Ⅱ．手術の目的と手術法の選択

1．手術の目的

上述のごとく，学童期以後は，視機能の回復を期待して行うが，それ以前は，弱視予防のために行う。そのため，学童以前の白内障手術では，視軸上の混濁を除去し，透明性を維持することが重要になる。すなわち，後発白内障のような混濁も視機能発達時期の乳幼児には，白内障と同様に弱視のリスクになる。ある程度の年齢であれば，後発白内障によって視機能が低下して数ヶ月以上放置されていても，適切な処置を行うことで視機能は回復する。しかし，例えば，生後6ヶ月で，後発白内障による視軸の混濁が特に片眼に強く生じてしまい数ヶ月も放置されれば，強固な弱視の誘因となる。

2．手術法の選択

白内障の手術方法としては，小児には硬い核がないため，吸引で除去が可能である。水晶体後嚢を残すと，後発白内障がほぼ必発である。成人であればYAGレーザーによる後嚢切開術で対応が可能であるが，6歳以下の小児では，後嚢切開を行えたとしても前部硝子体が混濁することが多く，後嚢切除，前部硝子体切除が必要となる[2]。従って，6歳以下の症例では，基本的に白内障除去の際に後嚢切除，前部硝子体切除を合わせて行い透明性の維持をはかる。

3．術後矯正

術後矯正としては，眼鏡・コンタクトレンズ・眼内レンズがある。眼内レンズの光学的な有用性，利便性は，成人では確立しているが，小児には，成人にはないいくつかの問題点がある（表5）。一つは，乳幼児，特に3歳未満は，成長に伴う眼球の変化（眼軸長が長くなる）が大きく，術後の矯正に要する度数が変化する[3]。コンタクトレンズや眼鏡であれば作り変えれば済むが，眼内レンズでは，現実的には，摘出・再挿入は無理なので屈折状態の変化には対応できない。この度数の変化は，低年齢時に挿入すればするほど大きく，また，症例ごとのばらつきも大きく予想は困難である。また，眼内レンズを挿入する分，切開創は大きくなり，炎症が増加するとともに，眼球打撲などへの抵抗力が減弱する。成人でも生じる眼内レンズに伴うレンズ偏位，瞳孔異常などは，小児では外科的な整復が困難なことが多い。また，眼内レンズ挿入により後発白内障が増加することが，特に生後6ヶ月未満で顕著であることが報告されている（表6）。

表5 小児における眼内レンズ挿入の長所・短所

●長 所
コンタクトレンズ管理からの開放
屈折矯正のコンプライアンスの向上
経済的負担が少ない
緑内障の発生が少ない？
●短 所
度数変更ができない（眼軸長の変化に対応できない）
術後炎症が強くなる
後発白内障が生じやすい
瞳孔捕獲など合併症を生じた場合の対応が難しい

表6 生後6ヶ月以内に手術したコンタクトレンズでの矯正眼と眼内レンズ挿入眼での再手術

手 術	コンタクトレンズ装用（11眼）	眼内レンズ挿入眼（10眼）
後発白内障	0/0	8/7*
緑内障	0/0	2/2
IOL 2次挿入・交換	4/4	2/1*
計	4/4	12/10

（文献4より改変して引用）
* 1眼で2度の再手術が行われた（著者追加）

Ⅲ．眼内レンズ挿入の是非

眼内レンズ挿入は，時に重篤な障害をもたらすものの，経過が良好な場合には，コンタクトレンズ管理，術後の視能矯正，眼鏡に伴う視野の制限や外見上の問題などを解決するものとして優れた点がある。ただ，加齢によって生じた白内障とは異なり，成長期にある水晶体が混濁した白内障眼では，眼球形成，視機能形成が未熟な部分が残る分，また，通常の診察が難しく十分な検査ができにくく，異常の発見が遅れがちなことも危惧される点である。以前は，小児に眼内レンズを挿入することは，ほとんど行われていなかったが，成人の白内障手術成績が安定化するとともに小児にも眼内レンズを挿入する施設が増加している。ただ，6歳未満の小児の場合，前述のごとく後発白内障をYAGレーザーで対応できない点，乳幼児例であればあるほど，前嚢切開が流れやすくCCCを完成することが難しい点[5]などから，小児の特殊性を理解した上での手術が必須となる。これらを踏まえた上での手術適応は2歳以上とする施設も多い。一方，限られた施設では，1歳未満や

生後6ヶ月以内での眼内レンズ挿入を行っている。ただ，生後6ヶ月以内であると，水晶体自体の大きさがかなり小さく[6]，また，例え後嚢切除，前部硝子体切除を行ってもかなり高率に後発白内障による追加手術が必要になるとの報告[1]があり，その適応には議論が多い。十分な小児の眼の特殊性を理解の上，かなり高度なテクニックや特別な対応法に習熟し，さらに術後の十分なケアができる場合にのみ行うべきであると考える。

Ⅳ．術後のケア

手術合併症としては，眼内レンズを挿入しない場合には，手術時に水晶体前嚢・後嚢を十分に切除し，前部硝子体を切除することで後発白内障の発生をほぼ抑えることが可能である。術後の炎症についても，基礎疾患の無い場合には，ステロイド剤，非ステロイド性消炎剤，散瞳剤などによりコントロールできることが多い。長期的には，緑内障・網膜剝離の可能性があり，特に緑内障は，初回手術後10年以上の経過後にも発生することが報告されており，小眼球など未熟性のある眼の場合には特に注意深く定期的に長期間にわたる経過観察が必要になる[7]。

眼内レンズを挿入した場合には，術後の炎症がときに強くなることがあり，また，上述のごとく低年齢であればあるほど，後発白内障も強く生じてくる可能性がある。乳幼児では，後発白内障が，弱視形成のリスクとなるため速やかな処置が必要で，定期的な診察とすぐに対応ができるための準備を行っておく必要がある。眼内レンズ挿入眼で，緑内障が多くなるのか低くなるのか，結論は出ていない。長期にわたる経過観察が必要である（図2）。

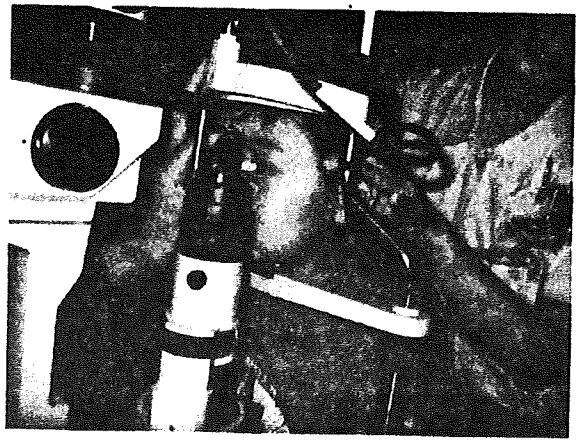

図2　小児での眼圧測定
3歳を過ぎたころから細隙顕微鏡検査および圧平眼圧計を用いた眼圧測定が可能になる。

術後矯正は，患児の年齢によって，弱視を予防するため，もしくは弱視治療のために必要となる。たとえ眼内レンズを挿入した場合でも，コンタクトレンズや眼鏡の装用が必要になることが多い。また，片眼症例では，健眼遮蔽も年齢によっては必須である。これらの適切な術後治療無しには，乳幼児の視機能発達は望めなく，小児白内障の手術を行う意味もなくなってしまうことを，医療・患者の両親サイドもよく認識しておくことが重要である。

おわりに

小児の白内障手術は，手術時，術後の反応，ケアのポイントなどで成人と異なる点があり，この点の理解無しには，治療は成功しない。さらに発達期にある眼は，術後も長期にわたり変化していくので，治療をする場合には，その点を家族・本人にも自覚させ，自身も責任を持って経過観察できる体制を整えて手術に臨むことが大切である。

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One-Year Prospective Intrapatient Comparison of Aspherical and Spherical Intraocular Lenses in Patients with Bilateral Cataract

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• PURPOSE: To conduct longitudinal, intrapatient comparisons of aspherical and spherical silicone intraocular lenses (IOL) of the same material and platform in patients undergoing bilateral cataract surgery.

• DESIGN: Prospective, randomized study.

• METHODS: Sixty-two eyes of 31 patients were randomized to receive a silicone aspherical IOL (Tecnis Z9000; AMO Inc, Santa Ana, California, USA) in 1 eye and a silicone spherical IOL (CeeOn 911A; AMO Inc) in the other eye. Best spectacle-corrected visual acuity (BSCVA); corneal and ocular wavefront aberrations; contrast sensitivity under photopic (180 lux), intermediate (75 lux), and scotopic (15 lux) illumination; amount of IOL decentration and tilt; and degree of posterior capsular opacification were measured at 1, 3, 6, and 12 months after surgery. All-distance visual acuity (VA) was measured 3 months after surgery.

• RESULTS: There were no significant differences between IOLs with regard to BSCVA, amount of IOL decentration and tilt, degree of posterior capsule opacification, and all-distance VA at any point after surgery. Regarding corneal wavefront aberrations, there was no difference in third- and fourth-order root mean square (RMS). In ocular wavefront aberrations, aspherical IOLs showed significantly lower fourth-order RMS ($P < .001$) than spherical IOLs throughout the study, but not in third-order RMS. Contrast sensitivity under photopic and mesopic conditions was not different between IOLs, but contrast sensitivity under scotopic conditions was significantly better with aspherical IOLs than with spherical IOLs ($P < .01$) at all measurement points.

• CONCLUSIONS: The silicone aspherical IOL (Tecnis Z9000; AMO Inc) significantly reduced ocular spherical aberration and improved scotopic contrast sensitivity, and these results were consistent through the 1-year follow-up. (Am J Ophthalmol 2009;147:984–989. © 2009 by Elsevier Inc. All rights reserved.)

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IN YOUNG PHAKIC EYES, THE CORNEA HAS A POSITIVE spherical aberration that is balanced by the negative spherical aberration resulting from the asphericity of a natural crystalline lens.[1] Because positive spherical aberration of the cornea is maintained throughout life,[1] implantation of a spherical intraocular lens (IOL) after cataract surgery tends to increase the overall positive spherical aberration of the eye. Increases in spherical aberration of the eye are associated with decreases in contrast sensitivity.[2]

A silicone aspherical IOL, the Tecnis Z9000 (AMO Inc, Santa Ana, California, USA), was developed to compensate for positive spherical aberration of the cornea and to minimize total ocular spherical aberration after IOL implantation.[3] Several studies have demonstrated that the aspherical Tecnis Z9000 IOL successfully decreases ocular spherical aberration and improves contrast sensitivity, as well as quality of vision, compared with traditional spherical IOLs.[4–9] In these studies, however, aspherical and spherical IOLs were evaluated in different individuals, and similarity of corneal aberration was not confirmed before comparing ocular aberration between IOLs. It has been known that the amount of ocular and corneal aberrations varies widely among subjects.[10–12] Moreover, very few studies evaluated aspherical and spherical IOLs made of same material and platform manufactured by a same company. Although short-term outcomes of aspherical IOLs have been reported, long-term results of aspherical IOLs have not been examined in detail. We conducted 1-year prospective study to compare silicone aspherical and spherical IOLs of same material and platform. Patients with bilateral cataract received a spherical IOL in 1 eye and an aspherical IOL in the contralateral eye, so that intraindividual comparison could be carried out.

METHODS

THIS STUDY COMPRISED 31 PATIENTS (11 MALES AND 20 females) scheduled to undergo bilateral cataract surgery. The mean patient age was 70.5 ± 6.3 years (mean ± standard deviation [SD]). They were selected from consecutive cases among the clinic population who matched our inclusion criteria. None of the eyes had any history of

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previous ocular surgery. Eyes were not included if they had any ocular diseases that might affect surgical outcomes.

We used a silicone aspherical IOL (Tecnis Z9000; AMO Inc) and a spherical IOL (CeeOn 911A; AMO Inc). Both IOLs are made of same material and are based on a similar design, except for the asphericity of the optic. One eye of a patient was assigned to receive an aspherical IOL, and the contralateral eye was assigned to receive a spherical IOL. The assignment was determined randomly using an envelope method. All cataract surgery, consisting of phacoemulsification and IOL implantation through a 3.0-mm scleral incision, was performed by 1 surgeon (Ka.M.) using identical surgical methods for each eye within 1 week.

At 1, 3, 6, and 12 months after surgery, best spectacle-corrected visual acuity (BSCVA), corneal and ocular wavefront aberration, contrast sensitivity under 3 illumination levels, amount of IOL decentration and tilt, and the degree of posterior capsular opacity (PCO) were assessed. All-distance visual acuity (VA) was measured 3 months after surgery. All measurements were conducted by masked examiners who were unaware of the assignment of eyes.

Higher-order wavefront aberrations were measured with the Hartman-Shack wavefront analyzer KR-9000PW (Topcon, Tokyo, Japan), and corneal and ocular aberrations were evaluated for a 4-mm diameter pupil.[13,14] The root mean square (RMS) values of the third- and fourth-order aberrations were calculated.

Contrast sensitivity was assessed with the Functional Acuity Chart Test (Stereo Optical, Chicago, Illinois, USA) under scotopic (15 lux), mesopic (70 lux), and photopic (180 lux) illuminations. The test was performed monocularly with undilated pupils at 2.5 m with full spectacle correction. Mean area under the log contrast sensitivity function was calculated.[15]

The Anterior Segment Analysis System (NIDEK EAS-1000, Gamagori, Japan) was used to quantify the amount of IOL decentration and tilt, as well as the degree of PCO. For decentration and tilt, 4 Scheimpflug images of the IOL were obtained after full mydriasis at slit angles of 0, 45, 90, and 135 degrees with a charge-coupled device camera. The tilt angle of the IOL optic axis relative to the visual axis was quantified by the image analysis computer, and the length of decentration was indicated by the distance between the IOL optic vertex and the visual axis.[16,17] The degree of PCO was analyzed using Scheimpflug slit images of 4 sections from 0 to 135 degrees. The mean density of the central 3 mm on the posterior capsular area was derived by densitometry, and the scatter light density was expressed as the computer-compatible tape steps.[18,19]

All-distance VA was measured using an all-distance vision tester (AS-15; KOWA, Tokyo, Japan).[20,21] With full distance correction, decimal VA at 5.0, 1.0, 0.7, 0.5, and 0.3 m was recorded. This device measures equivalent VA from far to near distances by adding various diopters of spherical lens on a screen.

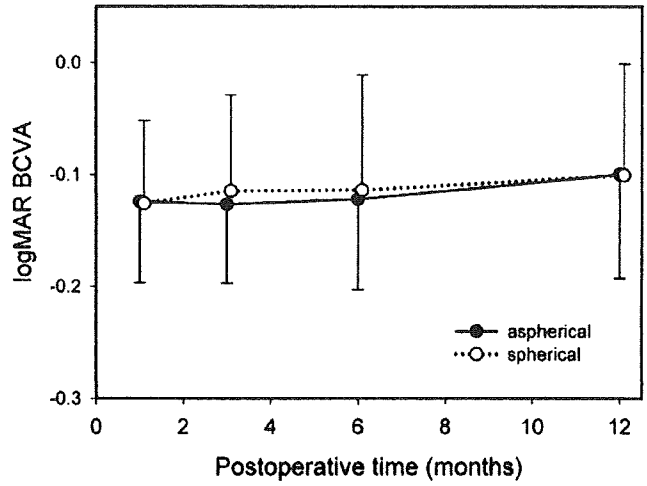

FIGURE 1. Graph showing the time course of changes in logarithm of minimum angle of resolution (logMAR) units of best spectacle-corrected visual acuity after implantation of aspherical and spherical intraocular lenses (IOL).

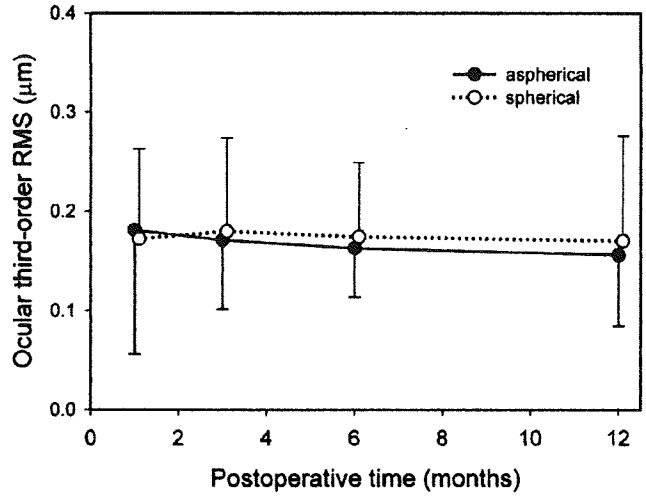

FIGURE 2. Graph showing the time course of changes in third-order root mean square (RMS) of ocular aberration after implantation of aspherical and spherical IOLs.

Intraindividual differences between eyes with spherical and aspherical IOLs were analyzed statistically using the paired *t* test. Level of significance was set at less than 5% ($P < .05$). All data are reported as mean ± SD, unless otherwise specified.

RESULTS

THE NUMBER OF PATIENTS EXAMINED AT EACH POSTOPERative follow-up was 31 patients at 1 and 3 months, 26 patients at 6 months, and 22 patients at 12 months. Mean

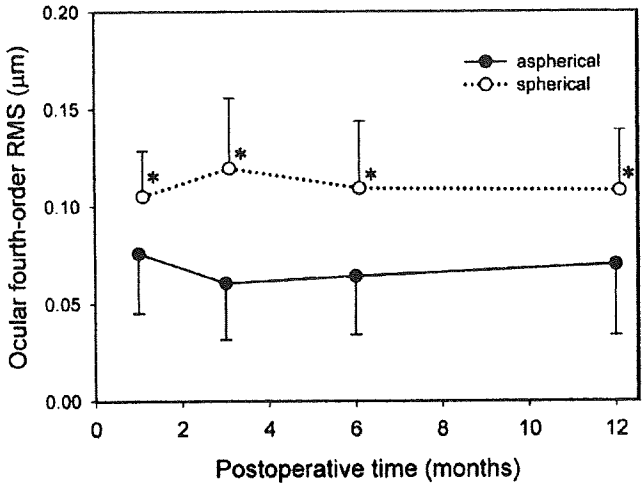

FIGURE 3. Graph showing the time course of changes in fourth-order RMS of ocular aberration after implantation of aspherical and spherical IOLs. *Significantly different between groups ($P < .001$, paired t test).

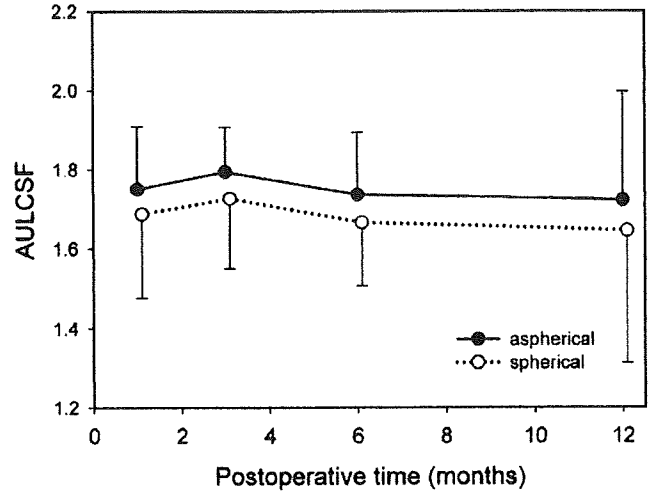

FIGURE 5. Graph showing the time course of changes in contrast sensitivity function (AULCSF) under mesopic conditions (70 lux) after implantation of aspherical and spherical IOLs.

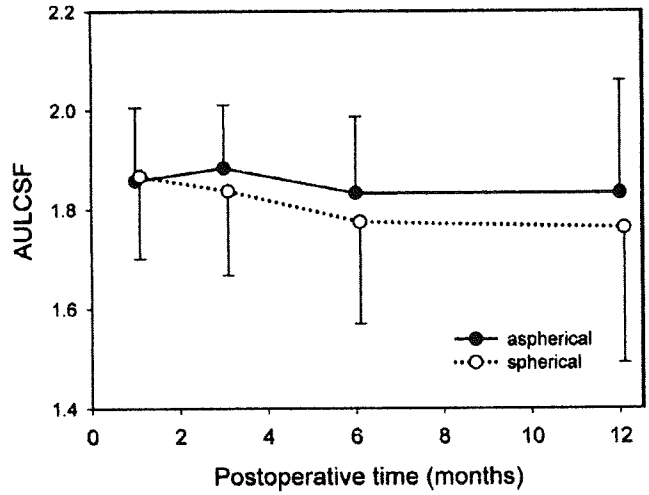

FIGURE 4. Graph showing the time course of changes in contrast sensitivity function (area under the log contrast sensitivity function [AULCSF]) under photopic conditions (180 lux) after implantation of aspherical and spherical IOLs.

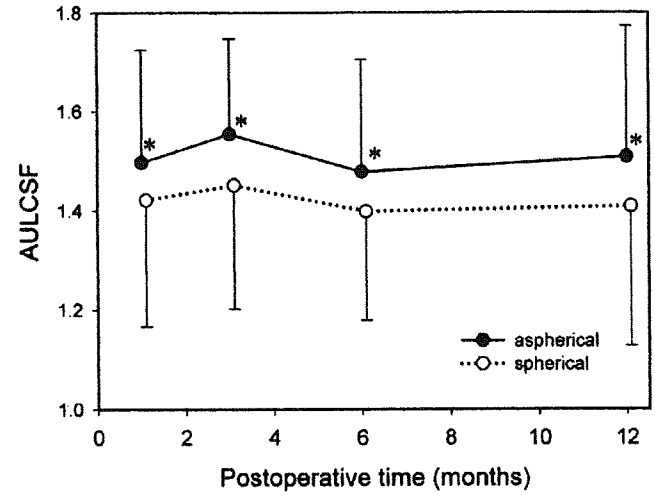

FIGURE 6. Graph showing the time course of changes in contrast sensitivity function (AULCSF) under scotopic conditions (15 lux) after implantation of aspherical and spherical IOLs. *Significantly difference between groups ($P < .01$, paired t test).

preoperative pupil diameters under scotopic conditions (3 lux) were 5.5 ± 0.8 mm for both groups.

The time course of changes in logarithm of minimum angle of resolution BSCVA is shown in Figure 1. BSCVA was stable during the study, and there was no statistically significant difference between groups.

Regarding corneal wavefront aberration, there was no difference in third- or fourth-order RMS throughout the 1-year follow-up. In ocular wavefront aberration, there was no significant difference in third-order RMS (Figure 2), but fourth-order RMS was significantly lower in the aspherical IOL group than in the spherical IOL group ($P < .001$; Figure 3).

Contrast sensitivity under photopic (Figure 4) and mesopic (Figure 5) conditions did not differ between groups at any measurement points. Contrast sensitivity under scotopic illumination (Figure 6) was significantly better with the aspherical IOL than with the spherical IOL on all postoperative visits ($P < .01$).

Mean IOL decentration and tilt were approximately 0.2 mm and 2 degrees, respectively, in both groups, which did not fluctuate significantly for 1 year. There was no significant increase in the degree of PCO for either group during the study. There were no significant intergroup differences in these parameters.

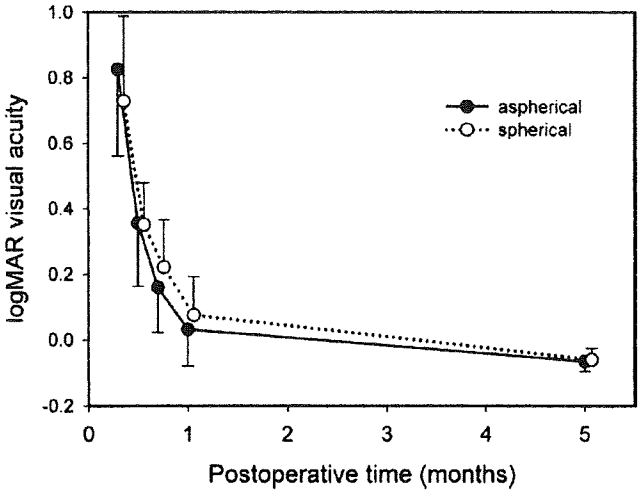

FIGURE 7. Graph showing the measurement results of all-distance vision tester after implantation of aspherical and spherical IOLs. Visual acuity at 0.3, 0.5, 0.7, 1.0, and 5.0 m with full distance correction was not significantly different between groups.

Results of the all-distance vision tester are shown in Figure 7. VA at 0.7 and 1.0 m with full distance correction was slightly worse in the aspherical IOL group than in the spherical IOL group, but the difference did not reach statistical significance.

DISCUSSION

AS SHOWN IN THE RESULTS, OCULAR SPHERICAL ABERRATION was significantly smaller with the aspherical IOL (Tecnis Z9000; AMO Inc) than with the spherical IOL (CeeOn 911A; AMO Inc). Moreover, scotopic contrast sensitivity was significantly better in the aspherical IOL group than in the spherical IOL group. These results are consistent with those of previous studies.[4–8] However, a study by Kasper and associates showed no difference in contrast sensitivity measured with the Frankfurt-Freiburg contrast sensitivity test system on black-and-white display under illuminations of 10, 1, and 0.01 lux.[22] Their study design was intraindividual comparison of aspherical and spherical IOLs, as in the current study. In their study, however, the optic material and design were different between the IOLs: silicone aspherical IOL (AMO Tecnis Z9000) vs acrylic spherical IOL (AMO Sensar AR40e). Such differences in IOL materials and design and measurement methodology might have contributed to the discrepancy between our and their studies. If design and material of IOLs are different, stability of those lenses in the eye may be different. Such a possibility cannot be ruled out unless postoperative decentration and tilt are measured.

We assessed the postoperative stability of IOLs for 1 year. It was shown that decentration and tilt of both IOLs were minimum and stable throughout the 1-year study. Mean decentration remained at approximately 0.2 mm and tilt remained at approximately 2 degrees. Previous studies discussing the sensitivity of the Tecnis IOL to tilt and decentration reported that for a 5-mm pupil, this lens can be decentered 0.3 or 0.4 mm and tilted as much as 7 degrees before its performance drops below that of a spherical IOL.[3,23] The decentration and tilt in our patients were below these thresholds, and thus the aspherical Tecnis IOL was effective in compensating corneal spherical aberration and reducing ocular spherical aberration throughout the 1-year study. Moreover, the amounts of decentration and tilt were similar between the aspherical and spherical IOLs. These data support the fact that both IOLs are made of same material based on the same platform manufactured by the same company, resulting in similar physical and anatomic outcomes. With similar mechanical stability in the eye, the current study could evaluate solely the difference in optical characteristics of the IOLs, asphericity of the optic.

In general, the difference in visual function after implantation of aspherical and spherical IOLs is rather small. Moreover, the amount of ocular and corneal aberrations varies widely among subjects.[10–12] There have been few studies that assessed corneal aberration before comparing ocular aberration in eyes with aspherical and spherical IOLs. Thus, a meticulous study design is needed to compare these 2 IOLs strictly in clinical settings. Until now, there have been only 2 studies that made significant efforts to reduce the bias that can occur in comparative clinical studies of aspherical and spherical IOLs, by making the study an intraindividual comparison, using the same IOL material manufactured by the same company, and having the same surgeon perform bilateral surgery within 1 week using an identical surgical technique.[24,25] It was demonstrated that postoperative VA did not differ between the aspherical and spherical IOLs, but there were significant between-group differences in contrast sensitivity, especially under mesopic conditions, in AcrySof IQ (Alcon Laboratories Inc, Fort Worth, Texas, USA) vs the AcrySof Natural IOLs[24] and silicone Tecnis Z9001 vs ClariFlex IOLs (AMO Inc).[25] In the current study, we found similar results using a different pair of aspherical and spherical IOLs, silicone Tecnis ZA9000 vs CeeOn 911A. Our study represents the first intraindividual comparative study that confirmed the similarity of corneal aberration in both eyes and concluded that the difference in ocular spherical aberration was attributable to the different asphericity of IOLs.

We compared all-distance VA between aspherical and spherical IOLs. Theoretically, spherical aberrations increase depth of focus, but decrease modulation transfer function at high spatial frequencies at optimum focus.[26] Spherical aberrations, therefore, play an important role in the balance between VA and depth of focus. In experimental studies, it has been reported that depth of focus is narrower in eyes with aspherical IOLs than in eyes with spherical IOLs.[27–29] Rocha and associates measured image

resolution (VA) in 2 out-of-focus scenarios: fixing the focus of each eye to infinity (distance corrected) and measuring VA at 0.33 and 1 m.[30] They reported that residual spherical aberration after cataract surgery can improve depth of focus, and the tolerance to defocus seems to be lower in eyes implanted with aspherical IOLs (AcrySof IQ) than in spherical IOLs.[30] In our study, VA at 0.7 and 1.0 m with full distance correction was slightly worse in the aspherical IOL group than in the spherical IOL group, but the difference did not reach statistical significance. Our results indicate that depth of focus is not compromised in eyes implanted with aspherical IOLs (Tecnis Z9000; AMO Inc). At present, we do not have a clear explanation for the discrepancy between our results and those of previous studies, but it may be that the Tecnis IOL provides the best compromise between spherical and chromatic aberrations and depth of focus as demonstrated by an in vitro computation study.[27]

There are several limitations in our study. First, the number of subjects (31 patients) involved in the study was rather small. In the intraindividual comparative studies of aspherical and spherical IOLs, however, Tzelikis and associates evaluated 25 patients and Kasper and associates assessed 21 patients.[22,24,25] Few studies have enrolled larger study populations. Second, not all patients returned to the all prescheduled postoperative visits. Although all 31 patients were examined at 1 and 3 months after surgery, 26 and 22 patients were seen at 6 and 12 months after surgery, respectively. Despite our efforts to recall patients, some were lost to follow-up for several reasons. Those patients who are satisfied with the treatment outcome do not tend to return for a follow-up examination. Nonetheless, there have been no studies that evaluated the time course of changes in surgical outcome after implantation of aspherical IOLs; thus, we believe that the current study could add new knowledge in this regard. Third, the small but statistically significant differences in fourth-order RMS and scotopic contrast sensitivity may not have clinical meanings. This may represent the limitation of this IOL technology. It is not meaningless, however, to try to improve any visual function parameters, even a little at a time, unless adverse effects are associated. Fourth, we measured pupil diameters only under scotopic condition. The study would have benefited had pupil diameters been measured for each of the lighting conditions.

In conclusion, the current prospective, randomized, intraindividual study demonstrated that a silicone, foldable, aspherical IOL (Tecnis Z9000; AMO Inc) yielded significantly lower ocular wavefront aberration and better contrast sensitivity under scotopic conditions throughout 1-year follow-up. Depth of focus was not compromised in our patients.

THE AUTHORS INDICATE NO FINANCIAL SUPPORT OR FINANCIAL CONFLICT OF INTEREST. INVOLVED IN CONCEPTION AND design (S.O., S.G., Ka.M., T.O.); analysis and interpretation (S.O., Ka.M., T.O.); writing the article (S.O., T.O.); critical revision of the article (S.O., Ka.M., T.O.); final approval of the article (S.O., S.G., M.H., Y.K., Ke.M., Ka.M., T.O.); data collection (S.O., S.G., M.H., Y.K., Ke.M., Ka.M.); provision of materials and patients (S.O., S.G., M.H., Y.K., Ke.M., Ka.M.); statistical expertise (T.O.); obtaining funding (Ka.M., T.O.); literature search (S.O., T.O.); and administrative and technical support (Ka.M., T.O.). The study and data accumulation were carried out with approval from the Institutional Review Board of the Meiwakai Medical Foundation, Miyata Eye Hospital, Miyazaki, Japan. The study was approved by the local ethics committee.

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Mesopic Contrast Sensitivity and Ocular Higher-Order Aberrations in Eyes With Conventional Spherical Intraocular Lenses

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• PURPOSE: To investigate relationship between mesopic contrast sensitivity (CS) function and ocular higher-order aberrations in eyes implanted with conventional spherical intraocular lenses (IOL).
• DESIGN: Prospective, nonrandomized case series.
• METHODS: Sixty-eight eyes of 48 patients who attained best spectacle-corrected visual acuity (BSCVA) of 20/20 or better after phacoemulsification and spherical IOL implantation were included in the study. At 2 months postoperatively, mesopic CS was measured with the Mesotest II (Oculus; Wetsler, Germany), and ocular higher-order aberrations for a 4-mm pupil were measured with the Hartmann-Shack aberrometer. CS and letter CS under photopic conditions were recorded with the CSV-1000 charts (Vector Vision Co, Greenville, Ohio, USA).
• RESULTS: There was significant correlation between mesopic CS and ocular fourth-order root mean square (RMS) of wavefront aberration (Spearman $r_s = -0.293$; $P = .017$), but no correlation was found between mesopic CS and ocular third-order RMS ($r_s = 0.196$; $P = .189$). Ocular third- and fourth-order RMS did not correlate with other parameters, including BSCVA, and CS and letter CS under photopic conditions.
• CONCLUSIONS: Mesopic CS is significantly associated with ocular fourth-order RMS of wavefront aberrations in eyes implanted with conventional spherical IOLs. (Am J Ophthalmol 2009;148:298–302.

SINCE CATARACT SURGERY HAS EVOLVED IN BOTH surgical technologies and intraocular lenses (IOL), visual acuity (VA) improvement is no longer the only index of success. VA is commonly used to characterize an individual's ability to see, but there is considerably more to functioning in everyday life than being able to resolve fine details in well-illuminated, high-contrast black-and-white patterns. In the real world, one must detect and recognize a variety of targets varying in contrast, size, shape, and lighting conditions. In an attempt to extend the idea of an optical transfer to the processing occurring in the retina and brain, the contrast sensitivity (CS) function has evolved. CS function has been widely accepted as a sensitive measure for gauging visual performance under various clinical situations.[1–4]

Mesopic CS is a parameter that can assess subtle changes and differences in quality of vision.[5–7] It has been shown that photorefractive keratectomy[8] and laser in situ keratomileusis[9] induced significant reductions in CS under mesopic conditions, even though the photopic CS function was normal. Several studies have demonstrated that postoperative VA did not differ between the aspherical and spherical IOLs, but there was significant between-group difference in CS especially under mesopic conditions.[10–12]

Night visual disturbance is of critical importance in daily activities. Mesopic CS in pseudophakic eyes, however, has not been investigated in detail, and no studies have been available on the factors relevant to mesopic CS in eyes with spherical IOLs. We conducted the current study to evaluate mesopic CS function in eyes with conventional spherical IOLs and to explore which factors influence mesopic vision in these patients.

METHODS

• SUBJECTS: Sixty-eight eyes of 48 patients (21 men and 27 women) who attained postoperative best spectacle-corrected visual acuity (BSCVA) of 20/20 or better after phacoemulsification and IOL implantation were included in the study. They were selected from consecutive cases from our hospital population who matched the study inclusion criteria. None of the subject eyes had other ocular pathology and a history of previous ocular surgery. Videokeratography (TMS-4; Tomey Co, Aichi, Japan) and meticulous slit-lamp microscopy were performed before surgery to preclude eyes with corneal diseases. Optical coherence tomography and funduscopy were carried out after surgery to rule out pathologies in the posterior segment of the eye. There were no cases with severe dry eye. Subjects ranged in age from 28 to 85 years (66.9 ± 10.8 years, mean ± standard deviation [SD]). The IOL used in each patient was a single-piece, hydrophobic, acrylic, foldable lens with spherical surfaces (SA60AT; AcrySof; Alcon Laboratories Inc, Fort Worth, Texas,

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TABLE 1. Results of Mesopic Contrast Sensitivity Test In Eyes With Conventional Spherical Intraocular Lenses

Contrast Level	Number (%) of Eyes That Passed[a]
1/2	4 (5.9)
1/2.7	9 (13.2)
1/5	17 (25.0)
1/23	24 (35.3)
No recognition	25 (36.8)

[a]If patients identified the Landolt images in 3 of 6 different directions, the contrast level was considered to be passed.

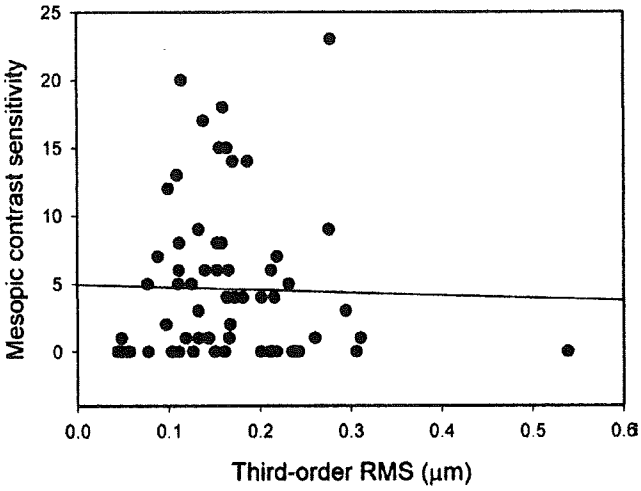

FIGURE 1. There was no significant correlation between ocular third-order root mean square (RMS) of wavefront aberration and mesopic contrast sensitivity (CS) ($r = 0.008$; $P = .950$) in eyes with conventional spherical intraocular lenses (IOL).

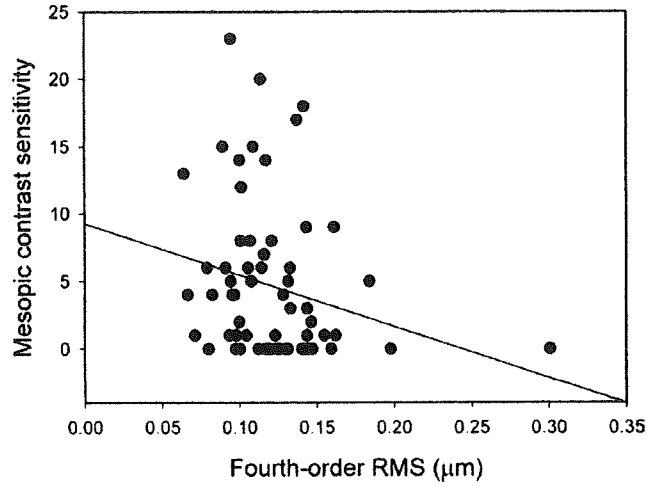

FIGURE 2. There was significant correlation between ocular fourth-order RMS of wavefront aberration and mesopic CS ($r = -0.293$; $P = .017$) in eyes with conventional spherical IOLs.

USA), which was implanted through a 3.0-mm scleral incision. Surgery was performed by a single surgeon (T.O.). Written informed consent was obtained from each patient.

• EXAMINATIONS: At 2 months postoperatively, BSCVA, mesopic CS function, photopic CS function, ocular wavefront aberrations, and pupil diameter under mesopic illumination were measured.

Mesopic CS was measured using the Mesotest II (Oculus, Wetsler, Germany).[5,7,13,14] The measurements were performed following 10 minutes of dark adaptation, with best-correcting spectacles. A Landolt ring equivalent to 20/200 as a virtual image at a distance of 5 m was displayed in 6 directions at 4 different contrast levels. The tested contrast levels were 1:23 (95.7%), 1:5 (80%), 1:2.7 (63%), and 1:2 (50%). The background illumination was 0.032 cd/m^2. Measurements started from the highest contrast level and advanced to the lower contrast levels in sequence. The number of Landolt images correctly answered was used for the subsequent analyses.

We used 2 CSV-1000 charts (Vector Vision Co, Greenville, Ohio, USA) to evaluate CS function under photopic conditions: CSV-1000E sine wave grating chart for CS and CSV-1000LV chart for letter CS. The test luminance level was calibrated automatically to 85 cd/m^2. From the data obtained with the CSV-1000E chart, the area under the log CS function (AULCSF) was calculated according to the method of Applegate and associates.[15]

Ocular higher-order aberrations (HOA) were measured for a 4-mm pupil using the Hartmann-Shack aberrometer (KR-9000PW; Topcon, Tokyo, Japan).[16,17] Wavefront aberrations were expanded into a set of orthogonal Zernike polynomials. The root mean square (RMS) of third-order Zernike components (Z_3^{-3} to Z_3^{3}) was used to represent coma-like aberrations, and RMS of fourth-order Zernike components (Z_4^{-4} to Z_4^{4}) was used to represent spherical-like aberrations.

Pupil diameter was measured under mesopic conditions with an open-window-type electronic pupillometer (FP-10000; T.M.I. Co, Ltd, Saitama, Japan). The vertical and horizontal diameters were averaged and used for the analysis.

To evaluate the correlation between ocular wavefront aberrations and visual function, the Spearman-rank correlation coefficients were used. $P < .05$ was judged as statistically significant.

RESULTS

RESULTS OF MESOPIC CS TEST ARE SUMMARIZED IN TABLE 1. Twenty-five eyes (36.8%) could not recognize the target at any contrast level. Results of visual performance under

TABLE 2. Correlation Between Ocular Wavefront Aberration and Visual Function Parameters in Eyes With Conventional Spherical Intraocular Lenses

	Third-Order RMS	Fourth-Order RMS
Mesopic contrast sensitivity	r_s = 0.008; P = .950	r_s = −0.293; P = .017[a]
LogMAR BSCVA	r_s = 0.148; P = .264	r_s = −0.222; P = .092
AULCSF	r_s = −0.174; P = .169	r_s = −0.002; P = .990
Letter contrast sensitivity	r_s = −0.018; P = .891	r_s = −0.038; P = .765

AULCSF = area under the log contrast sensitivity function; BSCVA = best spectacle-corrected visual acuity; logMAR = logarithm of minimal angle of resolution; RMS = root mean square.
[a]Significant correlation was found (Spearman-correlation test).

photopic conditions are as follows: logarithm of minimal angle of resolution (logMAR) BSCVA was −0.06 ± 0.06 (mean ± SD), AULCSF calculated from the data of the CSV-1000E chart was 1.161 ± 0.261, and letter CS was 22.9 ± 1.7.

Ocular third-order and fourth-order RMS of wavefront aberrations were 0.166 ± 0.080 μm and 0.122 ± 0.035 μm, respectively. The average pupil diameter under mesopic conditions was 4.1 ± 0.6 mm.

Correlation between ocular wavefront aberrations and visual function was tested. There was no significant correlation between mesopic CS and ocular third-order RMS (Spearman r_s = 0.008; P = .950; Figure 1), but statistically significant correlation was found between mesopic CS and ocular fourth-order RMS (r_s = −0.293; P = .017; Figure 2). Ocular third-order and fourth-order RMS did not show significant correlation with other parameters, such as logMAR BSCVA, AULCSF, and letter CS (Table 2).

There was no significant correlation between age and mesopic CS (r = −0.017; P = .895) and pupil diameter and mesopic CS (r = 0.144; P = .329).

DISCUSSION

IN THE CURRENT STUDY, WE EVALUATED THE INFLUENCE of ocular HOAs on visual performance in eyes implanted with conventional spherical IOLs. Visual function was assessed under both photopic and mesopic conditions. Under photopic conditions, logMAR BSCVA and CS were evaluated. To assess visual performance under mesopic conditions, mesopic CS was measured.

As shown in the results, ocular wavefront aberrations did not show significant correlation with visual functions under photopic conditions, such as logMAR BSCVA, AULCSF calculated from the data obtained with the sine wave grating chart, and letter CS. On the other hand, ocular fourth-order RMS significantly correlated with mesopic CS, while there was no association between ocular third-order RMS and mesopic CS. To the best of our knowledge, this is the first report that ocular wavefront aberration significantly influences mesopic CS in eyes with spherical IOLs.

Several studies used mesopic CS to compare visual function in eyes with aspherical and spherical IOLs. Rocha and associates demonstrated that CS values in photopic conditions were similar between aspherical and spherical IOLs, but aspherical IOL showed better results in mesopic CS.[10] Tzelikis and associates showed that aspherical IOL with a modified posterior surface induced significantly less spherical aberration than spherical IOL, resulting in better CS under mesopic conditions.[11] There were no statistically significant differences in VA and photopic CS. Another study by Tzelikis and associates reported that eyes with aspherical IOLs showed better CS than eyes with spherical IOLs under both photopic and mesopic conditions.[12] The differences reached statistical significance under photopic conditions at 3 spatial frequencies and under mesopic conditions at all spatial frequencies.[12] A more recent study, which also compared aspherical and spherical IOLs, indicated that aspherical IOL yielded significantly lower ocular wavefront aberration and better CS under scotopic conditions without compromising depth of focus.[18] Similar results have been reported by other studies that compared visual function between aspherical and spherical IOLs.[19,20] Judging from the results of these and our studies, it seems that ocular spherical aberration significantly influences some aspects of visual function, which can be best detected by CS test under dim light conditions.

In the present study, we used Mesotest II for measuring CS under mesopic illumination. The Mesotest II can measure mesopic CS in the presence or absence of glare,[5,7,13,14] which has been used to set a legal standard for driving at night by the German Ophthalmologic Society (DOG). The guidelines of the DOG state that patients must recognize Mesotest II contrast levels of 1:5 or better with and without glare to meet the minimum legal night-driving standards for private cars. Schlote and associates reported that 36.4% of post–photorefractive keratectomy eyes could not recognize the target at any contrast level using the Mesoptometer II (a device similar to the Mesotest II).[13] Scharwey and associates demonstrated that nearly 40% of persons over

the age of 60 have reduced night driving ability, and the majority of this age group were not able to fulfill the actual criteria for night driving ability according to the recommendations of the DOG.[21] In the present study, 24 eyes (35.3%) did not recognize the target at the highest contrast level 1:23 without glare, and 79.4% of eyes did not reach the contrast level 1:5 without glare recommended by the DOG guidelines for night driving. In general, the Mesotest II is quite difficult for older patients, and it appears that easier charts would be used to measure this parameter depending on the purpose of the study and subject population. In the present study, we employed the highly sensitive Mesotest II, since all patients were free from any ocular pathology except cataract and attained good BSCVA after uncomplicated cataract surgery.

We assessed the patients at 2 months postoperatively. We selected this timing because if tests were carried out too soon after surgery, low level of cystoid macular edema may compromise CS even in patients with good BSCVA. If patients were evaluated too late after surgery, the development of posterior capsular opacification and glistenings of the IOL optics can induce a similar problem.

Patients were included in the study only if postoperative BSCVA was 20/20 or better. Being 20/20 or better, however, does not preclude the pathology that can impact CS, such as mild corneal pathology, dry eye, glaucoma, cellophane maculopathy, early macular degeneration, other macular diseases, asteroid hyalosis, and optic nerve pathology. In order to screen out these diseases, we conducted videokeratography (TMS-4) and meticulous examination with slit-lamp microscopy to detect corneal disorders before surgery. Optical coherence tomography and funduscopy were carried out after surgery to rule out pathologies in the posterior segment of the eye. There were no cases with severe dry eye, as demonstrated by videokeratography and slit-lamp microscopy, but eyes with mild dry eye might have been included in the subjects because of the lack of detailed screening for dry eye, such as routine Schirmer test and tear breakup time test. It seems improbable that mild dry eye significantly influenced CS, but such an issue might be considered in the future studies.

Although the current study showed that CS under mesopic conditions was significantly associated with ocular fourth-order RMS, mesopic CS can be affected by multiple factors, including age, pupil diameter, retinal function, and brain processing.[22,23] In our study, we found that age and pupil diameter did not correlate with mesopic CS. We confirmed that all patients attained postoperative BSCVA of 20/20 or better, and eyes with ocular diseases were precluded with careful ocular examinations. Thus, retinal function and brain processing in our patients seem to be normal. Nonetheless, the optics alone cannot explain the level of mesopic CS, as indicated by the low correlation coefficient between fourth-order aberration and mesopic contrast sensitivity ($r = -0.293$). Moreover, we evaluated only 1 type of IOL. This can be one limitation of our study, though it is unlikely that ocular HOA differs significantly among spherical IOLs of the current generation.[24–26] Further clarification of this theme will be the subject of future studies using optical as well as psychophysical and psychometric approaches.

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Intraindividual Comparison of Aspherical and Spherical Intraocular Lenses of Same Material and Platform

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Purpose: There have been few studies which compared aspherical and spherical intraocular lenses (IOLs) of same material and platform in bilateral cataract cases. We performed an intraindividual comparison of ocular aberration and scotopic, mesopic, and photopic contrast sensitivity with aspherical and spherical IOLs, using the same IOL material and platform manufactured by the same company.

Design: Prospective, randomized, controlled study.

Participants: Eighty-two eyes of 41 patients undergoing bilateral cataract surgery.

Methods: One eye of a patient was assigned to acrylic foldable aspherical IOL (Tecnis ZA9003, Advanced Medical Optics), and the contralateral eye was allocated to acrylic foldable spherical IOL (AR40e, Advanced Medical Optics). All patients were examined at 2 days, 1 week, and 1 month postoperatively.

Main Outcome Measures: Best-corrected visual acuity (BCVA), contrast sensitivity under scotopic (15 lux), mesopic (70 lux), and photopic (180 lux) conditions, corneal and ocular wavefront aberrations, anterior chamber depth, amount of IOL decentration and tilt, pupil diameter under scotopic (3 lux) and photopic (250 lux) conditions, area of anterior capsule opening, degree of posterior capsule opacification, and all-distance visual acuity.

Results: There was no significant difference between IOLs in BCVA, anterior chamber depth, amount of IOL decentration and tilt, pupil diameter, area of anterior capsule opening, and degree of posterior capsule opacification. In corneal wavefront aberrations, there was no difference in 3rd-, 4th-, and total higher-order root-mean-square (RMS). In ocular wavefront aberration, aspherical IOL showed significantly lower 4th-order ($P<0.001$) and total higher-order RMS ($P<0.001$) than spherical IOL, but not in 3rd-order RMS ($P = 0.103$). Contrast sensitivity under scotopic conditions was significantly better with aspherical IOL than with spherical IOL at 3 ($P = 0.0015$), 6 ($P = 0.0192$), and 12 cycles per degree ($P = 0.0315$). Contrast sensitivity under mesopic and photopic conditions was not significantly different between IOLs. There was no between-group difference in visual acuity at 0.3, 0.5, 0.7, 1.0, or 5.0 meters measured with full distance correction.

Conclusions: Acrylic foldable aspherical IOL (Tecnis ZA9003) yielded significantly lower ocular wavefront aberration and better contrast sensitivity under scotopic condition without compromising depth of focus.

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Aspherical intraocular lenses (IOLs) having negative spherical aberrations are designed to compensate for the positive spherical aberration of the cornea. There have been many clinical studies comparing clinical outcomes, such as ocular higher-order aberration and contrast sensitivity, between aspherical and spherical IOLs.[1–20]

In general, the difference in visual function after implantation of aspherical and spherical IOLs is rather small. Moreover, the amount of ocular and corneal aberrations varies widely among subjects.[21–25] There have been few studies comparing corneal aberration before comparing ocular aberration in eyes with aspherical and spherical IOLs.[10,14] Thus, a meticulous study design is needed to compare these 2 IOLs in clinical settings. Until now, there have been only 2 studies that made significant efforts to reduce the bias that can occur in a comparative clinical study of aspherical and spherical IOLs, by making the study an intraindividual comparison, using the same IOL material manufactured by the same company, and having the same surgeon perform bilateral surgery within 1 week using an identical surgical technique.[19,20] One of them compared acrylic foldable aspherical (AcrySof IQ, Alcon, Fort Worth, TX; spherical aberration, −0.20 μm) and spherical IOLs (AcrySof Natural, Alcon),[19] and the other assessed silicone foldable aspherical (Tecnis Z9001, Advanced Medical Optics, Santa Ana, CA; spherical aberration, −0.27 μm), and spherical IOLs (ClariFlex, Advanced Medical Optics).[20] Several aspheric IOLs with a different amount of asphericity in the optic are marketed. In the current study, we compared acrylic foldable aspherical (Tecnis ZA9003, Advanced Medical Optics; spherical aberration, −0.27μm) and spherical IOLs (Sensar AR40e, Advanced Medical Optics) in patients undergoing bilateral cataract surgery.

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Patients and Methods

Patient Selection

The current prospective, randomized study included 82 eyes of 41 patients who were undergoing bilateral cataract surgery. Their ages ranged from 52 to 82 years (mean ± standard deviation, 75.3±5.3), and there were 13 males and 28 females. They were selected from consecutive cases among the clinic population who matched our inclusion criteria. None of the eyes had any history of previous ocular surgery. Eyes were not included if they had any ocular diseases that could affect surgical outcomes. The research protocol had institutional review board approval, and written informed consent was obtained from each patient. The study adhered to the tenets of the Declaration of Helsinki.

Intraocular Lenses

We used acrylic foldable aspherical IOL (Tecnis ZA9003) and spherical IOL (Sensar AR40e). Both lenses have overall length of 13.0 mm with the optic of 6.0 mm in diameter, which is made of foldable acrylic material (refractive index, 1.470). The haptics consist of polymethylmethacrylate material and have 5° configuration.

One eye of a patient was assigned to aspherical IOL, and the contralateral eye was assigned to spherical IOL. The assignment was randomly determined using an envelope method. All cataract operations, consisting of phacoemulsification and IOL implantation, were performed by one surgeon (K.M.) using identical surgical methods for each eye.

Outcome Measures

Patients were followed at 2 days, 1 week 1, and 1 month after surgery. Best-corrected visual acuity (BCVA), contrast sensitivity under scotopic (15 lux), mesopic (70 lux), and photopic (180 lux) conditions, corneal and ocular wavefront aberrations, anterior chamber depth, amount of IOL decentration and tilt, pupil diameter under scotopic (3 lux) and photopic (250 lux) conditions, area of anterior capsule opening, degree of posterior capsule opacification, and all-distance visual acuity were measured. All measurements were conducted by masked examiners who were unaware of the assignment of eyes.

All-distance visual acuity was measured using an all-distance vision tester (AS-15; KOWA, Tokyo, Japan).[26,27] With full distance correction, decimal visual acuity at 5.0, 1.0, 0.7, 0.5, and 0.3 meters was recorded. This device measures equivalent visual acuity from far to near distances by adding various diopters of spherical lens on a screen. Contrast sensitivity was measured by using CSV-1000E (Vector Vision, Greenville, OH). The test was performed monocularly with undilated pupils at 2.5 meters with full spectacle correction. Corneal and ocular wavefront aberration in the central 4-mm area was measured with the Hartmann-Schack wavefront analyzer KR-9000PW (Topcon Co., Tokyo, Japan), and the root-mean-square (RMS) of 3rd-, 4th-, and total higher-order aberrations were calculated.[28–31]

The Anterior Segment Analysis System (NIDEK EAS-1000) was used to quantify anterior chamber depth, degree of IOL decentration and tilt, area of anterior chamber opening, and degree of posterior capsule opacification. For decentration and tilt, 4 Scheimpflug images of the IOL were taken after full mydriasis at slit angles of 0°, 45°, 90°, and 135° with the charge-coupled device (CCD) camera. The tilt angle of the IOL optic axis relative to the visual axis was quantified by the image analysis computer, and the length of decentration was indicated by the distance between the IOL optic vertex and the visual axis.[32,33] The area of anterior capsular opacification was measured on the retroillumination photograph taken with the EAS-1000.[34,35] The degree of posterior capsular opacification was also analyzed using Scheimpflug slit images of 4 sections from 0° to 135°. The mean density of the central 3 mm on the posterior capsular area was derived by densitometry and the scatter light density was expressed as the computer-compatible tape steps.[36,37]

Statistical Analysis

The difference in contrast sensitivity was set as primary outcome. A prestudy power calculation using a significance level of 5% (α) and a power of 80% ($1-\beta$) revealed that a sample size of 36 in each group would be required to detect a mean log contrast sensitivity difference of 0.1 between the aspherical and spherical IOL groups. The study size was also estimated using data from previous studies that compared the postoperative performance of 2 acrylic foldable spherical IOLs.[38,39] Aiming to detect a difference in decentration of 0.06 mm with a significance level of 5% and a power of 80%, a sample size of 64 eyes of 32 patients was calculated. For the detection of a difference in tilt of 0.8° with a significance level of 5% and a power of 80%, a sample size of 60 eyes of 30 patients was calculated. To account for dropouts because of loss to follow-up during the postoperative period, 82 eyes of 41 patients were included in this study.

The parameters were statistically compared between eyes intraindividually using Wilcoxon signed-rank test. For statistical analysis of visual acuity, logarithm of the minimum angle of resolution was used. Statistical analyses were performed using SPSS 16.0 software (SPSS, Chicago, IL). $P<0.05$ was considered significant.

Results

Preoperative pupil diameter under photopic condition was 3.57±0.37 and 3.59±0.43 mm (P = 0.440, Wilcoxon signed-rank test) in the aspherical and spherical IOL groups, respectively. Pupil diameter before surgery under scotopic condition was 5.31±0.69 and 5.29±0.71 mm (P = 0.367) in the aspherical and spherical IOL groups, respectively. Table 1 summarizes the postoperative measurement results. There was no significant difference between IOLs in BCVA, anterior chamber depth, amount of IOL decentration and tilt, pupil diameter, area of anterior capsule opening, and degree of posterior capsule opacification.

In corneal wavefront aberrations, there was no difference in 3rd-, 4th-, and total higher-order RMS (Fig 1). In ocular wavefront aberration, the aspherical IOL group showed significantly lower values in 4th-order ($P<0.001$) and total higher-order RMS ($P<0.001$) than the spherical IOL, but not in 3rd-order RMS (P = 0.103; Fig 2).

Contrast sensitivity under scotopic condition (15 lux) was significantly better with the aspherical IOL than with the spherical IOL at 3 (P = 0.0015), 6 (P = 0.0192), and 12 cycles per degree (P = 0.0315; Fig 3). Contrast sensitivity under mesopic (70 lux) and photopic (180 lux) conditions was not significantly different between IOLs (Figs 4 and 5).

The results of the all-distance vision tester are shown in Figure 6. Visual acuity at 0.3, 0.5, 0.7, and 1.0 meters with full distance correction was slightly worse in the aspherical IOL group than in the spherical IOL group, but the difference did not reach significance.

Discussion

Aspherical IOLs have prolate optic, which is intended to compensate for the positive spherical aberration of the cor-

Table 1. Measurement Results

	Aspherical (ZA9003)	Spherical (AR40e)	P*
BCVA (logMAR)			
2 Days	−0.121±0.075	−0.125±0.086	0.386
1 Week	−0.137±0.069	−0.143±0.064	0.261
1 Month	−0.137±0.054	−0.140±0.057	0.218
Anterior chamber depth (mm)			
1 Week	3.80±0.26	3.89±0.28	0.287
1 Month	3.75±0.25	3.79±0.26	0.602
IOL decentration (mm)			
1 Week	0.232±0.097	0.211±0.088	0.170
1 Month	0.197±0.082	0.218±0.096	0.136
IOL tilt (degrees)			
1 Week	2.13±0.96	1.99±1.03	0.302
1 Month	2.19±0.88	2.02±0.90	0.182
Pupil diameter (mm)			
Photopic	3.60±0.50	3.61±0.51	0.343
Scotopic	5.09±0.73	5.09±0.74	0.797
Area of anterior capsule opening (mm^2)			
1 Week	22.49±3.36	21.84±3.70	0.242
1 Month	21.42±3.63	20.42±3.90	0.094
Posterior capsule opacification (CCT)			
1 Week	27.30±7.84	28.68±7.08	0.087
1 Month	27.62±8.27	28.87±7.73	0.168

BCVA = best-corrected visual acuity; CCT = computer-compatible tape step; IOL = intraocular lens; logMAR = logarithm of the minimum angle of resolution.
Values are presented as means ± standard deviation.
*Wilcoxon signed-rank test.

nea. Thus, it is a reasonable result that ocular 4th-order and total higher-order aberrations were significantly lower in the aspherical IOL group than in the spherical IOL group, although there was no intergroup difference in corneal aberrations. Many studies have compared ocular aberrations between aspherical and spherical IOLs, but there have been few studies assessing both corneal and ocular aberrations at the same time.[10,14] We believe that compatibility of corneal

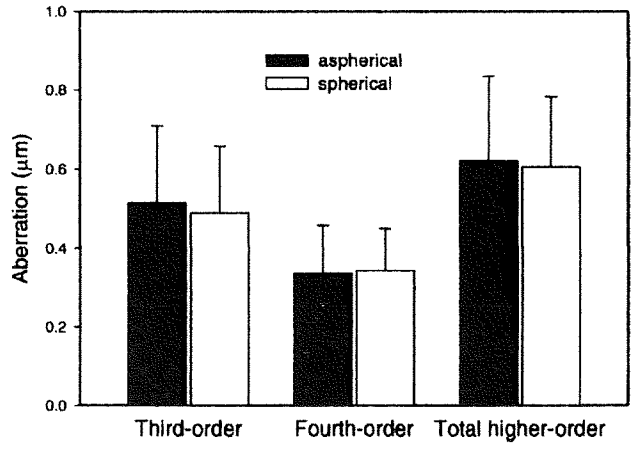

Figure 1. Corneal wavefront aberration measured 1 month after surgery. There was no difference in 3rd-, 4th-, and total higher-order root-mean-square between the aspherical and spherical intraocular lens groups.

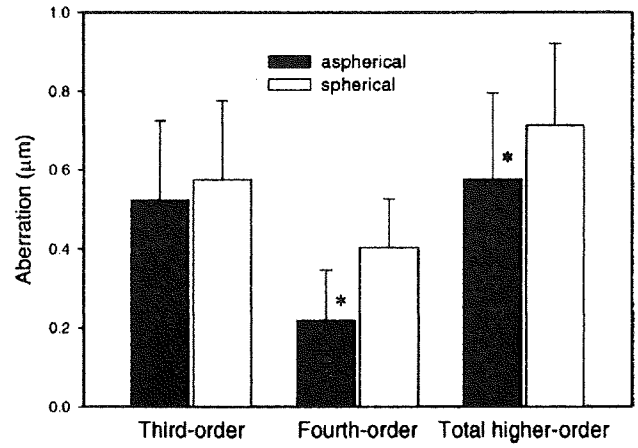

Figure 2. Ocular wavefront aberration measured 1 month after surgery. The aspherical intraocular lens (IOL) group showed significantly lower values in 4rth-order ($P<0.001$) and total higher-order root-mean-square (RMS; $P<0.001$) than the spherical IOL, but not in 3rd-order RMS ($P = 0.103$).

aberration should be first confirmed before comparing the influence of different asphericity of IOLs on ocular aberration. This is especially so if aspherical and spherical IOLs are compared in different individuals, because the amount of ocular and corneal aberrations varies widely among subjects.[21–25]

Tzelikis et al[19,20] have reported 2 studies that made significant efforts to reduce the bias that can occur in comparative clinical study of aspherical and spherical IOLs, by making the study an intraindividual comparison, using the same IOL material manufactured by the same company, and having the same surgeon perform bilateral surgery within 1 week using an identical operative technique. It was demonstrated that postoperative visual acuity did not differ between the aspherical and spherical IOLs, but there was significant between-group difference in contrast sensitivity, especially under mesopic conditions, in AcrySof IQ versus

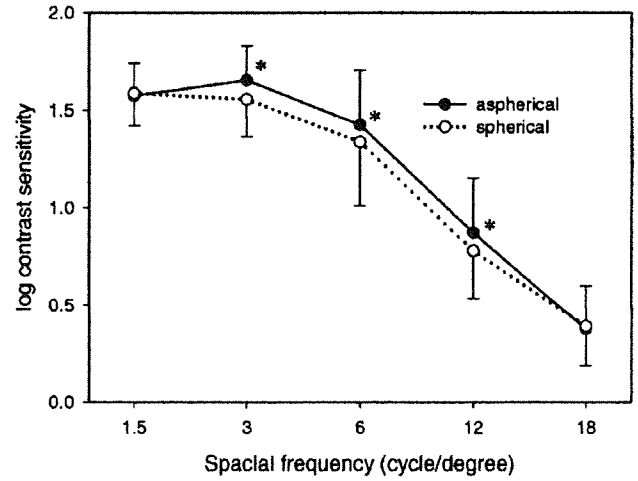

Figure 3. Contrast sensitivity under scotopic condition (15 lux) was significantly better with the aspherical intraocular lens (IOL) than with the spherical IOL at 3 ($P = 0.0015$), 6 ($P = 0.0192$), and 12 cycles per degree ($P = 0.0315$).

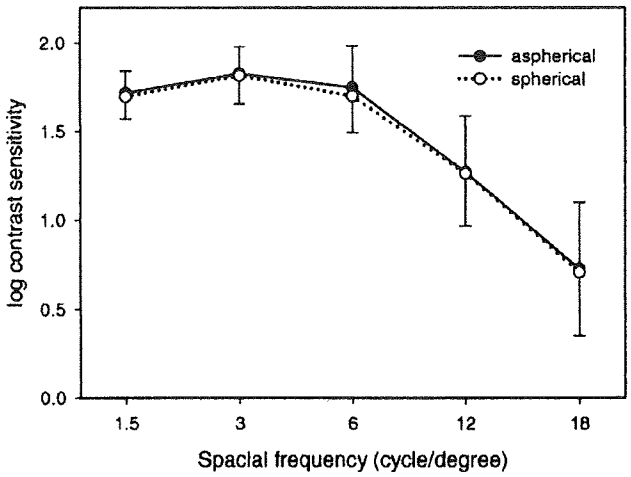

Figure 4. Contrast sensitivity under mesopic condition (70 lux) was not significantly different between groups.

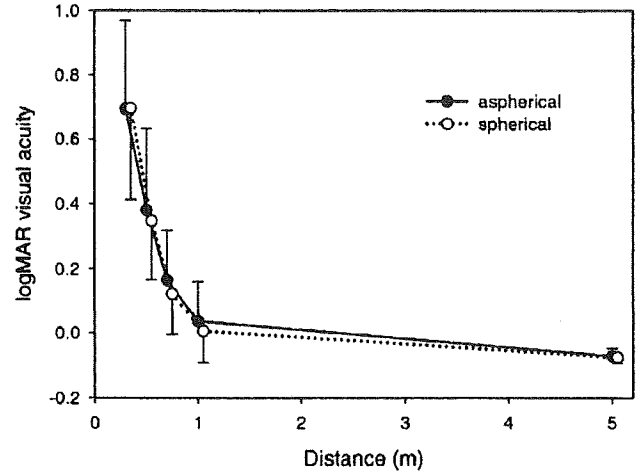

Figure 6. Results of the all-distance vision tester. Visual acuity at 0.3, 0.5, 0.7, 1.0, and 5.0 meters with full distance correction was not different between the aspherical and spherical intraocular lens groups. logMAR = logarithm of the minimum angle of resolution.

AcrySof Natural IOLs[19] and silicone Tecnis Z9001 versus ClariFlex IOLs.[20] In the current study, we found similar results using a different pair of aspherical and spherical IOLs, acrylic Tecnis ZA9003 versus Sensar AR40e.

In the current study, we tested the postoperative stability of aspherical and spherical IOLs. It was revealed that both IOLs had excellent postoperative stability in the eye, in terms of amount of IOL decentration and tilt, area of anterior capsule opening, and degree of posterior capsule opacification. These data support the fact that both IOLs are made of similar material based on similar platform, resulting in similar physical and anatomic outcomes. Thus, the current study could evaluate solely the difference in optical characteristics of the IOLs, asphericity of the optic.

Theoretically, spherical aberrations increase depth of focus, but decrease modulation transfer function at high spatial frequencies at optimum focus.[40] Spherical aberrations, therefore, play an important role in the balance between visual acuity and depth of focus. In experimental studies, it has been reported that depth of focus is narrower in eyes with aspherical IOLs

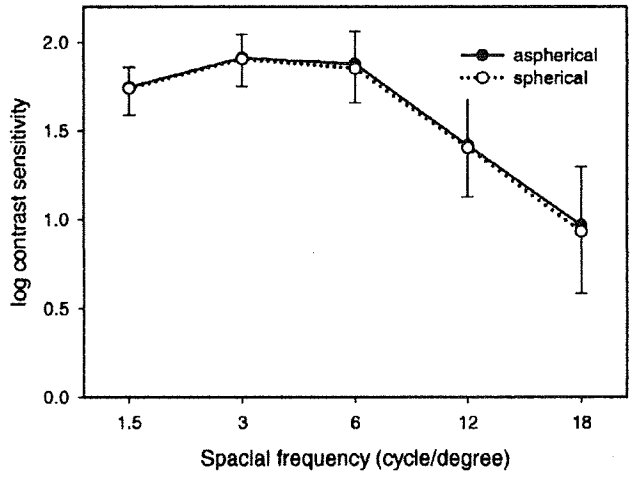

Figure 5. Contrast sensitivity under photopic condition (180 lux) was not significantly different between groups.

than in eyes with spherical IOLs.[15,41,42] Rocha et al[13] measured image resolution (visual acuity) in 2 out-of-focus scenarios: fixing the focus of each eye to infinity (distance corrected) and measuring visual acuity at 0.33 and 1 meters. They reported that residual spherical aberration after cataract surgery can improve depth of focus, and the tolerance to defocus seems to be lower in eyes implanted with aspherical IOLs (AcrySof IQ) than in spherical IOLs.[13] In our study, visual acuity at 0.3, 0.5, 0.7, and 1.0 meters with full distance correction was slightly worse in the aspherical IOL group than in the spherical IOL group, but the difference did not reach significance. Our results indicate that depth of focus is not compromised in eyes implanted with aspherical IOLs (Tecnis ZA9003). At present, we do not have clear explanation for the discrepancy between our and previous studies, but it may be that Tecnis IOL provides the best compromise between spherical and chromatic aberrations and depth of focus as demonstrated by an in vitro computation study.[15]

There are several limitations to our study, one of which is the short follow-up period. In our study, postoperative measurements were conducted only 1 month after surgery. It may be that different measurements are obtained in a longer term study. It is unlikely, however, that wavefront aberration and contrast sensitivity will change considerably after 1 month, as reported by previous studies.[8,13,19]

In conclusion, the current prospective, randomized, intraindividual study demonstrated that acrylic foldable aspherical IOL (Tecnis ZA9003) yielded significantly lower ocular wavefront aberration and better contrast sensitivity under scotopic condition without compromising depth of focus.

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