Analysis of the possible benefits of aspheric intraocular lenses: Review of the literature

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We reviewed recently published studies that analyzed the visual and optical quality in eyes with different spherical and aspheric intraocular lenses (IOLs). Recent studies focused on visual quality metrics, such as visual acuity and contrast sensitivity, under photopic and mesopic lighting conditions and optical metrics, such as wavefront aberrations, especially spherical aberration. The results in this review were used in an attempt to understand whether there is a visual and/or optical benefit of implanting aspheric IOLs over implanting spherical IOLs.

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Today, the goal of cataract surgery is not only to restore visual acuity but also to provide the best visual quality to patients. Wavefront-sensing technology has recently been applied to cataract surgery with the introduction of new intraocular lens (IOL) designs. Aspheric IOLs were designed to correct for the spherical aberration of the cornea. It has been reported that as the eye ages, optical quality worsens; the source of this degradation is the loss of balance between corneal aberration and lens aberration.[1,2] The shift in the spherical aberration of the lens toward less negative or even positive values,[3] combined with the positive corneal spherical aberration, implies a decrease in ocular optical quality with age. After cataract surgery, the natural lens is replaced with an artificial lens. Eyes with spherical IOLs have reduced optical quality (increased higher-order aberrations[4] [HOAs]), caused in part by the increased positive spherical aberration of the IOL. Thus, an aspheric IOL with negative spherical aberration would be required to compensate for the positive spherical aberration of the cornea.[5]

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However, recent studies of aspheric IOLs[6–30] show discrepancies about whether these IOLs improve visual performance over that with spherical IOLs. Centration, tilt, and the asphericity of the IOL, in addition to intersubject variability in corneal spherical aberration, play a significant role in explaining these results.

In this paper, we discuss findings and conclusions obtained through careful review of several studies of aspheric and spherical IOLs in the peer-reviewed literature. The purpose of the review was to clarify whether implantation of an aspheric IOL results in better visual quality after lens replacement than that in eyes with a spherical IOL.

LITERATURE REVIEW

Theoretical Benefits and Drawbacks of Aspheric Intraocular Lenses

From an optical viewpoint, an aspheric IOL generates a negative spherical aberration to compensate for the positive corneal spherical aberration. The balance between corneal aberration and IOL aberration provides good optical quality for the whole eye after IOL implantation. Depending on the asphericity of the first or second surface of the aspheric IOL, a different amount of spherical aberration is generated. This amount of asphericity is intended to reduce or eliminate the spherical aberration in the eye and improve functional vision over that with a spherical IOL. The theoretical benefit of making 1 or both surfaces of the IOL aspheric was analyzed by Atchison,[31] who found aspheric IOLs had better in-focus performance than spherical IOLs. Several other points must be considered, including centration/tilt of the

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IOL, the effect of cataract surgery on corneal spherical aberration, depth of focus, and corneal spherical aberration.

From a theoretical viewpoint, IOL decentration could limit, cancel, or turn into disadvantages the benefits of aspheric IOLs. For example, the advantages of asphericity are lost when IOL decentration is greater than 0.5 mm.[31,32] Holladay et al.[5] report that optical quality measurements provide evidence that if an aspheric IOL were centered within 0.4 mm and tilted fewer than 7 degrees, it would exceed the optical performance of a conventional spherical IOL. Model-eye simulations by Dietze and Cox[33] indicate that image quality with either design deteriorates at a similar rate when the IOL is tilted and that spherical IOLs perform more robustly when the IOL is displaced. If tilt and decentration occur in combination, the performance of aspheric IOLs strongly depends on the direction of the offset. Dietze and Cox's[33] model eye with aspheric IOLs showed that with increasing decentration, asymmetrical 3rd-order aberrations increased at a much faster rate than with spherical IOLs; symmetrical 4th-order aberrations remained constant (spherical IOL) or nearly constant (aspheric IOL).

From a clinical viewpoint, the mean IOL centration with continuous curvilinear capsulorhexis and in-the-bag placement is reported to be from 0.1 to 0.3 mm.[34–36] Wang and Koch[37] recently concluded that with current surgical techniques, implantation of aspheric and monochromatic wavefront-corrected IOLs would reduce total ocular HOAs to below corneal HOA values in approximately 45% and 86% of eyes, respectively (with a 6.0 mm pupil). The performance of any static correcting method is limited by residual aberrations arising from misalignments. To obtain the optimum benefit, the IOL should be centered on the visual axis. Because the visual axis does not generally pass through the center of the pupil,[38] it should be measured before surgery; if not, the assistance of the patient may be required during surgery. Capsule fibrosis and other biomechanical events that modify the permanently fixed position of the IOL may also play a role in the final optical quality of the eye.

The surgery itself can have an effect on corneal spherical aberration. Marcos et al.[39] found that cataract surgery with a small (3.2 mm) superior incision induced consistent and significant changes in several corneal Zernike terms (ie, vertical astigmatism, trefoil, and tetrafoil), resulting in a significantly increased overall corneal root-mean-square wavefront error. However, the surgery did not induce significant changes in spherical aberration or coma. The amount and orientation of the induced aberrations depend on the surgical meridian and incision location. Pesudovs et al.[40] studied the effect of 2 types of spherical IOLs—poly(methyl methacrylate) (PMMA) and acrylic—and 2 incision locations—corneal and scleral—on total wavefront aberrations. The authors found that scleral incisions induced fewer aberrations than corneal. The PMMA–scleral group (5.2 mm incision) had fewer aberrations than the acrylic–corneal group (3.5 mm incision) and had aberrations comparable to those in the control group. There were higher amounts of total tetrafoil in the acrylic–corneal group than in the phakic group. In addition, enlargement of the incision at different steps of the procedure,[41] in particular differences between injectors,[42] may play a role in the trends observed. Elkady et al.[43] conclude that microincision cataract surgery does not modify corneal optical aberrations, although findings by Yao et al.[44] indicate that microincision cataract surgery has no significant advantage in reducing corneal HOAs over small-incision cataract surgery. Considering previous research of small standard-incision cataract surgery, aspheric IOLs designed to compensate for the mean preoperative corneal spherical aberration work under the xassumption that spherical aberration remains practically unchanged.

Another point is that best-corrected eyes with spherical IOLs should perform better at near tasks than best-corrected eyes with aspheric IOLs. Marcos et al.[12] found that the tolerance to defocus was significantly higher with spherical IOLs than with aspheric IOLs; it was necessary to add 1.5 diopters (D) with the spherical IOL and 1.1 D with the aspheric IOL to make the 20/20 line illegible on simulation. Recently, Rocha et al.[21] concluded that the reduction in spherical aberration after aspheric IOL implantation may degrade distance-corrected near visual acuity and intermediate visual acuity. They point out that residual spherical aberration can improve depth of focus and that the tolerance to defocus seems to be higher in eyes with a spherical IOL than in eyes with an aspheric IOL. However, it must be kept in mind that this refers to a monofocal IOL that was not designed to provide a large depth of focus, as are pseudoaccommodating IOLs.

Table 1 shows the characteristics of 4 aspheric IOLs currently on the market. At present, 3 of the IOLs are approved by the U.S. Food and Drug Administration for correction of spherical aberration; they are the Tecnis (Advanced Medical Optics), AcrySof IQ (Alcon), and SofPort AO (Bausch & Lomb). The main difference between these aspheric IOLs is the difference in their asphericity, and thus the spherical aberration they are capable of correcting when implanted. These 3 IOLs have different strategies for correcting spherical aberration. The SofPort AO IOL produces minimal change in the ocular spherical aberration (lens

Table 1. Main characteristic of selected aspheric IOLs.

	Aspheric Intraocular Lens			
Characteristic	Tecnis	AcrySof IQ	SofPort AO	Acri.Smart
Manufacturer	Advanced Medical Optics	Alcon Laboratories	Bausch & Lomb	Zeiss
Model	Z9000, Z9002, Z9003	SN60WF	LI61AO	36A
Optic (mm)	6	6	6	6
Material	Silicone (Z9000, Z9002); acrylic (Z9003)	Acrylic	Silicone	Acrylic
Chromophore	UV blocking	UV blocking	UV blocking	UV blocking
Overall length (mm)	12	13	13	11
Design	Prolate anterior surface	Prolate posterior surface	Prolate anterior and posterior surfaces	
Refractive index	1.46	1.55	1.43	1.46
Spherical aberration (μm) with a 6.0 mm pupil	−0.27	−0.20	0	−0.26

spherical aberration approximately zero). The Tecnis IOL corrects the full corneal spherical aberration, and the AcrySof IQ IOL compensates to a lesser degree. It has been suggested that the best optical quality is obtained if the entire amount of spherical aberration is corrected (ie, there is zero total spherical aberration after surgery). After computing variations with a model eye, Dietze and Cox[33] concluded that under low-light conditions, all HOAs in the pseudophakic aging eye produce a wavefront variance that barely exceeds the variance of a wavefront with 0.25 D of defocus. The model eye predicted correcting spherical aberration in the average pseudophakic eye by an amount equivalent to 0.05 D spherical defocus, less than the smallest commonly corrected refractive error (±0.25 D) and less than the smallest perceptible change of blur.[45] Piers et al.,[46] using an adaptive optics simulator, concluded that when spherical aberration is corrected, visual performance is as good as or better than normal spherical aberration for defocus levels as large as ±1.00 D. However, Beiko[47] suggests that some residual spherical aberration after surgery represents a better choice. Two studies[48,49] found that patients with a total postoperative ocular spherical aberration of +0.10 μm had significantly better contrast sensitivity under photopic and mesopic conditions than control patients. After performing theoretical simulations, Wang and Koch[50] concluded that there are 2 main reasons for customizing the asphericity of the IOL. First, there is a wide range of corneal spherical aberration within the population.[51,52] Second, other higher-order corneal aberrations interact with spherical aberration to increase or decrease optical performance.[53] In fact, some residual defocus or astigmatism combined with spherical aberration may produce different outcomes depending on the balance between lower-order aberrations and HOAs. Recently, Packer et al.[54] and Beiko[55] showed that customized selection of aspheric IOLs based on corneal wavefront is feasible and produces favorable results compared with results in patient populations whose aspheric IOLs were not selected based on this parameter. The authors computed corneal spherical aberration from topography and selected the aspheric IOL by taking the desired postoperative ocular spherical aberration into consideration.

Although this review is focused on monofocal IOLs, prolate surfaces have recently been used to design multifocal IOLs.[56–59] The addition of asphericity aims to reduce unwanted visual phenomena associated with multifocal IOL performance and to increase the range of focus, improving image quality. Therefore, good distance and near vision results could be expected due to the asphericity and intermediate vision would be functional. Only 1 study[60] compared the same multifocal IOL model with asphericity and without asphericity (diffractive apodized AcrySof ReSTOR IOL models SN6AD3 and SN60D3, respectively). The study found good high-contrast visual acuity at both distance and near and good contrast sensitivity under photopic and mesopic conditions with both IOL models. However, intermediate vision was significantly better with the aspheric IOL than with the spherical IOL.

Although IOL asphericity can be customized according to corneal spherical aberration and desired postoperative ocular spherical aberration, the following must be taken into account: The pupil in older patients is relatively small (senile miosis), HOAs are dominated by asymmetrical aberrations and thus cannot be compensated for by symmetrical IOL designs, and some tilting or displacement of the IOL and changes in corneal optical aberrations can occur after surgery (increasing asymmetrical aberrations). All these factors may contribute to unexpected visual performance outcomes after aspheric IOL implantation.

Table 2. Peer-reviewed studies evaluating aspheric and spherical IOLs.

	Measurement					
Study*	IOL (Eyes)	BCVA	Photopic CS	Mesopic CS	HOA	SA
Packer[6]	Tecnis (10) and AR40e (11)	No difference	Tecnis significantly better at 6, 12, and 18 cpd (85 cd/m^2)	Tecnis significantly better at 1.5 and 3 cpd (3 cd/m^2)	N/E	N/E
Mester[7]	Tecnis (37) and SI-40 (37)	Tecnis significantly better	Tecnis significantly better at all frequencies (85 cd/m^2)	Tecnis significantly better at all frequencies (6 cd/m^2)	N/E	Significantly higher in SI-40 at 4.0 mm
Kershner[8]	Tecnis (75), SA60AT (41), and AA4207-VF (105)	No difference	Tecnis significantly better at 1.5, 6, and 12 cpd (85 cd/m^2)	Tecnis significantly better at 6, 12 and 18 cpd (3 cd/m^2)	N/E	N/E
Packer[9]	Tecnis (37) and AR40e (39)	No difference	Tecnis significantly better at 3 and 6 cpd (85 cd/m^2)	Tecnis significantly better at 1.5, 3 and 6 cpd (3 cd/m^2)	N/E	N/E
Belluci[10]	Tecnis (5), 911 Edge (5), SA60AT (5), MA60BM (5), and AR40e (5)	N/E	N/E	N/E	No difference	Significantly lower in Tecnis at 4.0 and 6.0 mm
Belluci[11]	Tecnis (30) and SA60AT (30)	Tecnis significantly better	Tecnis significantly better at all frequencies except 1.5 cpd (85 cd/m^2)	Tecnis significantly at all frequencies except 1.5 cpd (6 cd/m^2)	N/E	N/E
Marcos[12]	Tecnis (10) and SA60AT (9)	N/E	N/E	N/E	Significantly lower in Tecnis at 4.5 mm	Significantly lower in Tecnis at 4.5 mm
Kasper[13]	Tecnis (21) and AR40e (21)	No difference	N/E	N/E	Significantly lower in Tecnis at 6.0 mm	Significantly lower in Tecnis at 3.0, 3.5, 4.0, 5.0 and 6.0 mm
Muñoz[14]	Tecnis (30), AR40e (15), and Stabibag (15)	No difference	No difference (80 cd/m^2)	No difference (5 cd/m^2)	No difference	Significantly lower in Tecnis at 4.0 and 6.0 mm
Rocha[15]	AcrySof IQ (40), SN60AT (40), and AR40e (40)	No difference	No difference (85 cd/m^2)	IQ significantly better at 3 cpd (3 cd/m^2)	Significantly lower in IQ at 4.0 and 5.0 mm	Significantly lower in IQ at 4.0 and 5.0 mm
Kasper[16]	Tecnis (20) and AR40e (20)	No difference	No difference (167 cd/m^2)	No difference (1.67 and 0.167 cd/m^2)	No difference (physiological mesopic pupil)	Significantly lower in Tecnis (physiological mesopic pupil)
Padmanabhan[17]	Tecnis (64), MA60BM (32), AR40e (32)	N/E	N/E	N/E	No difference at 6.0 mm	Significantly lower in Tecnis at 6.0 mm
Belluci[18]	Tecnis (30) and 911 Edge (30)	N/E	N/E	N/E	Significantly lower in Tecnis at 4.0 mm	Significantly lower in Tecnis at 4.0 mm

(*continued on next page*)

Table 2 (Cont.)

Study*	Measurement					
	IOL (Eyes)	BCVA	Photopic CS	Mesopic CS	HOA	SA
Denoyer[19]	Tecnis (20) and 911 Edge (20)	No difference	No difference (80 cd/m^2)	Tecnis significantly at 13 and 30 cpd (0.15 cd/m^2)	No difference at 5.0 mm	Significantly lower in Tecnis at 5.0 mm
Kurz[20]	Acri.Smart 36A (52) and Acri.Smart 46 S (25)	No difference	No difference (80 cd/m^2)	N/E	N/E	Significantly lower in Acri.Smart 36A at 4.5 mm
Rocha[21]	AcrySof IQ (35), SN60AT (36), and AR40e (34)	No difference	N/E	N/E	Significantly lower in IQ at 5.0 mm	Significantly lower in IQ at 5.0 mm
Caporossi[22]	SN60AT (50), AR40e (50), Tecnis (50), AcrySof IQ (50), and SofPort (50)	No difference	Tecnis, IQ, and SofPort significantly better at 6, 12, and 18 cpd (85 cd/m^2) No differences between them	Tecnis, IQ, and SofPort significantly better at all frequencies (3 cd/m^2). No differences between them	N/E	Significantly lower in Tecnis, IQ and SofPort at 5.0 mm
Sandoval[23]	AcrySof IQ (28) and SN60AT (25)	No difference	No difference	N/E	Significantly lower in IQ at 5.0 mm	Significantly lower in IQ at 5.0 mm
Awwad[24]	AcrySof IQ (15) and SN60AT (13)	N/E	N/E	N/E	Significantly lower in IQ at 6.0 mm	Significantly lower in IQ at 4.0 and 6.0 mm
Pandita[25]	AcrySof IQ (36), SN60AT (36), and SA60AT (36)	No difference	IQ significantly better at 18 cpd (85 cd/m^2)	IQ significantly better at all frequencies (2.7 cd/m^2)	N/E	N/E
Tzelikis[26]	AcrySof IQ (25) and SN60AT (25)	No difference	IQ significantly better at 18 cpd (85 cd/m^2)	IQ significantly better at all frequencies (5 cd/m^2)	Significantly lower in IQ at 5.0 and 6.0 mm	Significantly lower in IQ at 5.0 and 6.0 mm
Tzelikis[27]	Tecnis (25) and ClariFlex (25)	No difference	Tecnis significantly better at 18 cpd (85 cd/m^2)	Tecnis significantly better at all frequencies (5 cd/m^2)	Significantly lower in Tecnis at 5.0 and 6.0 mm	Significantly lower in Tecnis at 5.0 and 6.0 mm
Awwad[28]	AcrySof IQ (27) and SN60AT (25)	No difference	No difference (85 cd/m^2)	IQ significantly better at 12 and 18 cpd (3 cd/m^2)	Significantly lower in IQ at 4.0, 5.0, and 6.0 mm	Significantly lower in IQ at 4.0, 5.0, and 6.0 mm
Cadarso[29]	AcrySof IQ (20) and SN60AT (20)	No difference	N/E	N/E	Significantly lower in IQ at 6.0 mm	Significantly lower in IQ at 3.0, 4.5, and 6.0 mm
Mester and Kaymak[30]	AcrySof IQ (42) and SN60AT (20)	No difference	IQ significantly better at 3 and 6 cpd (85 cd/m^2)	IQ significantly better at 1.5, 3 and 18 cpd (3 cd/m^2)	Significantly lower in IQ at 5.0 mm	Significantly lower in IQ at 4.0 and 5.0 mm

BCVA = best corrected visual acuity; cd = candelas; CS = contrast sensitivity; cpd = cycles per degree; HOA = higher-order aberrations; N/E = not evaluated; SA = spherical aberration
*First author

Clinical Studies Comparing Aspheric and Spherical Intraocular Lenses

All studies in the peer-reviewed literature that compared the visual and optical performance of eyes with aspheric IOLs and eyes with spherical IOLs were analyzed. The search, which was in progress up until June 2008, was performed using the ISI Web of Knowledge (The Thomson Corp.). Studies included a comparison of different aspheric and spherical IOLs reporting visual acuity, and/or contrast sensitivity, and/or wavefront aberration. These parameters were considered taking into account that asphericity is expected to change ocular spherical aberration and hence visual performance (visual acuity and/or contrast sensitivity). Although some studies evaluated visual quality metrics without wavefront aberrations and vice versa, both types of studies were included in the whole analysis for comparison purposes.

Table 2 shows the studies found in the search[6–30] and the measurements performed in each. Twenty-five studies compared the visual and/or optical outcomes in eyes with aspheric IOLs and eyes with spherical IOLs (2002 to the present). The aspheric IOLs evaluated were the Tecnis Z9000, AcrySof IQ, Acri.Smart 36A (Carl Zeiss Meditec AG), and SofPort AO. The spherical IOLs were the SN60AT (Alcon), Sensar AR40e (Advanced Medical Optics), SA60AT (Alcon), AA4207-VF (Staar Surgical), CeeOn 911 Edge (Pharmacia), MA60BM (Alcon), SI-40 (Allergan), Acri.Smart 46S (Zeiss), ClariFlex (Advanced Medical Optics), and Stabibag (Zeiss). Table 3 shows the number of eyes with each type of IOL. Of the 1861 IOLs evaluated, 914 were aspheric and 947 spherical.

Visual Acuity Only 2 studies (Mester et al.[7] and Belluci et al.[11]) found better best corrected visual acuity (BCVA) in eyes with an aspheric IOL than in eyes with a spherical IOL. In both studies, the Tecnis aspheric IOL was compared with the spherical SI40 IOL and SA60AT IOL. However, other comparisons between the Tecnis IOL and SA60AT IOL[8,15] and the Tecnis and other spherical IOLs (AR40e,[6,9,13,14,16] AA4207-VF,[8] Stabibag,[14] MA60BM,[10] 911 Edge,[19] ClariFlex[27]) did not find statistically significant differences. Thus, although the results of the spherical IOLs compared in the 2 studies[7,11] were different in general terms, 18 studies evaluated the same IOL (Tecnis) and other aspheric IOLs (AcrySof IQ, Acri.Smart 36A, SofPort AO) and did not find statistically significant differences in BCVA between aspheric IOLs and spherical IOLs (Table 3). Five of these studies did not report BCVA outcomes. From the studies, it may be concluded that no visual acuity differences are found between aspheric and spherical IOLs or that visual performance metrics used (high-contrast photopic BCVA measurement) are not accurate enough to detect subtle visual changes due to spherical aberration reduction by asphericity.

Table 3. Number of eyes for each IOL type.

IOL Type	Number of Eyes
Aspheric	
Tecnis	494
AcrySof IQ	318
Acri.Smart 36A	52
SofPort AO	50
Spherical	
SN60AT	290
AR40e	267
SA60AT	121
AA407-VF	75
911 Edge	55
MA60BM	37
SI-40	37
Acri.Smart 46S	25
Clariflex	25
Stabibag	15

Photopic Contrast Sensitivity The visual performance index that most usefully documents human spatial vision is contrast sensitivity function, which plots the reciprocal of the threshold contrast for sinusoidal gratings as a function of their spatial frequency. It thus gives information on visual performance for a range of object scales. Seventeen studies evaluated photopic contrast sensitivity (Table 2). Ten studies of the Tecnis aspheric IOL reported photopic contrast sensitivity (80 to 167 candelas [cd]/m^2); 7 found significantly better outcomes with the Tcnis IOL than with spherical IOLs (AR40e,[6,9,22] SI40,[7] SA60AT,[8,11] AA4207-VF,[8] SN60AT,[22] ClariFlex[27]), and 3 found no significant differences at any spatial frequency (AR40e,[14,16] Stabibag,[14] 911 Edge[19]). In studies reporting differences, the differences were dependent on the spatial frequency analyzed (1.5 cpd,[7,8] 3 cpd,[7,9,11] 6 cpd,[6–9,11,22] 12 cpd,[6–8,11,22] and 18 cpd[6,7,11,22,27]). Only 1 study[7] found that photopic contrast sensitivity with the Tecnis IOL was significantly better at all spatial frequencies. Studies with differences between IOLs found them at medium (85%) and high (71%) spatial frequencies. Differences in the material and design of spherical IOLs between studies may play a role in the significant differences found. However, studies were also performed with the same spherical IOL model (AR40e) (ie, same material and design); some found significant differences[6,9,22] between the AR40e IOL and the aspheric IOL and some did not.[14,16] Of the 7 studies reporting photopic contrast sensitivity (85 cd/m^2) with the AcrySof IQ IOL, 3 found no statistically significant differences at any spatial frequency compared with the SN60AT IOL[15,23,28] and AR40e IOL[15] and 4 found differences compared with the spherical SN60AT IOL,[22,25,26,30] AR40e IOL,[22] and SA60AT[25] IOL at 3 cpd,[30] 6 cpd,[22,30] 12 cpd,[22] and 18 cpd.[22,25,26] Similar to the Tecnis IOL studies, these studies found contradictory outcomes (AcrySof IQ versus SN60AT[15,22,25,26,28,32] and AcrySof IQ versus AR40e[15,22]). The only study evaluating the aspheric Acri.Smart 36A IOL[22] did not find statistically significant differences under photopic conditions compared with the spherical Acri.Smart 46S IOL. In contrast, the SofPort AO IOL was found to be significantly better than spherical SN60AT and AR40e IOLs at 6 cpd, 12 cpd, and 18 cpd.[22]

Mesopic Contrast Sensitivity The results under mesopic conditions also vary between studies. Nine studies evaluated the Tecnis IOL and mesopic contrast sensitivity. Muñoz et al.[14] and Casper et al.[16] found no statistically significant differences in mesopic contrast sensitivity (0.167 to 5 cd/m^2 at any spatial frequency between the Tecnis IOL and spherical AR40e and Stabibag IOLs and AR40e IOL, respectively). Others studies report significantly better mesopic contrast sensitivity (0.15 to 6 cd/m^2) outcomes with the Tecnis IOL at 1.5 cpd,[6,7,9,22,27] 3 cpd,[6,7,9,11,22,27] 6 cpd,[7–9,11,22,27] 12 cpd,[7,8,11,22,27] 13 cpd,[19] 18 cpd,[7,8,11,22,27] and 30[19] cpd than with AR40e,[6,9,13] SI-40,[6] SA60AT,[8,11] AA4207-VF,[8] 911 Edge,[18] and ClariFlex[27] IOLs. Six studies evaluated the AcrySof IQ IOL. All found significant differences, specifically at 1.5 cpd,[22,25,26,30] 3 cpd,[15,22,25,26,30] 6 cpd,[22,25,26] 12 cpd,[22,25,26,28] and 18 cpd,[22,25,26,28,30] compared with SN60AT,[15,22,25,26,28,30] SA60AT,[25] and AR40e[15] IOLs. A study by Caporossi et al.[22] found significantly better results with the aspheric SofPort AO IOL than with spherical SN60AT and AR40e IOLs at all spatial frequencies (3 cd/m^2).

A comparison of the contrast sensitivity results for all aspheric IOLs showed less contradictory outcomes between studies under mesopic conditions. Differences between aspheric and spherical IOLs were more consistent when lighting conditions were reduced and pupil diameter was increased. This is an expected result considering the reduction in ocular spherical aberration with large pupil diameters with an aspheric IOL compared with that with a spherical IOL.

Ocular Aberrations Eleven studies evaluated ocular aberrations after Tecnis IOL implantation. Bellucci et al.,[10] Muñoz et al.,[14] Kasper et al.,[16] Padmanabhan et al.,[17] and Denoyer et al.[19] did not find statistically significant differences in HOAs between the Tecnis IOLs and several spherical IOLs (911 Edge,[10,19] SA60AT,[10] MA60BM,[10,17] AR40e,[10,14,16,17] Stabibag[14]). However, Marcos et al.[12] at 4.5 mm, Kasper et al.[13] at 6.0 mm, Bellucci et al.[18] at 4.0 mm, and Tzelikis et al.[27] at 5.0 mm and 6.0 mm found significantly lower HOAs in eyes with the Tecnis IOL than in eyes with spherical IOLs (SA60AT,[12] AR40E,[13] 911 Edge,[18] ClariFlex).[27] Eight studies of the aspheric AcrySof IQ IOL found lower HOAs than with spherical IOLs (Rocha et al. at 4.0 mm[15] and 5.0 mm[15,21]; Sandoval et al.[23] at 5.0 mm; Awwad et al.[24] at 6.0 mm; Tzelikis et al.[26] at 5.0 mm and 6.0 mm; Awwad et al.[28] at 4.0 mm, 5.0 mm, and 6.0 mm; Cadarso et al.[29] at 6.0 mm; Mester and Kaymak[30] at 5.0 mm). No data were available for the other 2 aspheric IOLs (SofPort AO and Acri.-Smart 36A). Findings generally indicate that a reduction in HOAs after aspheric IOL implantation occurs when the pupil is at least 4.0 mm in diameter. Large differences between spherical IOLs and aspheric IOLs are found with larger pupils (ie, 5.0 mm and 6.0 mm). As previously discussed, decentration and/or tilt and a combination of different aberrations may contribute to the high level of the reduction in HOAs with aspheric IOLs.

All the studies found significantly lower spherical aberration values with the aspheric IOLs (Tecnis, AcrySof IQ, Acri.Smart 36A, and SofPort AO). However, these differences were significant only with some pupil sizes: the Tecnis at 3.0 mm,[13] 3.5 mm,[13] 4.0 mm,[7,10,13,14,18] 4.5 mm,[12,13] 5.0 mm,[13,19,22,27] and 6.0 mm[10,13,14,17,27]; the AcrySof IQ at 3.0 mm,[29] 4.0 mm,[15,24,28,30] 4.5 mm,[29] 5.0 mm,[15,21–23,26,28,30] and 6.0 mm[24,26,28]; the Acri.Smart 36A at 4.5 mm[20]; and the SofPort AO at 5.0 mm.[22] It can be concluded that all aspheric designs reduce ocular spherical aberration; however, some studies found little or no benefit of aspheric designs in terms of spherical aberration reduction in eyes with smaller pupils. Table 4 shows the postoperative ocular spherical aberration after aspheric IOL implantation. The table shows the mean coefficient for the postoperative ocular spherical aberration found in previous studies[7,10,12–15,17–24,26–30] as a function of pupil diameter. A detailed analysis of values that are comparable (for the same pupil) showed a wide variation in postoperative ocular spherical aberration values. For example, after Tecnis IOL implantation, values ranged from 0.005 to 0.050 μm at 4.0 mm, 0.01 to 0.05 μm at 5.0 mm, and −0.03 to 0.08 μm at 6.0 mm. After AcrySof IQ implantation, the values ranged from −0.04 to 0.02 μm at 4.0 mm, 0.01 to 0.20 μm at 5.0 mm, and 0.02 to 0.11 μm at 6.0 mm. Residual ocular spherical aberration variability may be the result of different corneal spherical aberration. However, if the largest pupil diameter (6.0 mm) is

Table 4. Ocular spherical aberration values Z(4,0) with aspheric IOLs as a function of the pupil diameter.

	Mean Spherical Aberration ± SD* (μm)				
IOL/Study†	3.0 mm Pupil	4.0 mm Pupil	4.5 mm Pupil	5.0 mm Pupil	6.0 mm Pupil
Tecnis					
Mester[7]	—	0.007 ± 0.031	—	—	—
Belluci[10]	—	0.005 ± 0.017	—	—	0.018 ± 0.024
Marcos[12]	—	—	−0.008 ± 0.049	—	—
Kasper[13]	0.006	—	—	—	0.089
Muñoz[14]	—	0.005 ± 0.035	—	—	−0.032 ± 0.285
Padmanabhan[17]	—	—	—	—	0.07 ± 0.12
Belluci[18]	—	0.05	—	—	—
Denoyer[19]	—	—	—	0.01 ± 0.06	—
Caporossi[22]	—	—	—	0.05 ± 0.06	—
Tzelikis[27]	—	—	—	0.01 ± 0.02	0.024 ± 0.030
AcrySof IQ					
Rocha[15,21]	—	−0.0008 ± 0.05	—	0.03 ± 0.05	—
Caporossi[22]	—	—	—	0.11 ± 0.10	—
Sandoval[23]	—	—	—	0.20 ± 0.03	—
Awwad[24]	—	−0.04 ± 0.03	—	0.09 ± 0.04	—
Tzelikis[26]	—	—	—	0.014 ± 0.02	0.026 ± 0.034
Awwad[28]	—	−0.01 ± 0.03	—	0.03 ± 0.02	0.09 ± 0.04
Cadarso[29]	−0.006 ± 0.024	0.001 ± 0.035	—	0.031 ± 0.067	0.114 ± 0.147
Mester[30]		0.02 ± 0.04	—	0.04 ± 0.05	—
Acri.Smart					
Kurz[20]	—	—	−0.09	—	—
SofPort AO		—			
Caporossi[22]	—	—	—	0.19 ± 0.08	—

*When reported
†First author

considered, residual spherical aberration with the Tecnis IOL is approximately 0.0 μm and with the AcrySof IQ, approximately +0.1 μm. If we consider that the spherical aberration of the IOL with a 6.0 mm pupil is −0.27 μm for the Tecnis and −0.20 μm for the AcrySof IQ (Table 1), the clinical residual spherical aberration values are similar to those expected theoretically. In the case of the SofPort AO IOL (spherical aberration 0.0 μm), the residual ocular spherical aberration should have the largest positive value; that is, approximately 0.2 μm for a 5.0 mm pupil.[22] The result for the Acri.-Smart IOL, which is designed to cancel the full spherical aberration of the cornea, was approximately 0.0 μm for a 4.5 mm pupil.[20] Therefore, in general terms and despite the variability, the theoretical expectations of designing an aspheric IOL with a specific asphericity to cancel, reduce, or maintain ocular spherical aberration after implantation were achieved. The goal of all 3 strategies of the aspheric IOLs evaluated is to provide the best optical and visual benefits for patients.

Packer et al.[54] recently showed that customized selection of aspheric IOLs based on corneal wavefront is feasible and produces favorable results compared with results in patient populations with aspheric IOLs that were not selected on this basis. Packer et al. created a protocol, including corneal spherical aberration computation, to choose the aspheric IOL based on the desired ocular spherical aberration. Using corneal spherical aberration as a criterion, Beiko[55] suggests that the best aspheric IOLs to achieve an ocular spherical aberration target of +0.10 μm are as follows: for a value between −0.15 and +0.15 μm, SofPort AO or ClariFlex; for +0.16 to +0.33 μm, AcrySof IQ; and for more than +0.33 μm, Tecnis. The findings in the present review agree with both studies; that is, surgeons should combine the spherical aberration of the cornea with the spherical aberration of the IOL to obtain the best optical quality.

DISCUSSION

Most analysis of whether aspheric IOLs have benefits over spherical IOLs has been performed by theoretical and physical eye modeling, not with measurements of the visual performance (visual acuity and contrast sensitivity) in eyes with these IOLs. The present review clearly shows the variability in results. The main source of the discrepancies between studies of aspheric IOLs is probably the difference in corneal spherical aberration in the eyes with the IOLs. In no study reported here was corneal spherical aberration computed before surgery to choose the best asphericity to reduce postoperative ocular spherical aberration and thus improve visual performance.

An important limitation to the benefits of reducing spherical aberration is the degree of correction of defocus and astigmatism. Although the benefit to visual performance has been discussed, it is clear that the optical advantages of aspheric IOLs over spherical IOLs are especially related to pupil size, IOL tilt and/or decentration, depth of focus, and customization to a specific corneal spherical aberration. The potential benefits of aspheric IOLs are limited by inaccurate or absent preoperative measurement of the ocular parameters necessary for IOL power calculation, inaccurate manufacturing, inability to locate the IOL in the correct plane, and surgically induced aberrations. However, the optical and visual performance of aspheric IOLs is, even in the worst cases, equal to or better than that with spherical IOLs. Surgeons should consider aspheric IOLs for patients and try to customize the asphericity depending on the patient's corneal spherical aberration to obtain the optimum visual performance.

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