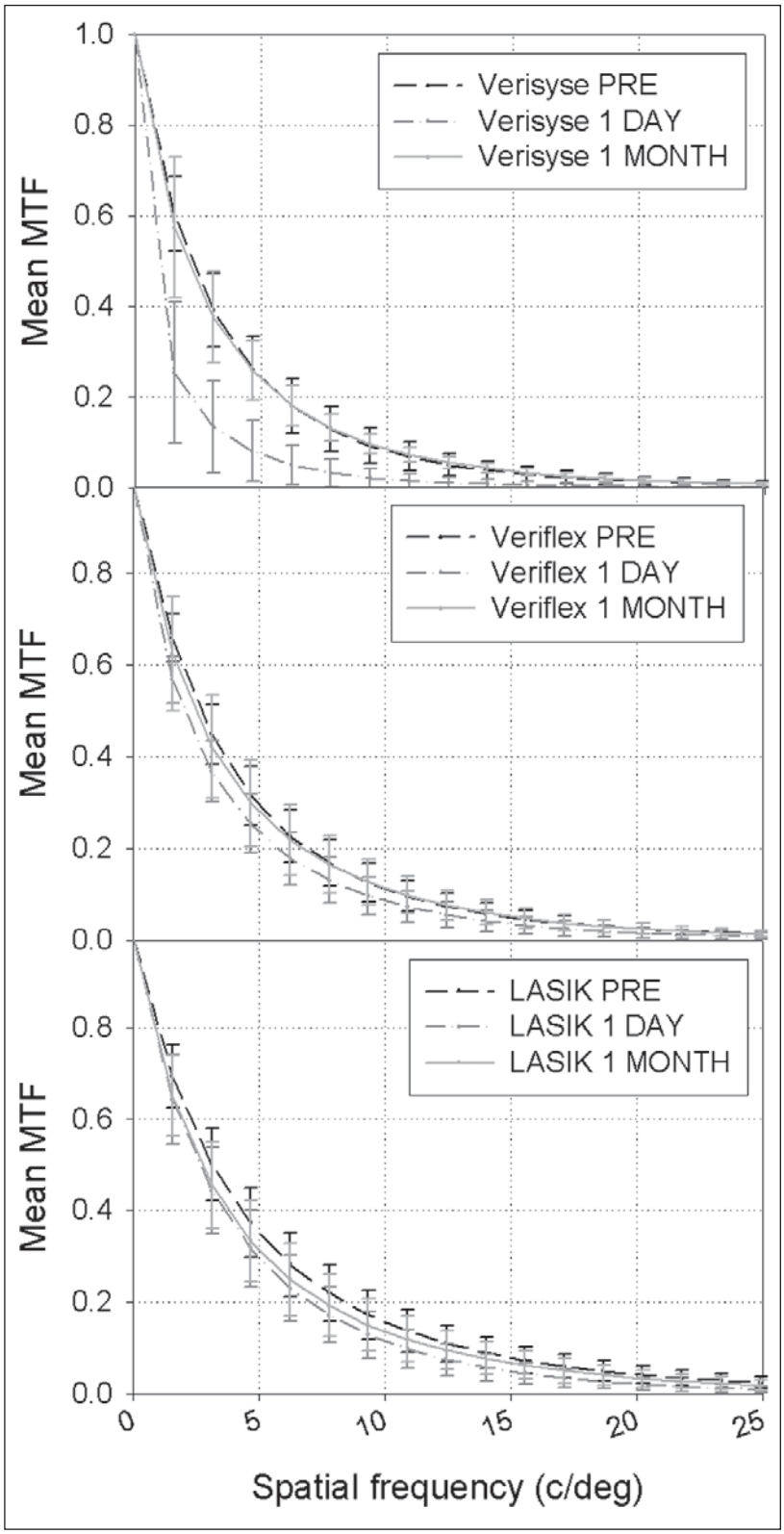

Figure 5. Mean modulation transfer function (MTF) for 9 Verisyse patients **(top)**, 11 Veriflex patients **(middle)**, and 25 LASIK patients **(bottom)** preoperatively and 1 day and 1 month after surgery.

TABLE 3

Mean Pre- and Postoperative Optical Quality Analysis System Values For Contrasts of 100%, 20%, and 9%, Strehl Parameter, BSCVA, and UCVA For Patients Who Underwent LASIK and Implantation of Verisyse and Veriflex IOLs

	Mean±Standard Deviation					
	OV 100%	OV 20%	OV 9%	Strehl Parameter	BSCVA (logMAR)	UCVA (logMAR)
Verisyse IOL						
Preoperative	0.71±0.22	0.67±0.21	0.66±0.21	0.126±0.041	0.11±0.06	—
1 day postop	0.31±0.26	0.29±0.22	0.28±0.18	0.070±0.035	0.31±0.16	0.36±0.08
1 month postop	0.67±0.26	0.66±0.26	0.67±0.26	0.124±0.051	0.13±0.08	0.18±0.07
Veriflex IOL						
Preoperative	0.86±0.25	0.82±0.22	0.79±0.20	0.145±0.040	0.10±0.08	—
1 day postop	0.68±0.28	0.65±0.26	0.66±0.26	0.136±0.062	0.13±0.12	0.17±0.11
1 month postop	0.79±0.26	0.78±0.26	0.78±0.26	0.142±0.052	0.10±0.09	0.15±0.12
LASIK						
Preoperative	1.01±0.26	0.98±0.26	0.96±0.27	0.162±0.052	0.04±0.04	—
1 day postop	0.73±0.21	0.74±0.22	0.77±0.25	0.142±0.046	0.17±0.13	0.20±0.14
1 month postop	0.89±0.25	0.87±0.26	0.87±0.29	0.149±0.062	0.06±0.07	0.10±0.07

OV = Optical Quality Analysis System values, BSCVA = best spectacle-corrected visual acuity, UCVA = uncorrected visual acuity
Note. Analysis performed for 9 Verisyse IOL, 11 Veriflex IOL, and 25 LASIK patients.

TABLE 4

Mean Post-/Preoperative Ratio of Optical Quality Analysis System Values For Contrasts of 100%, 20%, and 9%, Strehl Parameter, Safety Index, and Efficacy Index For Patients Who Underwent LASIK and Implantation of Verisyse and Veriflex IOLs For Myopia

	Mean±Standard Deviation					
	OV 100%	OV 20%	OV 9%	Strehl Parameter	Safety Index	Efficacy Index
Verisyse						
1 day/preop	0.39±0.31	0.40±0.30	0.42±0.26	0.509±0.257	0.66±0.23	0.54±0.15
1 month/preop	1.02±0.40	1.06±0.42	1.11±0.46	1.046±0.298	0.96±0.14	0.83±0.18
Veriflex IOL						
1 day/preop	0.75±0.31	0.75±0.31	0.78±0.30	0.806±0.281	0.92±0.17	0.77±0.24
1 month/preop	1.04±0.43	1.07±0.45	1.07±0.44	1.092±0.311	0.99±0.11	0.86±0.22
LASIK						
1 day/preop	0.74±0.25	0.78±0.28	0.84±0.34	0.810±0.228	0.77±0.20	0.69±0.25
1 month/preop	0.89±0.26	0.91±0.29	0.93±0.33	0.888±0.250	0.97±0.16	0.84±0.23

OV = Optical Quality Analysis System value
Note. Analysis performed for 9 Verisyse IOL, 11 Veriflex IOL, and 25 LASIK patients.

is due to surgically induced astigmatism, which was still present a few days after surgery.

Although measurements taken 1 month after surgery are considered early results, because the optical properties of the eye could keep evolving with time, they provide useful information on the optical quality performance of these surgical techniques. In fact, the results correlate with the findings of previous studies[11,25,41,42] in which the wavefront-guided LASIK technique was shown to cause more higher order aberrations (specifically, spherical and coma), and therefore lower vision quality than phakic IOLs.

Table 4 shows that the loss of optical quality just after surgery is remarkable in patients with Verisyse IOLs. For these patients, the mean OVs were at approximately 40% of their initial value 1 day after surgery. The Strehl parameter ratio shows a 50% reduction. One month after surgery, however, the optical quality of these patients was similar to the original quality, with OV and Strehl parameter ratios close to unity or even higher. This could be due to the great sensitivity of the OVs and Strehl parameter (their values can change due to small variations in measurement conditions).

With the Veriflex implant (Table 4), the optical quality in terms of OVs 1 day after surgery is 75% of the initial value, which was better than the value obtained with the Verisyse IOL. On the other hand, the Strehl parameter was about 80% of its initial value. One month later, the optical quality parameters were similar to the originals, and the calculated ratios were again close to unity, which means that the patients have good optical quality.

As with the Veriflex IOL (Table 4), the OVs and Strehl parameter for LASIK 1 day after surgery were approximately 75% and 80% of initial values, respectively. One month after surgery, however, these parameters were approximately 90% of their initial value, which is much lower than the values obtained with the other techniques. Patients who have undergone LASIK, especially those with dry eyes, may still see improvement throughout the first month after surgery.

Figure 6 shows the ratios of the MTF profiles 1 month after surgery compared to preoperative MTF profiles. Again, for the Verisyse and Veriflex implants, the profiles were $\geqslant 1$ for all spatial frequencies analyzed, whereas the profile obtained for the LASIK treatment was lower, especially for high spatial frequencies.

For all patients analyzed, the results obtained for the safety index generally agree with those obtained for the OVs and Strehl ratio. The efficacy index values were slightly lower due to the small refractive errors that remain in some patients after surgery.

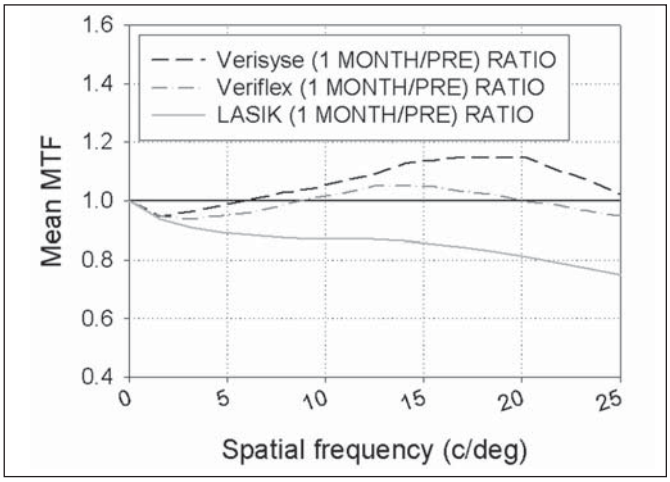

Figure 6. Mean modulation transfer function (MTF) ratio at 1 month after surgery/preoperatively (1 MONTH/PRE) for 9 Verisyse IOL patients, 11 Veriflex IOL patients, and 25 LASIK patients. c/deg = cycles per degree

Our results agree with the findings of previous studies in which measurements were taken using aberrometers and subjective visual functions (visual acuity and contrast sensitivity). However, this study uses the double-pass technique to consider the combined influence of higher order aberrations and intraocular scattering. In future research, the influence of these two factors on optical quality should be considered independently.

AUTHOR CONTRIBUTIONS

Study concept and design (M.V., J.P., J.C.O., P.A., J.L.G.); data collection (M.V., A.P., J.C.O.); interpretation and analysis of data (M.V., A.P., J.P., J.C.O., P.A.); drafting of the manuscript (M.V., A.P., J.P., J.L.G.); critical revision of the manuscript (M.V., A.P., J.P., J.C.O., P.A.); statistical expertise (M.V., A.P., J.C.O.); obtained funding (J.P.); supervision (M.V., J.P.)

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