Wavefront technology in cataract surgery

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Purpose of review

As advances in technology allow cataract surgeons to address higher order optical aberrations, the measurement of functional vision becomes increasingly critical. Contrast sensitivity testing is assuming a prominent place in our evaluation of surgical modalities because it reflects functional vision and correlates with visual performance. The Tecnis Z9000 intraocular lens (IOL) (Pfizer, New York) is the first foldable IOL designed to correct higher order optical aberrations and represents a first step toward the integration of wavefront technology and cataract surgery.

Recent findings

Contrast sensitivity declines with age, even in the absence of ocular pathology. Wavefront science demonstrates that the youthful crystalline lens compensates for aberrations in the cornea. The aging lens loses its balance with the cornea, as both the magnitude and the sign of its spherical aberration change. Older pseudophakic patients have generally the same contrast sensitivity as their age-matched counterparts without cataract. The Tecnis Z9000 IOL (Pfizer, New York) has been designed with a modified prolate anterior surface to compensate for the spherical aberration of the cornea, thus eliminating total ocular spherical aberration. Clinical data demonstrate that this modified prolate IOL provides superior functional vision, similar to that of younger people, and hence improves visual performance when compared with conventional spherical IOLs. It appears likely that the decline in functional vision with age involves changes in the spherical aberration of the crystalline lens.

Summary

The integration of wave-front technology and lens-based surgery represents a step toward improving functional vision and quality of life for cataract patients.

Keywords

functional vision, contrast sensitivity, spherical aberration

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Abbreviations

IOL intraocular lens

1040-8738

Introduction

The term *functional vision* describes the impact of sight on quality of life. Recognizing faces and facial expressions, reading the newspaper, driving at night, performing vocational tasks, and participating in recreational pursuits all bear a relation to functional vision for ophthalmic patients. Functional vision not only implies the role of sight in safety and accident prevention, but also suggests the importance of high-quality vision in vocations such as astronomy, aeronautics, and visual arts.

Visual acuity does not entirely reflect functional vision. As stated in the American Academy of Ophthalmology Basic and Clinical Science Course, "We know intuitively that given the appropriate set of circumstances each of us with 20/20 vision will function as a visually handicapped individual. Thus, when a person is driving into the sun at dusk, or dawn, changes in contrast sensitivity and the effect of glare alter detail discrimination" [1].

Multiple scientific studies have demonstrated that contrast sensitivity represents a robust indicator of functional vision [2–10]. The contrast sensitivity function, measured under varying conditions of luminance and glare, establishes the limits of visual perception across the spectrum of spatial frequencies. Contrast sensitivity testing determines the relationship between the optical efficiency of the eye (modulation transfer function) and the minimum retinal threshold for pattern detection (modulation threshold function) [11,12]. Therefore, contrast sensitivity testing effectively describes the function of the physiologic visual system as a whole.

The correction of spherical and cylindrical refractive errors, whether by spectacles, contact lenses, or surgery, represents an integral part of the determination of the intrinsic contrast sensitivity of the visual system. Ametropias produce blur and hinder recognition of objects [1]. Higher order optical aberrations such as spherical aberration and coma also have an impact on contrast sensitivity and functional vision [13–20,21••]. The total effect of all monochromatic optical aberrations, as measured by wavefront-sensing techniques [22] and described by Zernike polynomials [23], represents an expression of the optical quality of the eye. High optical quality is necessary for high contrast sensitivity.

To test the limits of the visual system beyond the retina, we must first produce an image of the highest possible

quality on the retina. The production of this high-quality image remains the goal of lenticular surgery.

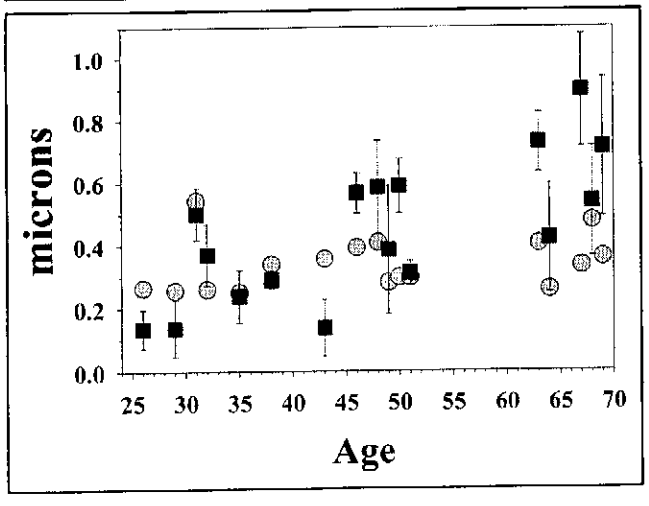
Contrast sensitivity and spherical aberration

Contrast sensitivity declines with age, even in the absence of ocular pathology such as cataract, glaucoma, or macular degeneration [24•]. Advances in wavefront science have allowed researchers to show that this decline in visual capability likely involves decreased retinal image quality due to changes in the spherical aberration of the crystalline lens [25••]. It has been shown that spherical aberration of the human lens increases with age, while the amount of spherical aberration in the human cornea remains constant or tends to increase only slightly with age (Fig. 1) [26]. The youthful lens counteracts much of this defect by inducing negative spherical aberration, whereas the aging lens fails to compensate for aberrations in the cornea [27].

Conventional spherical and modified prolate intraocular lenses

Conventional spherical intraocular lenses (IOLs) have positive spherical aberration. As a result, contrast sensitivity of pseudophakic patients is no better than that of their age-matched counterparts without cataract [28]. In fact, patients with prior IOL surgery show statistically significant elevation of fourth-order spherical aberration and total wavefront variance for pupil sizes greater than 5 mm, compared with normal subjects [29]. Investigations have recently been conducted to evaluate a complementary IOL that would mimic the youthful crystalline lens by reducing total optical spherical aberration and improve contrast sensitivity levels [30••]. The amount of negative spherical aberration incorporated into this new IOL was based on the average positive spherical aberration present in a population of 71 cataract patients (Z [4,0] = 0.27 ± 0.02 μ). This mean corneal spherical aberration value has since been confirmed by independent investigators, whose study included 228 eyes of 134 subjects (Z [4,0] = 0.28 ± 0.086 μ) [31•].

Figure 1. Spherical aberrations with age



In youth, the total optical aberrations of the eye (squares) are less than those of the cornea (circles). With age, the total aberrations become greater than those of the cornea. (Published with permission [26].)

A unique IOL with a prolate anterior surface has been designed to compensate for the average spherical aberration of the cornea and improve the ocular optical quality of pseudophakic patients. Known as the Tecnis Z9000 IOL (Pfizer, New York), this lens features a modified prolate surface with negative spherical aberration, thereby approximating the optical system of the youthful eye. As a result, it is hypothesized to produce higher quality retinal images. The Tecnis Z9000 IOL has a biconvex design, a refractive index of 1.46, and an optic diameter of 6 mm. The lens has a posterior and anterior sharp-edge design. The superior optical performance of the Tecnis Z9000 IOL is maintained as long as the lens is tilted at an angle of less than 7 degrees and decentered less than 0.4 mm, surgical tolerances routinely achieved with continuous curvilinear capsulorhexis and in-the-bag placement of IOLs [30••]. Depth of focus is comparable to that of a spherical IOL [30••].

Clinical data evaluating a modified prolate intraocular lens with negative spherical aberration

Clinical data from a range of studies demonstrate that the use of a modified prolate IOL during cataract surgery has the potential to provide superior contrast sensitivity under both mesopic and photopic conditions. Clinical results also confirm the theoretical preclinical calculations that the spherical aberration of the eye after cataract surgery can be eliminated by modifying the anterior surface of the IOL.

The first published clinical data reported results of a prospective randomized trial comparing the contrast sensitivity obtained with the Tecnis Z9000 IOL with that obtained using the AR40e Opti-Edge IOL (AMO), a standard spherical intraocular lens [32••]. Assessment of peak mesopic contrast sensitivity showed that the Tecnis IOL provided a 0.27 log unit (77.9%) gain in peak contrast sensitivity at three cycles per degree compared with the control IOL. The authors found no statistically significant difference between the Tecnis Z9000 mesopic contrast sensitivity and the AR40e photopic contrast sensitivity. This remarkable finding implies that patients implanted with a modified prolate IOL see as well in very dim light as patients with a spherical IOL see in bright light. Furthermore, a comparison between patients in this study and healthy subjects aged 20 to 50 years showed that contrast sensitivity was actually better in the Tecnis patients than it was in the 20- to 30-year-old healthy subjects [33•].

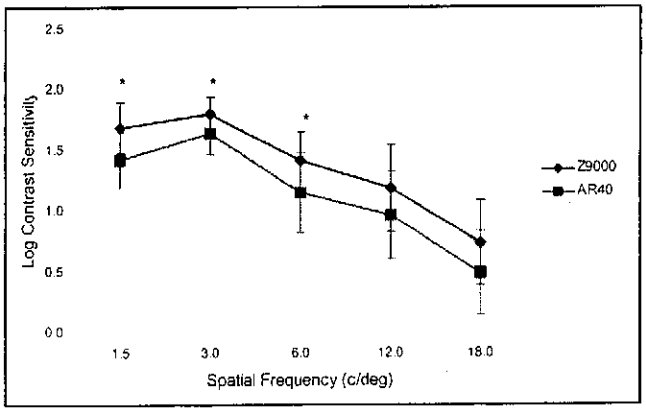
Results from an expansion of this earlier study show enhanced functional vision with the Tecnis IOL. The lens was associated with statistically significantly better contrast sensitivity versus the comparator lens, increasing by 23.4 to 62.6% (0.14 to 0.24 log unit difference) in photopic conditions and between 38.3 and 74% (0.15 to 0.27 log unit difference) under mesopic conditions (Fig. 2) [34].

Corroborating evidence

In another clinical comparative study, investigators carried out an intraindividual randomized study comparing the Tecnis Z9000 lens with the SI-40 IOL (AMO) in 45 patients with bilateral cataract [35••]. Thirty-seven patients were examined at all follow-up visits up to 3 months after surgery. Although the eyes with the Tecnis Z9000 IOL had significantly better best corrected visual acuity after 3 months, the improved quality of vision was more apparent when assessing low-contrast visual acuity and contrast sensitivity. Wavefront measurements revealed no significant spherical aberration in eyes with a Tecnis Z9000 IOL but significantly positive spherical aberration in eyes with an SI-40 IOL.

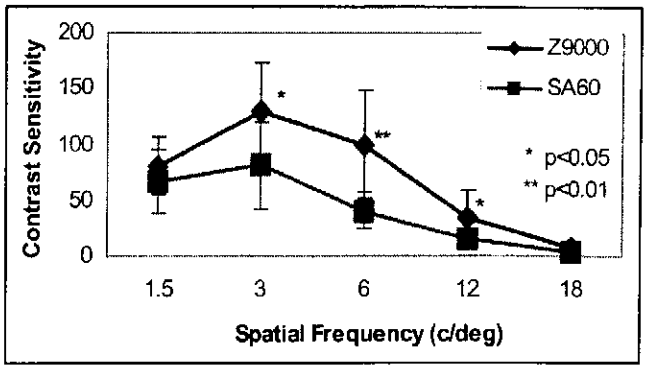
Clinical findings of a prospective study comparing the Tecnis IOL with the conventional spherical SA60AT (Alcon) IOL also showed improvements in contrast sensitivity with the Tecnis lens (Fig. 3) [36]. Thirty patients with senile cataract but no other eye pathology who were scheduled for sequential bilateral surgery were included in this prospective interindividual comparison. Statistically significant differences in photopic and low light contrast sensitivity were noted in favor of those eyes implanted with the Tecnis Z9000 foldable lens, generating significantly better functional results than those achieved with a conventional acrylic IOL.

Figure 2. Comparison of two implanted lenses



Statistically significant superior contrast sensitivity was found in the eyes implanted with the modified prolate IOL at 1.5, 3.0, and 6.0 cycles per degree. (Published with permission [34].)

Figure 3. Comparison of contrast sensitivity



Significant differences in contrast sensitivity under mesopic conditions occurred in this randomized, prospective study. (Published with permission [36].)

Retinal image contrast and contrast sensitivity

Another investigator has described a prospective, randomized study comparing the Tecnis Z9000 modified prolate (aspheric) IOL with conventional spherical silicone and acrylic IOLs in terms of effect on retinal image contrast and functional visual performance [37]. A total of 221 eyes of 156 patients were randomly assigned to receive one of three intraocular lenses, with 6 months of follow-up. Measured parameters included visual acuity, fundus photographic retinal image contrast, and functional acuity contrast testing. The differences in the preoperative and postoperative spherical and astigmatic refractive error and preoperative best corrected visual acuity between groups were not statistically significant. In the first postoperative month, uncorrected visual acuity was best in the aspheric group. The aspheric IOL group exhibited up to 47% increase in contrast for photopic, 38% in photopic with glare, 100% in mesopic, and 100% in mesopic with glare functional acuity contrast testing. Acrylic IOLs showed no increase in photopic, up to 38% increase in photopic with glare, 50% in mesopic, and 50% in mesopic with glare. Spherical silicone IOLs showed no increase in contrast testing when compared with cataract. Digital analysis of retinal imaging demonstrated increased threshold luminance levels in the aspheric group (range, 116–208) and a fourfold increase in image contrast compared with the silicone and acrylic groups. The aspheric IOL (Tecnis) provided significant improvement in objective retinal image contrast and in visual performance as measured by visual acuity and functional acuity contrast testing. This improvement was most pronounced in night vision and night vision with glare contrast testing when compared with conventional spherical silicone and acrylic IOLs.

Spherical aberration and night driving simulation studies

Data from a large prospective, randomized, double-masked multicenter trial involving 77 patients implanted

with the Tecnis Z9000 IOL in one eye and the SA60AT IOL in the fellow eye have been submitted to the US Food and Drug Administration. One of the most surprising results of this study was a statistically significant difference in best-corrected Early Treatment of Diabetic Retinopathy Study visual acuity favoring eyes implanted with the Tecnis IOL, assessed 90 days postoperatively (0.140 vs. 0.171 logMAR; difference = −0.031; P = 0.0066). Using wavefront aberrometry, spherical aberrations were eliminated in eyes implanted with the Tecnis IOL but still observed in control eyes [38].

Double-masked night driving simulator tests were conducted in a subpopulation of 29 patients. Using a variety of different targets, such as road signs or pedestrians, under a variety of different conditions, city or rural, improved detection and identification distances for virtually all targets were found for those eyes implanted with the Tecnis IOL. The results show that the Tecnis IOL is superior to the SA60AT in allowing detection of most of the targets under various conditions, with the greatest advantage seen for a hazard target (e.g., pedestrian) under rural (lower light) conditions. This suggests that the Tecnis IOL is superior, especially for low contrast targets under low illumination [38].

Additionally, evaluation of the effect of glare showed that those eyes with the Tecnis IOL performed as well as control eyes without glare. Also, the driving test performance of patients correlated significantly with their residual spherical aberration. This may suggest that correcting spherical aberration may improve a person's ability to recognize targets earlier while operating under reduced visibility conditions.

Conclusion

Evidence from several well-conducted, peer-reviewed clinical investigations confirm that correction of spherical aberration using an IOL with a modified anterior surface leads to a significant improvement in quality of vision in pseudophakia, as demonstrated by contrast sensitivity testing and night driving simulation. Clinical data demonstrate that the modified prolate IOL, designed to compensate for the positive spherical aberration of the cornea, provides superior functional vision and hence improved visual performance when compared with conventional spherical IOLs, as measured by sine wave grating contrast sensitivity, wavefront sensing, and night driving simulation testing.

Future directions include potential customization of this prolate lens, with a range of spherical powers to suit individual aberration values outside the estimated population average. The development of a prolate multifocal IOL offers further potential in the field of refractive optics. Another exciting technology that will employ wavefront sensing to correct optical aberrations is the Light Adjustable Lens (Calhoun Vision). This is a silicone IOL with photosensitive material that can be adjusted after implantation to correct myopia, hyperopia, astigmatism, and perhaps coma or spherical aberration [39].

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