

Optimizing the correction of low corneal astigmatism in cataract patients

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OBJECTIVE: To analyse the visual quality of patients with low corneal astigmatism implanted with toric, aspheric and spherical intraocular lenses (IOLs).

SETTING: FISABIO-Oftalmología Médica, Valencia, Spain.

METHODS: Forty-five patients, mean age 73 ± 18 years, with no systemic or ocular conditions who needed a SN60T3 IOL (corneal cylinder -0.75 D), were implanted with spherical, aspheric or toric IOLs. We measured the uncorrected and best corrected visual acuity (UCVA, BCVA), contrast sensitivity function (CSF) and ocular aberrations three months after surgery.

RESULTS: Implantation of a toric IOL reduced the refraction astigmatism by 80%. Aberrations increased in all patients, but while astigmatic aberration decreased with toric IOLs, spherical aberration decreased with aspheric IOLs. The UCVA was better with toric and aspheric IOLs (0.1 logMAR), whereas the BCVA was statistically better with aspheric IOLs compared to spherical ($p = 0.05$). The CSF was similar under photopic conditions. Under mesopic conditions however, spherical IOLs performed best, while toric lenses produced a decrease in the CSF ($p < 0.05$).

CONCLUSION: In patients with low corneal astigmatism, toric IOLs provide a similar visual performance to aspheric IOLs in photopic conditions. Under mesopic conditions, toric IOLs showed lower contrast sensitivity, probably due to a slight error in the axis position, which increases aberrations.

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Monofocal intraocular lenses (IOLs) are the most commonly implanted lenses in cataract surgery, despite the fact that they do not correct corneal astigmatism. Several authors have reported that

among the population diagnosed with senile cataracts, more than 60% present corneal astigmatism between 0.25 - 1.5 D^{1,2}. In order to compensate for this refractive error, several options can be chosen, such as spectacles, limbal relaxing incisions³, photorefractive keratectomy (PRK), or laser in situ keratomileusis (LASIK) surgery^{4,5}. However, all these techniques have disadvantages (for example, relaxing incisions lack precision, they present varied healing responses, there is limited cylinder correction⁶, there may be under- or overcorrection⁶⁻⁸, perforation⁹ or regression⁶, and they may distort or denervate the cornea¹⁰), with outcomes similar to those obtained with a toric IOL¹¹⁻¹³. Moreover, PRK and LASIK surgery can produce haze, dry eye, diffuse lamellar keratitis, and under- or overcorrection¹⁴⁻¹⁶. Today, leading surgeons consider toric IOL implantation as a novel method to compensate for corneal astigmatism, and several studies have shown that toric IOLs can obtain a satisfactory improvement in visual acuity (VA)¹⁷⁻²⁰.

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Implantation of a toric IOL requires more care and experience, since the cylinder axis must be positioned in a specific orientation. If the final orientation is rotated from the optimal position, the toric IOL becomes less effective²¹. This means that, as in the case of corneal incisions, the surgeon's skill is an important factor to consider. The IOL requires precise positioning which ensures adequate stability within the eye, although some studies show that lens rotation with time is no longer a problem in recent toric IOL designs²²⁻²⁴. In this respect, we must also consider surgery-induced astigmatism (SIA), which is added to the initial corneal astigmatism. Each surgeon induces a different SIA, which should be established before the IOL calculation, and introduced as a datum in the toric IOL calculator²⁵.

Finally, toric IOLs are available in discrete values of cylinder power, which means that many implanted patients do not achieve complete cylinder compensation, as they present residual astigmatism. However, this is always lower than the initial corneal astigmatism.

Total correction of corneal astigmatism is complicated due to these unavoidable inaccuracies. The question that arises is whether a toric IOL implant will be more efficient than a spherical or aspheric monofocal IOL implant for patients with low corneal cylinders.

We therefore performed a clinical study to verify whether toric IOLs are effective in patients who present a low corneal cylinder (around 1 D). To this end, we measured the patients' VA, contrast sensitivity function (CSF), and high order aberrations three months after surgery. All the eyes were implanted with a spherical toric IOL, a spherical monofocal IOL, or an aspheric monofocal IOL.

PATIENTS AND METHODS

Subjects

We analysed the data from a group of 11 patients (71 ± 12 years) implanted with toric IOLs, a second group of 10 patients (75 ± 7 years) implanted with spherical monofocal lenses, and a third group of 11 patients (71 ± 10 years) implanted with aspheric monofocal lenses.

These 32 patients were from an original group of 45 subjects who underwent surgery in the same year by the same surgeon, and who fulfilled the following inclusion criteria: patients with senile cataracts who required a calculated toric lens implant of SN60T3 (Alcon®, Fort Worth, USA), a predicted postoperative residual astigmatism less than 0.50 D and postoperative spherical refraction no higher than ± 0.50 D, since a higher refractive error would cause a VA decrease of more than one line on a decimal scale²⁴. Our aim was to analyse the loss due to residual cylinder but not due to residual sphere.

Exclusion criteria were patients who had a low endothelial cell count (less than 2000 cells/mm²) or endothelial anomalies such as guttatas, patients on ocular treatment of any nature for at least one month prior to the commencement of the study or who had been taking medication that could produce somnolence (antihistamines, etc.), or with a history of drug or alcohol addiction. None of the subjects had prior ocular surgery that could have distorted the measurement (LASIK or PRK).

We selected few patients for two reasons: one, because it is difficult to find healthy patients with senile cataract since these subjects are elderly; and two, because of the restriction of the postoperative spherical refraction value.

After gaining approval from the Ethics Committee and the Data Protection Commission, we approached prospective participants and asked them to participate. The study adhered to the tenets of the Declaration of Helsinki for Research Involving Human Subjects and was approved by the Institutional Review Board.

Intraocular lenses

We implanted three models of lenses. The first group of patients received the SN60T3 (toric); the second received the SN60AT (spherical monofocal); and the third the SN60WF (aspheric monofocal). All the lenses were manufactured by the same company (Alcon®, Fort Worth, USA), and were made of the same material (AcrySof® with UV and blue light-filtering chromophores and index refraction $n = 1.55$), so the only difference between them was the lens design. All the modulation transfer function (MTF) results were similar in photopic illumination conditions, but in mesopic conditions the optical quality of the spherical lens MTFs decreased more than the toric or aspheric IOLs; the aspheric design gave the best results (Figure 1).

Surgical technique

The surgical technique used to implant the toric lenses required administration of peribulbar anaesthesia. The first step prior to surgery was to mark the horizontal axis in the sclero-corneal limbus; these marks were the reference points used during the surgical procedure. The patient sat in a vertical position in order to compensate for the cyclorotation that occurs when a patient is in the supine decubitus position. The technique used in all cases was phaco-chop, using the Infinity System (Alcon®). Capsular bag implantation of the lenses was performed with the Monarch II injector (Alcon®), and no surgical complications arose. The toric IOLs were inserted through an approximately 2.2 mm corneal incision and the spherical and aspheric IOLs were inserted through a larger corneal incision (2.75 mm). All the incisions were

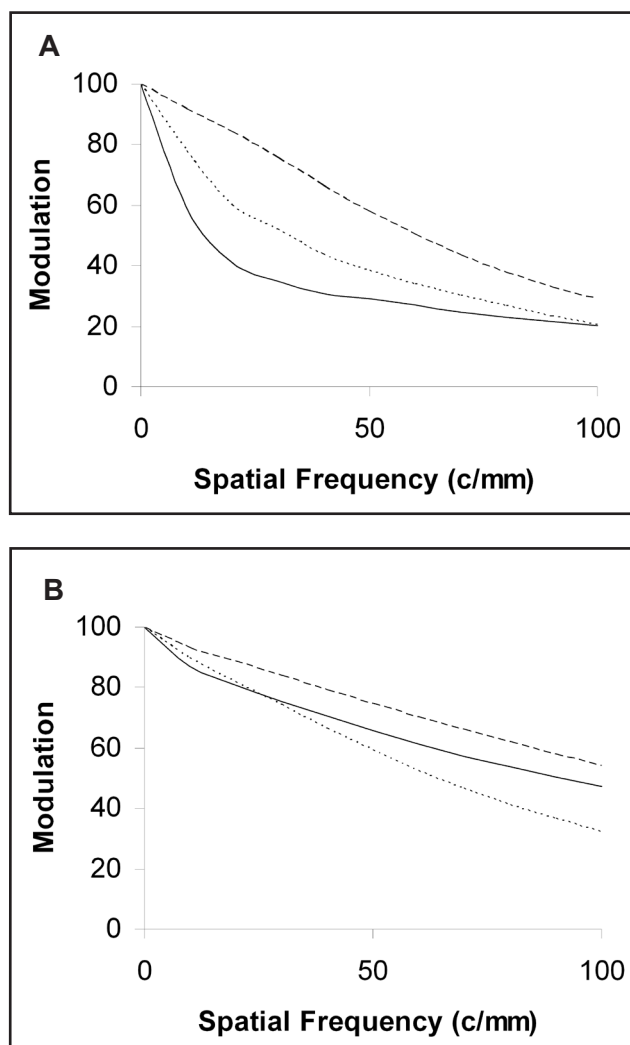


Figure 1. Modulation transfer function for each lens: spherical (continuous line), toric (dotted line), and aspheric (dashed line) measured for **A)** 3-mm and **B)** 5-mm sized pupils.

made in the temporal sector (at approximately 160°), as this induces less astigmatism^{25,26}. No limbal relaxing incisions were made as part of the surgical treatment. All the patients received postoperative antibiotic and topical corticoid treatment for four weeks (Tobramycin + Dexamethasone; Tobradex® Ophthalmic Suspension; Alcon Cusi S.A., Barcelona, Spain) at a tapering dosage. The procedure in the case of the other two IOLs was simpler, since these IOLs do not require special orientation, so it was not necessary to mark the IOL position before surgery.

Evaluation

All patients underwent ophthalmologic examination using the LOCS III® system to classify the cataract, and to rule out any other pathology. Biometry was performed using an OcuScan® (Alcon®) Ultrasound System, with a 10 MHz probe.

Corneal astigmatism (CA), biometric data, best corrected visual acuity (BCVA), uncorrected visual acuity (UCVA), contrast sensitivity function (CSF) and aberrations were measured before, and three months after cataract surgery. Visual acuity was evaluated with an EDTRS test. The CSF was determined under two different illumination conditions, photopic (80- 85 cd/m²) and mesopic (3-6 cd/m²), using a CSV1000 test which measures sensitivity at frequencies of 3 cycles per degree (cpd), 6 cpd, 12 cpd, and 18 cpd. A LADARwave System (Alcon®) that utilizes a Hartmann-Shack wavefront sensor and infrared laser (820 nm) was used to measure total ocular aberrations. The device was recalibrated at the beginning of each session, and five measurements were obtained for each eye. The artificial pupil size was 5 mm.

The toric IOL for each patient was determined by entering data on corneal astigmatism, biometry and SIA (0.5 D -175°) into the software of the website created by the commercial company (<http://www.acrysoftoriccalculator.com/calculator.aspx>).

This calculates the cylinder lens power and the angle at which the surgeon should place the axis of the cylinder, marked on the first surface of the lens by means of six points. The calculator also gives the anticipated postoperative residual astigmatism that we used to enrol the patient in the study.

The lens position was calculated by means of a slit lamp photo (Figure 2) to ensure that it was stable one day and three months after surgery. The patient's head was in a vertical position when the photo was taken. We then printed the photos of the lenses and plotted the position of the lens (in degrees) using a protractor.

Statistical Analysis

Statistical analysis was performed using SPSS statistical software (version 15.0, SPSS Inc, Chicago, IL, USA).

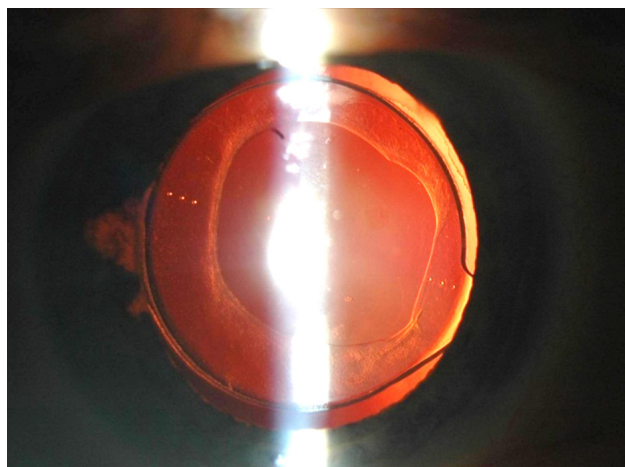


Figure 2. Photograph of a toric IOL implanted in the eye of a real patient.

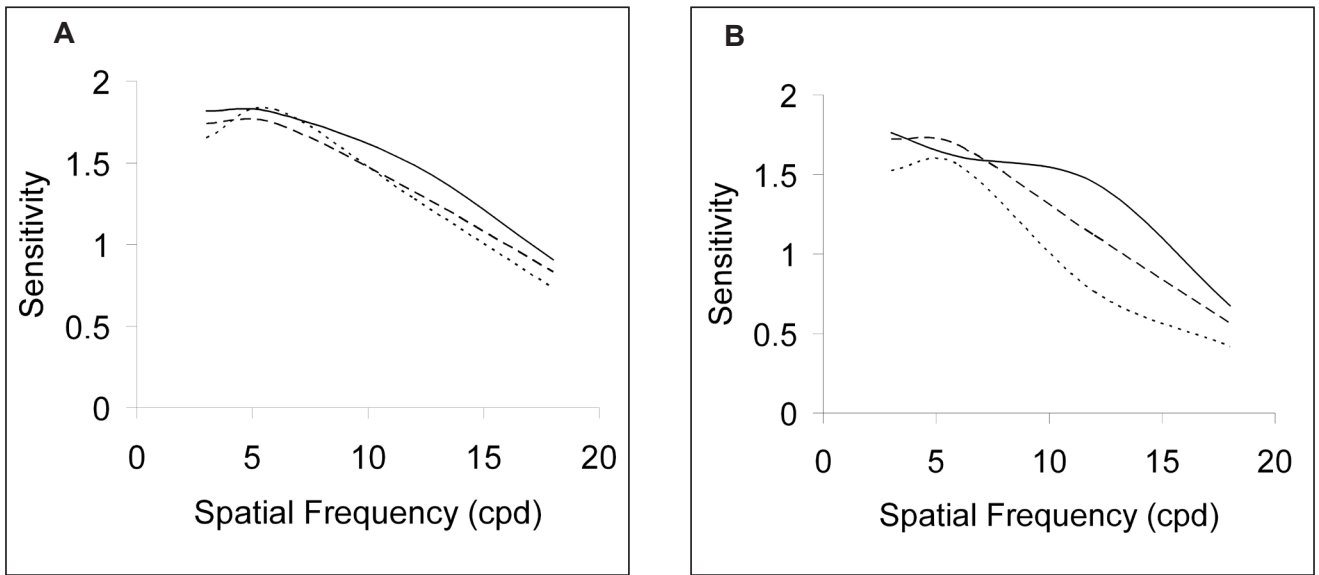


Figure 3. Mean CSF in photopic (A) and mesopic (B) conditions for each lens: spherical (continuous line), toric (dotted line), and aspheric (dashed line).

RESULTS

The mean results for all the parameters, corneal astigmatism, refractive astigmatism, VA, and CSF are shown in Table 1 and Figure 3.

Patients' visual quality

We calculated the difference between postoperative corneal astigmatism and refractive astigmatism to observe the efficacy of the implanted lenses with a vectorial analysis proposed by Thibos et al.²⁷ The decrease

in astigmatism was 42.8% in the case of the spherical lenses and 28.1% in aspheric lenses; it was 82.2% less in spectacles than in the cornea in the case of toric lenses (for example, if a patient has a corneal astigmatism of 1 D, the toric lens compensates approximately 0.822 D (mean value), so the residual astigmatism is 0.178 D).

Statistical Analysis

The Kolmogorov-Smirnoff one-sample test was used to verify the normality of the data. As it did not fit a normal distribution ($p > 0.05$), the Kruskal-Wallis test

Table 1. Mean values for corneal astigmatism (CA), refractive astigmatism (RA), uncorrected visual acuity (UCVA) and best corrected visual acuity (BCVA).

	CA		RA	UCVA		BCVA	
	pre	post	post	pre	post	pre	post
Toric	1.7 ± 0.6	1.5 ± 0.6	0.7 ± 0.5	0.3 ± 0.3	0.1 ± 0.3	0.2 ± 0.2	0.0 ± 0.3
Spherical	1.1 ± 0.4	1.1 ± 0.4	0.7 ± 0.5	0.3 ± 0.2	0.2 ± 0.3	0.3 ± 0.2	0.0 ± 0.3
Aspheric	0.8 ± 0.2	0.8 ± 0.2	0.5 ± 0.4	0.3 ± 0.2	0.1 ± 0.3	0.3 ± 0.3	0.0 ± 0.2

Table 2. Percentage of patients showing high order aberration values outside the normal range.

Lenses	Zernikes														
	3,-1	3, 1	3,-3	3, 3	4, 0	4,-2	4, 2	4,-4	4, 4	5,-1	5, 1	5, 3	5,-3	5,-5	5, 5
Toric	43	71	100	57	100	57	86	100	86	86	86	57	86	86	86
Spherical	63	50	100	50	50	50	63	100	88	100	75	75	75	100	63
Aspheric	88	75	75	63	25	38	75	100	100	75	50	100	75	100	50

was used to verify the results. A p -value < 0.05 was considered statistically significant.

The difference in rotation of the lenses one day and three months after surgery was not statistically significant.

UCVA improved by a mean of one line (on the Snellen scale) in toric and aspheric lenses compared with spherical lenses, but these differences were not statistically significant.

There were statistical differences between spherical and aspheric lenses in the postoperative BCVA ($p = 0.045$).

There were no statistical differences in photopic CSF, but under mesopic conditions the performance of the toric lenses was poorer. There was a difference in the lenses in CSF at the frequency of 12 cpd ($p = 0.03$), and toric and spherical lenses differed ($p = 0.04$) for 3 cpd. The spherical lenses performed better under these illumination conditions (Figure 3).

Table 2 shows the results for the high order aberrations. We calculated the percentage of patients who had an aberration value outside the normal range for this age. In general, all the patients had high order aberrations (higher than the normal range), but as expected, the aspheric lens significantly reduced spherical aberrations as well as the secondary astigmatism (4,-2), and the toric lens reduced one of the astigmatic components (Zernike (3,-1)).

Surgery-induced astigmatism

The SIA due to implantation of the three lenses was analysed using vectorial analysis and a nonparametric statistical test with a 95% significance level. The results show that the SIA was similar for the three lenses: toric 0.7 ± 0.3 D placed at $3 \pm 45^\circ$, spherical 0.7 ± 0.2 D placed at $164 \pm 42^\circ$ and aspheric lens 0.5 ± 0.3 D placed at $18 \pm 33^\circ$ (Figure 4). No statistical differences were found between the three groups ($p > 0.05$).

DISCUSSION

Our results showed that the postoperative BCVA for aspheric lenses was statistically better than for spherical lenses ($p = 0.03$). This is because the quality of aspheric lenses is higher, since they reduce spherical aberrations (Table 2).

The clinical efficacy of the SN60T3 toric lens was 82.2%. Patients implanted with toric IOLs needed less astigmatism correction in their spectacles than if they had not had a toric IOL implant (mean of 0.8 D less); this efficacy is higher than that found in the study by Statham et al. (0.542 D) under the same measurement conditions²⁸.

In addition, we observed a slight improvement (of one line on the Snellen scale) in the mean UCVA with toric lenses when compared with spherical lenses, as reported in previous studies^{20,28}; this difference was not statistically significant but is clinically important.

Generally speaking, cataract surgery increases high order aberrations of the eye in comparison with the normal aberration range, as can be seen in Table 2. As expected, patients with aspheric lenses have reduced spherical aberration (75%), while toric lenses reduce astigmatic aberrations (Table 2, Zernike [3,-1]). However, there is a higher incidence of some of the other high order aberrations (such as coma or spherical) in patients implanted with toric lenses than with the other two types. Aberrations are measured with a pupil size of 5 mm. Under mesopic illumination conditions, when the pupil is enlarged (5 mm or more), high order aberrations increase and impair visual quality. The increment of aberrations in patients implanted with a toric IOL, in comparison with the other lenses, could be due to small lens rotations, since a 5° rotation of the lens axis causes a deterioration in the lens quality²⁹. Our results show that the lens stability is good three months after surgery, and that it does not rotate with time. Thus, if the lens presents rotation, it is because it was not properly aligned during surgery.

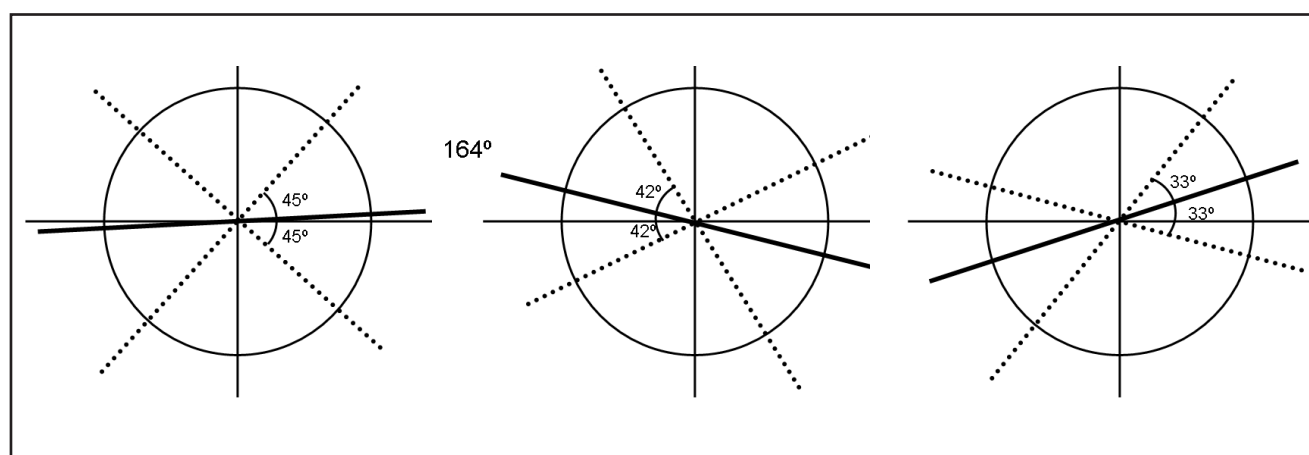


Figure 4. Representation of the mean axis and standard deviation for the SIA in patients implanted with a toric (a), spherical (b) or aspheric IOL (c).

There was no statistical difference between the CSF of the three lenses under photopic conditions, but under mesopic conditions spherical lenses performed best. In the case of the toric IOL, the decrease in contrast sensitivity could be explained by the decreased MTF (Figure 3) due to the increment in aberrations (Table 2) caused by the rotation of the lens axis.

The SIA analysis found no differences between the three groups, but as can be observed in Figure 4, the range of the axes for the induced astigmatism is very large, and could be very different from the values proposed in the lens calculation.

In conclusion, patients with low corneal astigmatism implanted with a toric IOL present better outcomes than patients with spherical lens implants, but similar outcomes when compared with aspheric IOLs, under photopic conditions (small pupil). Under mesopic conditions (5-mm pupil size), toric IOLs do not seem to perform as well as the other two, probably due the effect of small axis rotations and poor prediction of the SIA.

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