JULY/AUGUST 2007
Volume 5, Issue 4

Ophthalmology® ROUNDS

AS PRESENTED IN THE ROUNDS OF THE DEPARTMENT OF OPHTHALMOLOGY AND VISION SCIENCES, FACULTY OF MEDICINE, UNIVERSITY OF TORONTO

An Update on Advanced Intraocular Lens (IOL) Technology: Monofocal IOLs

By Baseer U. Khan, MD, FRCS(C)

The past two decades have witnessed incredible advancements in the technologies and therefore, the subsequent outcomes of cataract surgery. The first 10 years saw the near universal acceptance of phacoemulsification as the standard of care in cataract extraction, while the past decade has seen a plethora of advances in IOL technologies. Although originally proposed by Sir Harold Ridley in 1955, the IOL was not widely accepted until the mid-1980s. Today, a multitude of options exists for both patients and surgeons. Given the vast knowledge base and literature that is available regarding the various lenses, this article focuses only on the various monofocal lenses that are currently available to Canadian surgeons. Furthermore, while numerous companies manufacture IOLs, this issue of *Ophthalmology Rounds* will primarily review IOL products provided by the 3 main IOL manufacturing companies in North America: Advanced Medical Optics (AMO), Alcon, and Bausch and Lomb (B&L). Table 1 summarizes the advanced monofocal IOL technologies from each of these companies.

Aspheric lenses

The original intent of IOL implantation was to grossly correct spherical error following removal of the visual obstruction caused by the cataract. More recently, the advent of wavefront technology allowed for the analysis and understanding of how higher order optical aberrations, as defined by Zernicke's polynomials, influence vision. Previously defined by Snellen acuity, which represents only a small subset of the visual circumstances that patients experience every day, visual performance can now be more accurately measured using contrast sensitivity. Contrast sensitivity has been validated as a robust indicator of visual performance that can evaluate vision across the spectrum of luminance and glare of daily activities.[1-7] It is a function of the optical efficiency of the eye – measured using modulation transfer function (MTF) – and the minimal resolvable resolution of the retina.[8,9] MTF quantifies the ability of an optical system to accurately produce and image an object that varies in spatial frequency and luminance. A sinusoidal grating is often used as a standard test object in laboratory studies (Figure 1).

In the phakic eye, two optical structures are responsible for focusing light on the retina: the lens and cornea. The aberrations of the cornea have been well-studied and documented. Across the population, the average value for all aberrations is "0," except for the Z^4_0 polynomial representing spherical aberration, for which the value is 0.27 µm.[10-14] While this mean value has been reproduced in multiple studies, the reported standard deviation has varied from 0.02 µm to 0.089 µm.[10-14] Although the crystalline lens has not been as well studied, it has aberrations that generally offset those found in the cornea; this is sometimes referred to as "aberration emmetropization."[10,15-20] As such, the mean value of all aberrations of the lens across the population is also "0," except for that of Z^4_0, which is predictably negative.[10] However, unlike the cornea, which remains static over time, spherical aberration becomes increasingly positive with age, from -0.2 µm at birth to 0.0 µm by approximately age 70 years. These changes in the refractive properties of the lens likely account for the decreased visual performance and functional complaints in aging patients who do not otherwise manifest cataractous changes.[20]

While lower order aberrations, namely defocus and astigmatism, are amenable to spectacle correction, third or higher order aberrations are not. Yet, higher order aberrations can significantly impact vision in proportion to their magnitude and relative position to the apex of the Zernicke's pyramid.[21-23] Of the higher order aberrations, spherical aberration is by far the greatest in magnitude and relatively low in order.[10-14] Furthermore, of all the higher order aberrations, spherical aberration is the only one that is rotationally symmetric and, thus, easily amenable to correction with IOL design.[24]

Available on the Internet at: www.ophthalmologyrounds.ca

Department of Ophthalmology and Vision Sciences, Faculty of Medicine, University of Toronto,
60 Murray St.
Suite 1-003
Toronto, ON M5G 1X5

The editorial content of *Ophthalmology Rounds* is determined solely by the Department of Ophthalmology and Vision Sciences, Faculty of Medicine, University of Toronto

Table 1: Advanced monofocal IOL technology

Company	Wavefront corrected lens (Z^4_0 value)	Shortwave length blocking lens (colour)	Toric lens
Advanced Medical Optics	Technis Z9000 (-0.27 μm)	TBA	NA
Alcon	AcrySof IQ (-0.20 μm)	AcrySof IQ (blue) AcrySof toric (blue)	AcrySof toric
Bausch and Lomb	SofPort LI61AO	SofPort LI61AO (violet)	NA

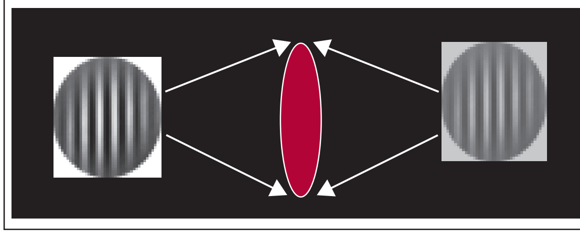
Wave-front corrected (aspheric) IOLs

Standard spherical IOLs have a mean positive spherical aberration of 0.10 μm; however, this value has been shown to be positively correlated with the spherical power of the lens,[25] thus, higher power IOLs induce a greater amount of spherical aberration. The implication of creating more spherical aberration was demonstrated in a study that found no differences in the MTFs between spherical-IOL pseudophakic eyes and age-matched phakic eyes.[26] In another study, pseudophakic patients were found to have a greater degree of spherical aberration than normals with pupil sizes >5 mm.[27]

The first wavefront corrected lens – the Technis Z9000 – was introduced in 2002 by Pharmacia. The first published study demonstrated a 77.9% gain in peak mesopic contrast sensitivity as compared to a standard spherical lens.[28,29] Even under photopic conditions, contrast sensitivity increased by 23.4% to 62.6%.[29,30] In a study designed to demonstrate the functional benefit of increased contrast sensitivity, patients receiving a Technis lens demonstrated a 0.5 second quicker response time to obstacles in a driving simulation.[31] No less than 30 studies have demonstrated the visual superiority of the Technis lens as compared to traditional spherical IOLs. The United States Food and Drug Administration (FDA) has approved 3 IOLs for the purpose of correcting spherical aberration: the Technis Z9000 (now under AMO), the AcrySof IQ (Alcon), and the SofPort LI61AO (B&L). Each offers a different degree of spherical aberration correction based on both philosophy and patent.

The spherical aberration values for the Technis, AcrySof IQ, and SofPort IOLs are -0.27 μm, -0.20 μm, and 0.0 μm, respectively. The original aspheric lens, the Technis, was designed to completely eliminate spherical aberration. The AcrySof IQ was designed to simulate the eyes of a 20-year-old adult, in whom the lens does not completely eliminate positive spherical aberration in the cornea and the net aberration in the optical system is 0.10 um. A number of studies have demonstrated that this small amount of positive spherical aberration is associated with supernormal visual acuity (better than 20/15).[32,33] The plausible explanation being that this residual spherical aberration offsets other higher order aberrations that exist within the ocular optical system. In a randomized masked clinical trial of 120 eyes, the AcrySof IQ outperformed both the AcrySof SA and AcrySof Natural lenses (both spherical lenses), with respect to contrast sensitivity and glare disability.[34] The concept of the neutral wave-front SofPort lens was to mitigate some of the potential pitfalls and drawbacks of a correcting spherical aberration lens as discussed below.

Figure 1: Modulation transfer function
A sinusoidal object (left) is projected through an optical system and the image (right) is generated. The ability of an optical system to maintain contrast is referred to as modulation transfer function (MTF). MTF varies for any given optical system depending on the spatial frequency of the object.



Limitations of wavefront corrected lenses

While the visual benefits of wavefront-corrected IOLs are well-established, some limitations must be recognized and considered by the surgeon. Excellent centration of the lens is a definite prerequisite to gain the superior optical performance of these lenses. The advantages of the Technis lens are lost if the lens is decentered more than 0.4 mm off the optical axis or if there is >7°of tilt.[35] It is, therefore, imperative that the capsulorhexis be round, centered, and achieves 360° of overlap of the pupil to prevent IOL migration, with eventual capsular fibrosis. Independent of surgeon performance, ocular anatomy provides further complexity in determining appropriate centration, since population studies indicated that the centre of the pupil is "off-centre" by approximately 0.4 mm (standard deviation 0.2 mm)[36-41] from the optical axis. Furthermore, the optical axis does not generally coincide with the eye's visual axis.[42]

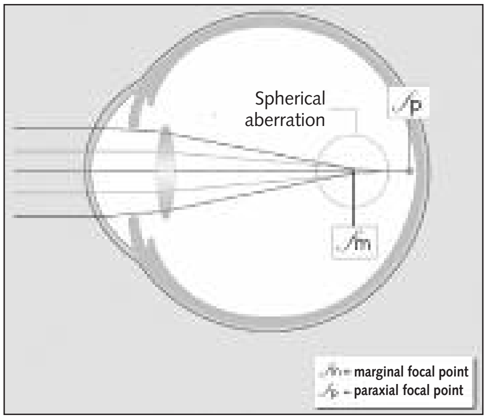
In comparison to the Technis lens, the centration requirements for the AcrySof IQ lens will be only marginally less, as its spherical aberration value is less. The advantage of the SofPort lens is the robustness of its optical function in the presence of decentration. With no inherent spherical aberration, the SofPort outperformed the Technis lens in the MTFs of a model eye when the lenses were decentered by >0.15 mm, 0.30 mm, and 0.38 mm in 3 mm, 4 mm, and 5 mm pupils, respectively.[43]

Positive spherical aberration in the eye results in a subjective refraction towards myopia (as peripheral light rays will be focused in front of the retina simulating a myopic eye; Figure 2).[32] The elimination of spherical aberration improves image quality and reduces blur; however, it does significantly reduce depth of focus for patients. In a comparison of the AcrySof IQ with the AcrySof SN lens, the minimum angle of resolution (MAR) with distance correction was less for the AcrySof IQ (0.02 versus 0.03). However, for intermediate and near distance, the MAR was significantly higher for the AcrySof IQ (intermediate: 0.43 versus 0.33, near 0.51 versus 0.39).[44] Being wavefront neutral, the SofPort lens provides approximately 0.5 dioptres of depth of focus with the residual 0.27 μm of spherical aberration found in the cornea.

Patient selection

Given all the theoretical considerations, practical questions that arise are: Which patient should receive an aspheric IOL? And if one is to be implanted, which lens should be used?

Figure 2: Subjective myopia from positive spherical aberration. In positive spherical aberration, marginal light rays are focused in front of the paraxial focal point, thereby creating a subjective appreciation of myopia. The degree of focus would be proportional to pupil size and, therefore, partially subjected to lighting conditions.



To answer the first question, it is more appropriate to determine who would *not* benefit from a wavefront corrected IOL. This would include patients whose corneas already produce negative spherical aberration, namely eyes with previous hyperopic refractive surgery and keratoconus. In these eyes, the negatively corrected IOLs would only accentuate existing spherical aberrations. Aside from these circumstances, every other eye is likely to benefit from implantation of an aspheric IOL. Other considerations are the visual requirements and symptoms of the individual patient. Those who require functionality under low-light condition (eg, truck drivers) and those who complain about glare and haloes, are most likely to appreciate and benefit from the advantages of aspheric IOLs. While statistically significant, the practical significance of decreased depth of focus is likely minimal since patients receiving monofocal lenses almost universally require reading correction for near vision. In this author's opinion, the superiority of contrast sensitivity inferred by aspheric IOLs far outways concerns regarding depth of focus and, thus, I encourage all patients to consider an aspheric IOL unless they are suitable candidates for a toric lens or wish to receive a multifocal lens.

Answering the second question, which pertains to aspheric IOL selection is more problematic. Most agree that the "one-size fits all" approach is not ideal and that customization of the aspheric IOL based on individual corneal asphericity is more effective. While the concept of customization is simple, its implementation is complex.

First, corneal aberration must be calculated. At present, the most commonly-used devices are wavefront aberrometers and corneal topography units, but these units are expensive, which may hinder access. When considering a more economical method to determine corneal asphericity, Beiko et al[45] recently reported that corneal keratometry readings could *not* be reliably used to predict corneal spherical aberration.

Furthermore, there is some debate as to whether corneal asphericity is modified by corneal wounds created during surgery. This is likely surgeon-dependent and, therefore, a "surgeon factor" for spherical aberration, in addition to sphero-cylindrical considerations, should be calculated.

When considering customization, the greatest conundrum and point of contention is the targeted endpoint. As the first aspheric IOL, the Technis intended to eliminate all spherical aberrations and its ability to improve functional vision is indisputable. However there is also good evidence to support the notion that 0.1 µm of spherical aberration is beneficial. Population studies have demonstrated this amount of spherical aberration in the 20-year-old eye. In addition, a study of navy pilots demonstrated that, as well as having better-than-average visual acuity, the pilots also had better-than-average contrast sensitivity with an average ocular spherical aberration of 0.1 µm.[46] Presented, but unpublished data, from Beiko also demonstrates that patients targeted for 0.1 µm outperformed nonselected patients at almost every spatial frequency. It will likely be some time until universal agreement is achieved on the targeted endpoint. Until then, the surgeon must determine what works best in his or her hands.

Surgeons should consider using the SofPort lens in cases where there are concerns of long-term decentration or tilt, such as patients with pseudo-exfoliation syndrome or other zonulopathies. As a 3-piece silicon lens, it can also be placed in the sulcus in the presence of a posterior capsular rupture and is probably superior to the Technis lens in this clinical scenario because of its robust optical performance in the presence of decentration. The implantation of the one-piece acrylic lens platform of the AcrySof IQ into the sulcus is contraindicated.

One final confounding variable between the 3 lenses is the presence of light-blocking technologies that target the shorter wavelengths in the visible spectrum found in the AcrySof IQ and the SofPort, dubbed "blue-blocking" and "violet-blocking", respectively (see discussion below).

Short-wavelength filtering lenses

The need to block potentially harmful light rays from entering the eye was recognized by Mainster in 1978 when, as a second-year resident, he proposed that ultraviolet (UV) light, which was known to be phototoxic to the eye, was transmitted by the IOLs used at that time.[47] In the 1980s, UV-filtering lenses were quickly adopted and became the standard of care.

In the 1990s, blue light was identified in both basic science and epidemiological studies as a possible contributor to age-related macular degeneration (ARMD).[48] This was the impetus for the introduction of the blue-blocking lens that matched the transmittance ability of a young adult crystalline lens in blocking UV light and attenuating blue light.[49]

In 2003, Alcon received approval from the US FDA for the AcrySof Natural lens for the purpose of visual correction of aphakia in adult patients (it was not specifically approved for the prevention or mitigation of ARMD). The proprietary covalently-bonded chromophore is now found in all of Alcon's premium lenses, namely the AcrySof IQ, AcrySof Toric, and AcrySof Restor. The concept of a blue-blocking lens has created a tremendous amount of controversy, particularly with respect to its ability to protect the eye from ARMD and the potential degradation in visual function by reducing the transmittance of blue light to the retina.

Blue light and ARMD and cataract surgery

Lipofuscin is a toxic byproduct of incomplete phagocytosis of photoreceptors that is deposited in the retinal pigmented epithelium (RPE) and implicated in the pathogenesis of ARMD.[50,51] Efforts to identify constituents of lipofuscin have isolated a major fluorophore, known as A2E, and found it to be maximally excited by blue light.[52-56]

As a lens ages, it naturally becomes more yellow, increasing the ability to filter out blue from reaching the retina. When a lens is removed and replaced with a clear lens during cataract surgery, the theoretical concern is that the retina is subsequently exposed to blue light levels that are greater than at any prior point of its lifetime. Dhillon et al estimated that the light absorption by A2E increases by a factor of "5" as a result.[57] The logical extrapolation of this argument should be increased rates of ARMD following cataract surgery; however, there are good studies to support, as well as contradict this assertion. Six of 8 major epidemiological studies designed to examine the risk of ARMD in relation to light exposure found no correlation,[58-63] and 1 study found an inverse relationship.[60] The AREDS study also found no correlation between cataract surgery and exudative ARMD.[63] However, Pollack et al reported a 4-fold increase in the rate of conversion from dry to wet ARMD in the first year following cataract surgery.[64] Furthermore, a pooled analysis of the Beaver Dam Eye study and the Blue Mountain Eye Study found an increased risk of advanced ARMD 5 years after cataract surgery.[65]

These studies indicate that a correlation between cataract surgery and ARMD remains unclear and, furthermore, if one does exist, it is unclear whether it is due to blue light exposure or other inflammatory mediators released during the intra- and post-operative period. An *in vitro* study by Sparrow et al[53] demonstrated a significant reduction in the death (by 72% to 82%) in cultured RPE cells when exposed to blue, green, and white light filtered through the AcrySof Natural lens as compared to a number of other clear lenses. These results have yet to be definitively proven in *in vivo* studies; something that will likely require many years and patients.

Visual performance

Following the introduction of the AcrySof Natural lens, concerns arose about the potential degradation of visual function, particularly scotopic vision in patients, since blue light would be attenuated. Ironically, one of the strongest adversaries to the blue blocker lens was Mainster, who reported on 2 types of photic retinopathy: blue-green and UV-blue phototoxicity.[66] The former is mediated by rhodopsin, while the latter is mediated by lipofuscin. Targeting blue-green toxicity would severely limit both scotopic and photopic vision and, therefore, the target of preventing photic retinopathy should focus on the latter. According to Mainster, UV light is responsible for 67% of UV-blue phototoxicity and not perceptible by the human eye. Therefore, blocking UV light makes complete sense. Violet light, with wavelengths from 400 to 440 nm, accounts for 18% of UV-blue phototoxicity, while providing only 10% of scotopic vision.[67] This parallels research suggesting that the absorbance of A2E falls quickly as wavelengths increase past 440 nm.[53,57] Finally, blue light (440-500 nm) contributes only 14% of UV-blue phototoxicity, while providing 35% of scotopic vision, given that the peak sensitivity for rods is 507 nm. This is the rationale behind the violet-blocking lenses that have and will enter the market from B&L and AMO, respectively (the SofPort lens currently comes with violet-blocking technology, AMO has yet to introduce their line of violet-blocking lenses, but their release is imminent).

The amount of blue light blocked by the AcrySof Natural lens is reported to be between 14% to 34%. The theoretical ramifications of this are both obvious and subtle. The reduction in blue light input into scotopic vision potentials results in decreased function during activities performed under low-light levels (eg, nighttime driving or walking around the house at night). Less obvious are the potential effects on circadian rhythmicity. Circadian photoentrainment is controlled by melanopsin, a blue light-sensitive photo pigment in retinal ganglion cells. Retinal ganglion cells have been found to mediate levels of melatonin secreted by the pineal gland, which modulates sleep wake and core body temperature cycles. When exposed to light, melanopsin is stimulated and melatonin is suppressed. At twilight or darkness, in the absence of stimulation of melanopsin, melatonin secretion rises. Circadian rhythmicity is disturbed in many diseases found in the elderly population, including insomnia, depression, coronary artery disease, cancer, dementia, and Alzheimer's disease. Reducing the transmittance of blue light to the retina may therefore potentiate circadian dysrhythmicities and contribute to the development of other diseases.[68]

While the AcrySof Natural lens may block more blue light than the standard UV-blocking-only IOL, it still transmits more light above 500 nm than the average young adult human lens whose transmittance in the blue-green region is approximately 60%.[69] Two prospective, randomized, masked clinical trials were conducted by Pandita et al[34] and Marshall et al[70] in 120 and 300 patients, respectively, that compared the AcrySof SA60 (a clear 1-piece acrylic lens) and the AcrySof Natural lens with respect to contrast sensitivity and colour perception. Both found no significant differences between the lenses. Espindle et al[71] published patient-reported, vision-related, and health-related functioning and quality-of-life data in patients who had either received or not received bilateral blue-blocking lenses. The study evaluated general vision, near-activities, distance activities, driving (particularly night driving), mental health, peripheral vision, and role difficulty scales; it found no significant difference between the groups.

Although there are good theoretical arguments against blue-blockers from a vision performance perspective, clinical trials have failed to corroborate these assertions. The arguments supporting violet-blocking lenses are strong; however, since they have only recently entered the market, there is a paucity of literature documenting their performance, particularly in comparison to their blue-blocking counterparts.

Table 2: AcrySof toric models

AcrySof toric Model	Cylinder power		Recommend corneal astigmatism correction ranges
	At IOL Plane	At Corneal Plane	
SN60T3	1.50 D	1.03 D	0.75 – 1.50 D
SN60T4	2.25 D	1.55 D	1.50 – 2.00 D
SN60T5	3.00 D	2.06 D	2.00 D and up

Toric lenses

Based on the principles discussed in the section about aspheric lenses, the closer an aberration is to the apex of Zernicke's pyramid, the greater its effect on optical degradation. As a lower order aberration, astigmatism has significant ramifications if left uncorrected postoperatively. Until recently, the only option to manage significant corneal astigmatism has been limbal relaxing incisions (LRIs), performed either intra- or postoperatively, and postoperative excimer ablations. Alcon has recently introduced toric lenses that are on the 1-piece acrylic AcrySof platform.

To ensure optical performance, the toric IOL must achieve excellent centration, and be rotationally accurate. The latter is accomplished by marking the intended axis of the corrective cylinder prior to surgery at the limbus, since cyclotorsion of the eye frequently occurs during surgery thus precluding accurate intra-operative determination of the axis. The lens has 3 dots etched at each haptic-optic junction to delineate its cylindrical axis, which must be lined-up with the limbal markings.

Alcon has provided a website at *www.acrysoftoriccalculator.com* where preoperative keratometry values, the calculated spherical IOL, as well as the surgeon factor, is input to determine the spherocyclindral power of the toric IOL. Table 2 lists the correcting lenses for various degrees of astigmatism. Furthermore, the website provides a pictorial illustration of the proper alignment of the lens within the eye. This is useful to post in the operating room so the surgeon can ensure that the lens has been rotated to the correct position. It has been estimated that for every 1° of rotation off the correct axis, 3.3% of the lens cylinder power is lost. A large trial has demonstrated that the median rotation of the AcrySof toric at 6 months was 0.7°, ranging from 0.1° to 1.8°, indicating its rotational stability.[72]

Patients should only be considered for a toric lens if their steep and flat meridians are approximately 90° apart, as determined by manual keratometry. Furthermore, the astigmatism should manifest as a symmetrical pattern, ie, bow-tie or wedge type, as identified by corneal topography. Intraoperatively, it is mandatory that the capsular bag be intact and that a continuous curvilinear capsulorhexis be present.

Summary

With all the technology that is available to patients and surgeons, discussing the various IOL options likely takes more time than explaining the cataract surgery itself. In the not so distant future, IOLs will probably be "customized" for individual patients, based on their particular wavefront image, similar to customized ablation in refractive surgery. Until then, as we learn more about the features of lenses that provide the best functional vision to our patients, we will have more variables to consider when choosing and recommending a particular IOL to a given patient.

Baseer U. Khan, MD, FRCS(C), is a Lecturer in the Department of Ophthalmology, University of Toronto.

References:

1. Packer M, Fine IH, Hoffman RS. Wavefront technology in cataract surgery. *Curr Opin Ophthalmol* 2004;15(1):56-60.
2. Owsley C, Sloane M. Contrast sensitivity, acuity, and the perception of "real world" targets. *Br J Ophthalmol* 1987;71:791-796.
3. Ginsburg AP, Evans DW, Sekule R, Harp SA: Contrast sensitivity predicts pilots' performance in aircraft simulators. *Am J Optom Physiol Opt* 1982; 59:105-109.
4. Rubin GS, Bandeen Roche K, Huang GH, et al. The association or multiple visual impairments with self-reported visual disability: SEE project. *Invest Ophthalmol Vis Sci* 2001;42:64-72.
5. Lord SR, Menz HB. Visual contributions to postural stability in older adults. *Gerontology* 2000;46:306-310.
6. Owsley C, Stalvey BT, Wells J, et al. Visual risk factors for crash involvement in older drivers with cataract. *Arch Ophthalmol* 2001;119:881-887.
7. Lord SR, Dayhew J. Visual risk factors for falls in older people. *J Am Geriatr Soc* 2001;49:676-677.
8. Campbell FW, Green DG. Optical and retinal factors affecting visual resolution. *J Physiol* 1965;181:576-593.
9. Schwiegerling J. Theoretical limits to visual performance. *Surv Ophthalmol* 2000;45:139-146.
10. Altmann GE. Wavefront-customized intraocular lenses. *Curr Opin Ophthalmol* 2004;15(4):358-64.
11. Oshika T, Klyce SD, Applegate RA, et al. Changes in corneal wavefront aberrations with aging. *Invest Ophthalmol Vis Sci* 1999;40:1351-1355..
12. Guirao A, Redondo M, Artal P: Optical aberrations of the human cornea as a function of age. *J Opt Soc Am A Opt Image Sci Vis* 2000;17:1697-1702.
13. He JC, Gwiazda J, Thorn F, et al. Wave-front aberrations in the anterior corneal surface and the whole eye. *J Opt Soc Am* 2003;20:1155-1163.
14. Wang L, Dai E, Koch DD, et al. Optical aberrations of the human anterior cornea. *J Cataract Refract Surg* 2003;29:1514-1521.
15. Tomlinson A, Hemenger RP, Garriott R. Method for estimating the spherical aberration of the human crystalline lens *in vivo. Invest Ophthalmol Visual Sci* 1993;34:621-629.
16. Glasser A, Campbell MCW. Presbyopia and the optical changes in the human crystalline lens with age. *Vision Res* 1998;38:209-229.
17. Smith G, Cox MJ, Calver R, et al. The spherical aberrations of the crystalline lens of the human eye. *Vision Res* 2001;41:235-243.
18. He JC, Ong E, Gwiazda J, et al. Wavefront aberrations in the cornea and the whole eye. *Invest Ophthalmol Visual Sci* 2000;41:s105.
19. Artal P, Guirao A, Berrio E, et al. Compensation of corneal aberrations by the internal optics in the human eye. *J Vision* 2001;1:1–8.
20. Artal P, Berrio E, Guirao A, et al. Contribution of the cornea and internal surfaces to the change of ocular aberrations with age. *J Opt Soc Am A* 2002; 19:137-143.
21. Thibos LN, Applegate RA, Schwiegerling JT, Webb R. VSIA Standards Taskforce Members. Vision Science and its Applications: Standards for reporting the optical aberrations of the eyes. *J Refract Surg* 2002;18: S652-S660.
22. Chen L, Singer B, Guirao A, et al. Image metrics for predicting subjective image quality. *Optom Vis Sci* 2005; 82:358-369.
23. Charman WN. The Charles W Prentice Award Lecture 2005: optics of the human eye: progress and problems. *Optom Vis Sci* 2006;83:335-345.
24. Bellucci R, Morselli S. Optimizing higher-order aberrations with intraocular lens technology. *Curr Opin Ophthalmol* 2007;18(1):67-73.
25. Padmanabhan P, Yoon G, Porter J, et al. Wavefront aberrations in eyes with Acrysof monofocal intraocular lenses. *J Refract Surg* 2006;22:237-242.
26. Navarro R, Ferro M, Artal P, et al. Modulation transfer functions of eyes implanted with intraocular lenses. *Appl Opt* 1993;32:6359-6367.
27. Miller JM, Anwaruddin R, Straub J, Schwiegerling J. Higher order aberrations in normal, dilated, intraocular lens, and laser in situ keratomileusis corneas. *J Refract Surg* 2002;18:S579-S583.
28. Packer M, Fine IH, Hoffman RS, Piers PA. Prospective randomized trial of an anterior surface modified prolate intraocular lens. *J Refract Surg* 2002; 18:692-696.
29. Packer M, Fine IH, Hoffman RS. Functional vision, wavefront sensing, and cataract surgery. *Int Ophthalmol Clin* 2003;43:79-91.
30. Packer M, Fine IH, Hoffman RS, Piers PA. Improved functional vision with a modified prolate intraocular lens. *J Cataract Refract Surg* 2004; 30:986-992.
31. Packer M. Evaluation of a modified prolate surface IOL with the WASCA Analyzer. Publication No: 000000-1276-350. Jena, Germany: Carl Zeiss Meditec;2003.
32. Cheng X, Bradley A, Thibos LN. Predicting subjective judgment of best focus with objective image quality metrics. *J Vision* 2004;4:310-321.
33. Levy Y, Segal O, Avni I, Zadok D. Ocular higher-order aberrations in eyes with supernormal vision. *Am J Ophthalmol* 2005;139:225-228.
34. Pandita D, Raj SM, Vasavada VA, et al. Contrast sensitivity and glare disability after implantation of AcrySof IQ Natural aspherical intraocular lens: prospective randomized masked clinical trial. *J Cataract Refract Surg* 2007;33(4):603-10.
35. Holladay JT, Piers PA, Koranyi G, et al. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. *J Refract Surg* 2002; 18:683-691.

36. Hayashi K, Harada M, Hayashi H, et al. Decentration and tilt of polymethyl methacrylate, silicone, and acrylic soft intraocular lenses. *Ophthalmology* 1997; 104:793-798.
37. Wang M-C, Woung L-C, Hu C-Y, et al. Position of poly(methyl methacrylate) and silicone intraocular lenses after phacoemulsification. *J Cataract Refract Surg* 1998;24:1653-1657.
38. Hayashi K, Hayashi H, Nakao F, et al. Comparison of decentration and tilt between one piece and three piece polymethyl methacrylate intraocular lenses. *Br J Ophthalmol* 1998;82:419-422.
39. Kimura W, Kimura T, Sawada T, et al. Postoperative decentration of three piece silicone intraocular lenses. *J Cataract Refract Surg* 1996;22:1277-1280.
40. Hwang IP, Clinch TE, Moshifar M, et al. Decentration of 3-piece versus platehaptic silicone intraocular lenses. *J Cataract Refract Surg* 1998;24:1505-1508.
41. Schwenn O, Kottler U, Krummenauer F, et al. Effect of large positioning holes on capsule fixation of plate-haptic intraocular lenses. *J Cataract Refract Surg* 2000; 26:1778-1785.
42. Rynders M, Lidkea B, Chisholm W, et al. Statistical distribution of foveal transverse chromatic aberration, pupil centration, and angle in a population of young adult eyes. *J Opt Soc Am A* 1995;12:2348-2357.
43. Altmann GE, Nichamin LD, Lane SS, Pepose JS. Optical performance of 3 intraocular lens designs in the presence of decentration. *J Cataract Refract Surg* 2005; 31(3):574-85.
44. Rocha KM, Soriano ES, Chamon W, Chalita MR, Nose W. Spherical aberration and depth of focus in eyes implanted with aspheric and spherical intraocular lenses a prospective randomized study. *Ophthalmology* 2007;18. [Epub ahead of print]
45. Beiko GH, Haigis W, Steinmueller A. Distribution of corneal spherical aberration in a comprehensive ophthalmology practice and whether keratometry can predict aberration values. *J Cataract Refract Surg* 2007;33(5):848-58.
46. Grimson JM, Schallhorn SC, Kaupp SE. Contrast sensitivity: establishing normative data for use in screening prospective naval pilots. *Aviat Space Environ Med* 2002; 73(1):28-35.
47. Mainster MA. Spectral transmittance of intraocular lenses and retinal damage from intense light sources. *Am J Ophthalmol* 1978;85(2):167-70.
48. Taylor HR, West S, Munoz B, Rosenthal FS, Bressler SB, Bressler NM. The long-term effects of visible light on the eye. *Arch Ophthalmol* 1992;110(1):99-104.
49. Braunstein RE, Sparrow JR. A blue-blocking intraocular lens should be used in cataract surgery. *Arch Ophthalmol* 2005;123(4):547-9.
50. Delori FC, Goger DG, Dorey CK. Age-related accumulation and spatial distribution of lipofuscin RPE of normal subjects. *Invest Ophthalmol Vis Sci* 2001; 42:1855-1866.
51. Holz FG, Bellman C, Staudt S, Schutt F, Volcker HE. Fundus autofluorescence and development of geographic atrophy in age-related macular degeneration. *Invest Ophthalmol Vis Sci* 2001;42:1051-1056.
52. Sparrow JR, Nakanishi K, Parish CA.The lipofuscin fluorophore A2E mediates blue light-induced damage to retinal pigmented epithelial cells. *Invest Ophthalmol Vis Sci* 2000;41:1981-1989.
53. Sparrow JR, Cai B. Blue light-induced apoptosis of A2E-containing RPE: involvement of caspase-3 and protection by Bcl-2. *Invest Ophthalmol Vis Sci* 2001;42:1356-1362.
54. Sparrow JR, Zhou J, Ben-Shabat S, Vollmer H, Itagaki Y, Nakanishi K. Involvement of oxidative mechanisms in blue light induced damage to A2E-laden RPE. *Invest Ophthalmol Vis Sci* 2002;43:1222-1227.
55. Sparrow JR, Vollmer-Snarr HR, Zhou J, et al. A2E-epoxides damage DNA in retinal pigment epithelial cells: vitamin E and other antioxidants inhibit A2E-epoxide formation. *J Biol Chem* 2003;278:18207-18213.
56. Sparrow JR, Zhou J, Cai B. DNA is a target of the photodynamic effects elicited in A2E-laden RPE by blue light illumination. *Invest Ophthalmol Vis Sci* 2003; 44:2245-2251.
57. Dillon J, Zheng L, Merriam JC, Gaillard ER. Transmission of light to the aging human retina: possible implications for age related macular degeneration. *Exp Eye Res* 2004;79(6):753-9.
58. The Eye Disease Case-Control Study Group. Risk factors for neovascular age-related macular degeneration. *Arch Ophthalmol* 1992;110(12):1701-8.
59. Hirvela H, Luukinen H, Laara E, Sc L, Laatikainen L .Risk factors of age-related maculopathy in a population 70 years of age or older. *Ophthalmology* 1996; 103(6):871-7.
60. Darzins P, Mitchell P, Heller RF. Sun exposure and age-related macular degeneration. An Australian case-control study. *Ophthalmology* 1997;104(5):770-6.
61. Delcourt C, Carriere I, Ponton-Sanchez A, et al; POLA Study Group.Light exposure and the risk of age-related macular degeneration: the Pathologies Oculaires Liees a l'Age (POLA) study. *Arch Ophthalmol* 2001;119(10):1463-8.
62. McCarty CA, Mukesh BN, Fu CL, Mitchell P, Wang JJ, Taylor HR. Risk factors for age-related maculopathy: the Visual Impairment Project. *Arch Ophthalmol* 2001;119(10):1455-62.
63. Clemons TE, Milton RC, Klein R, et al; Age-Related Eye Disease Study Research Group. Risk factors for the incidence of Advanced Age-Related Macular Degeneration in the Age-Related Eye Disease Study (AREDS) AREDS report no. 19. *Ophthalmology* 2005;112(4):533-9.
64. Pollack A, Bukelman A, Zalish M, Leiba H, Oliver M. The course of age-related macular degeneration following bilateral cataract surgery. *Ophthalmic Surg Lasers* 1998;29(4):286-94.
65. Klein R, Klein BEK, Wong TY, Tomany SC, Cruickshanks KJ. The association of cataract and cataract surgery with the long-term incidence of age-related maculopathy. *Arch Ophthalmol* 2002;120:1551-1558.
66. Mainster MA, Sparrow JR. How much blue light should an IOL transmit? *Br J Ophthalmol* 2003;87(12):1523-9.
67. Mainster MA. The spectra, classification, and rationale of ultraviolet-protective intraocular lenses. *Am J Ophthalmol* 1986;102(6):727-32.
68. Pauley SM. Lighting for the human circadian clock: recent research indicates that lighting has become a public health issue. *Med Hypotheses* 2004;63(4): 588-96.
69. Boettner EA, Wolter JR. Transmission of the ocular media. *Invest Ophthalmol* 1962;1:776-783.
70. Marshall J, Cionni RJ, Davison J, et al. Clinical results of the blue-light filtering AcrySof Natural foldable acrylic intraocular lens. *J Cataract Refract Surg* 2005; 31(12):2319-23.
71. Espindle D, Crawford B, Maxwell A, et al..Quality-of-life improvements in cataract patients with bilateral blue light-filtering intraocular lenses: clinical trial. *J Cataract Refract Surg* 2005;31(10):1952-9.
72. Weinand F, Jung A, Stein A, Pfutzner A, Becker R, Pavlovic S. Rotational stability of a single-piece hydrophobic acrylic intraocular lens: new method for high-precision rotation control. *J Cataract Refract Surg* 2007;33(5):800-3.

Department of Ophthalmology and Vision Sciences, University of Toronto

Upcoming events

October 13, 2007 International Ocular Blood Flow Symposium
Sutton Place Hotel, Toronto
Director: Dr. Neeru Gupta.
Contact: University of Toronto CME office – 416-978-2719

November 10-13, 2007 AAO, New Orleans, Louisiana

November 23-24, 2007 Department Walter Wright Program
The Revealing Retina
The Old Mill, Toronto
Course director: Dr. David Chow
Contact: U of T CME office – 416-978-2719

Note: This year's VPP rounds will be held at Mount Sinai Hospital, 18th Floor Auditorium, 600 University Avenue, Toronto. 5:30PM – 7:30PM.

Upcoming meeting

10-13 November 2007
American Academy of Ophthalmology
111th Annual Meeting
New Orleans, Louisianna
Contact: www.aao.org

Disclosure Statement: Dr. Khan has no disclosures to announce in association with the contents of this issue.

Change of address notices and requests for subscriptions for *Ophthalmology Rounds* are to be sent by mail to P.O. Box 310, Station H, Montreal, Quebec H3G 2K8 or by fax to (514) 932-5114 or by e-mail to info@snellmedical.com. Please reference *Ophthalmology Rounds* in your correspondence. Undeliverable copies are to be sent to the address above. Publications Post #40032303

This publication is made possible by an unrestricted educational grant from

Novartis Ophthalmics