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**Análise de qualidade óptica e performance visual em olhos implantados
com lentes intraoculares asféricas neutras**

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Programa de Oftalmologia

Orientador:

Prof. Dr. Newton Kara-José Junior

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Imagine a história da sua vida e acredite nela.

O trabalho e a persistência tem o poder de fazer os caminhos se abrirem.

E os sonhos se realizarem.

DEDICATÓRIA

Aos meus pais **Jorge e Ligia Santhiago**. Por terem me ensinado que não devemos desistir nunca. Pelo apoio irrestrito, fazendo o possível e, principalmente, o impossível para que eu caminhe em direção à realização dos meus sonhos.

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RESUMO

Objetivo: Determinar se o implante de uma determinada lente intraocular asférica resulta em redução das aberrações oculares e melhora da qualidade ótica e sensibilidade ao contraste sem que ocorra redução crítica da profundidade de foco.

Desenho: Estudo prospectivo, duplo-cego, randomizado.

Métodos: Este estudo que incluiu 25 pacientes com catarata bilateral, uma LIO asférica foi implantada em um olho e uma LIO esférica no olho contralateral. Aberrações de maior ordem e parâmetros de qualidade ótica foram obtidos através de aberrômetro de retinoscopia dinâmica, 1 e 3 meses após a cirurgia. Foi também medido a acuidade visual com e sem correção e a sensibilidade ao contraste. Acuidade visual para perto e distância intermediária foi obtida como forma de medida da profundidade de foco.

Resultados: Não houve diferença estatisticamente significativa entre os grupos para acuidade visual corrigida e não corrigida 1 e 3 meses após a cirurgia. Houve diferença estatisticamente significativa entre os grupos quanto a sensibilidade ao contraste sob condições fotópticas na frequência espacial de 12 ciclos por grau e sob condições mesópicas em todas as frequências espaciais estudadas. O grupo com a LIO Akreos AO obteve menores valores de aberrações de maior ordem totais e de aberração esférica com pupilas de 5 e 6 mm e melhores valores de qualidade ótica comparado ao grupo com LIO Akreos Fit ($p < 0.05$). Não houve diferença significativa entre os grupos quando se investigou visão de perto e intermediária corrigido para longe.

Conclusões: A LIO asférica Akreos AO induziu menos aberrações de maior ordem além de produzir melhores parâmetros de qualidade ótica com melhores resultados de sensibilidade ao contraste em condições mesópicas sem redução crítica de profundidade de foco quando comparado a LIO esférica Akreos Fit.

Descritores: Lentes intraoculares; aberrometria; facoemulsificação; Catarata.

SUMMARY:

PURPOSE: To determine whether implantation of an aspherical intraocular lens (IOL) results in reduced ocular aberrations and improved optical quality and contrast sensitivity after cataract surgery without critical reduction of depth of focus.

DESIGN: Double-blinded, randomized, prospective study.

METHODS: In an intraindividual study of 25 patients with bilateral cataract, an aspherical IOL (Akreos Advanced Optic [AO]; Bausch & Lomb, Inc., Rochester, New York, USA) was implanted in one eye and a spherical IOL (Akreos Fit; Bausch & Lomb, Inc) in the fellow eye. Higher-order aberrations with a 5- and 6-mm pupil and optical quality parameters were measured with a dynamic retinoscopy aberrometer at 1 and 3 months after surgery. Uncorrected and best-corrected visual acuity and contrast sensitivity under mesopic and photopic conditions also were measured. Distance-corrected near and intermediate visual acuity were studied as a measurement of depth of focus.

RESULTS: There was no statistically significant difference between eyes in uncorrected and best-corrected visual acuity at 1 and 3 months after surgery. There was a statistically significant between-group difference in contrast sensitivity under photopic conditions at 12 cycles per degree and under mesopic conditions at all spatial frequencies. The Akreos AO group obtained statistically significant lower values of higher-order aberrations and spherical aberration with 5- and 6-mm pupils and better optical quality parameters compared with the Akreos Fit group ($P < .05$). There was no significant difference in distance-corrected near and intermediate visual acuity between both groups.

CONCLUSIONS: Aspherical aberration-free Akreos AO IOL induced significantly less higher-order aberrations and spherical aberration than the Akreos Fit. Contrast sensitivity under mesopic conditions and optical quality parameters were better with the Akreos AO with similar results of depth of focus.

Descriptors: Intraocular lenses; aberrometry; phacoemulsification; Cataract.

1 INTRODUÇÃO

A partir do desenvolvimento de sensores de frente de onda, tornou-se possível medir com maior precisão as aberrações ópticas do olho humano. Desenvolveram-se então, opções que poderiam ir além da correção esfero-cilíndrica; o que significa corrigir ou, de alguma forma controlar, as aberrações mais complexas ou de maior ordem. Tais correções, teoricamente, podem ser atingidas através de ablações personalizadas da córnea ou lentes intraoculares.¹ O implante de lente intraocular (LIO) durante a cirurgia de catarata passou a significar não somente o restabelecimento da acuidade visual do paciente, através de um meio transparente, como também a possível melhora qualidade de imagem.

No olho humano jovem há um equilíbrio teórico no que se refere a uma das aberrações de maior ordem mais sintomática,¹ chamada aberração esférica, que é positiva na córnea e a negativa no cristalino. Esta composição de sinais positivo e negativo, leva a valores reduzidos de aberração esférica total. A qualidade do sistema óptico vai se deteriorando com a idade, e uma possível causa desta degradação é a inversão de padrão de aberração esférica do cristalino, que passa de negativo no adulto jovem, para valores negativos menores, ou até positivos no adulto com idade mais avançada. Enquanto que a aberração esférica da córnea se mantém constante ao longo da vida.³ Sendo assim há uma tendência a ruptura do equilíbrio que havia outrora, com consequente predominância de aberração esférica positiva na composição total do olho, e diminuição de qualidade de imagem.^{2,3} Recentemente, demonstrou-se que a cirurgia refrativa guiada pelos valores de aberração, ou a cirurgia de catarata utilizando-se LIOs especiais com valor negativo de aberração esférica, poderiam resultar em melhores parâmetros de qualidade óptica e melhor resultado nos testes de sensibilidade ao contraste.⁴

Quando se realiza a cirurgia de catarata, passa a ser a LIO, e não mais o cristalino, a responsável pela aberração esférica interna, participando da equação em conjunto com a aberração esférica da córnea, para determinar a aberração esférica final do olho. As LIOs chamadas esféricas geram um determinado valor positivo de aberração esférica. As LIOs chamadas asféricas foram inicialmente desenvolvidas com o objetivo de gerar valor negativo de aberração esférica de maneira a compensar os valores positivos médios de aberração esférica da córnea.⁴

As LIOs consideradas asféricas neutras, teoricamente não geram aberração esférica negativa e nem positiva, sendo assim, a equação para determinar a aberração esférica final do olho passa a contar apenas com a aberração esférica positiva da córnea. Este modelo especial de LIO parece ser capaz de melhorar a qualidade óptica sem que ocorra redução crítica da profundidade de foco.^{5,6} A LIO Akreos Advanced Optic [AO]; (Bausch & Lomb, Inc., Rochester, New York, USA) possui alterações nas superfícies anterior e posterior, criando uma LIO que teoricamente não gera aberração esférica residual interna, sendo considerada uma LIO asférica livre de aberrações, ou neutra.^{5,7,8}

Quando se compara olhos onde implantou-se LIOs asféricas com olhos onde implantou-se LIOs esféricas parece haver melhora dos parâmetros de qualidade óptica e sensibilidade ao contraste em favor das LIOs asféricas.⁹ Porém ainda não se determinou quais seriam os valores ideais para a melhor qualidade de imagem, ou ainda se seria benéfico para o paciente manter um determinado valor de aberração esférica final no olho para que não ocorra redução significativa da profundidade de foco

2 OBJETIVOS

Com base nos conceitos e situações acima descritos, seria razoável considerar que uma LIO asférica neutra seria capaz de reduzir o valor de aberração esférica total do olho, mantendo o ganho em qualidade de imagem comparada a uma LIO esférica, sem que ocorra redução crítica da profundidade de foco, pois manteria algum valor de aberração esférica.

Desenvolvemos então, estudo prospectivo randomizado duplo cego, cujos objetivos foram:

1. Determinar se o implante de uma LIO asférica neutra resultaria em menores valores de aberração ocular e melhora da sensibilidade ao contraste sem redução crítica da profundidade de foco.

2. Determinar se o implante de uma LIO asférica neutra resultaria em melhores em parâmetros de qualidade ótica.

3 REVISÃO DA LITERATURA

Lentes asféricas: avaliação da indicação clínica e das opções de lentes

Aspherical IOLs: clinical evaluation and options

Newton Kara-Jose Junior¹, Marcony Rodrigues de Santhiago²

RESUMO

Com a utilização de lentes intraoculares (LIOs) asféricas na cirurgia de catarata, o oftalmologista é capaz de oferecer, além da melhora da acuidade visual pela remoção do cristalino opacificado, benefícios adicionais como, por exemplo, a redução de aberrações ópticas oculares, que diminuem a sensibilidade ao contraste. Foram revisadas publicações recentes sobre LIOs asféricas e adicionadas conclusões de nossos estudos na área, a fim de expor neste artigo nossa percepção a respeito da influência da utilização de LIOs que diminuem a aberração esférica do olho, na qualidade visual após a cirurgia da catarata

Descritores: Lentes intraoculares; Catarata; Acuidade visual/fisiologia

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INTRODUÇÃO

O olho humano é opticamente imperfeito, assim, a qualidade da imagem projetada na retina é inferior à imagem real do objeto visualizado. Isso ocorre porque ao atravessar estruturas intraoculares, especialmente córnea e cristalino, os raios luminosos sofrem desvios, como dispersão, refração, absorção, além de diversas aberrações. Contudo, a imagem final interpretada no córtex cerebral será de muito melhor qualidade, pois o Sistema Visual tem um mecanismo compensatório (neuroadaptação) para a maioria das deficiências do Sistema Óptico⁽¹⁻¹²⁾.

Mesmo considerando a neuroadaptação, acredita-se que a correção de algumas aberrações ópticas pode melhorar ainda mais a qualidade visual. Uma modalidade de imperfeição óptica ocular que não pode ser resolvida com lentes corretoras (óculos), mas é passível de compensação, pela cirurgia de catarata com implante de LIOs especiais, é a aberração esférica (alta ordem), a qual trata-se de uma imprecisão na asfericidade periférica da córnea (a superfície corneal periférica é mais plana do que deveria ser), que prejudica a visão de longe em situações de pouca luminosidade, quando a midríase pupilar permite que os raios luminosos que incidem na periferia corneal sigam em direção à retina; esses raios serão focalizados anteriormente à mácula, diminuindo a qualidade visual⁽¹⁻⁵⁾.

Foi demonstrado que, com a idade, a qualidade óptica vai se deteriorando, e uma possível causa desta degradação é a inversão de padrão de aberração esférica do cristalino, de negativo no adulto jovem (que compensaria parcialmente a aberração corneal positiva), para valores negativos menores, ou até positivos quando o cristalino está opacificado⁽⁶⁻¹²⁾.

As lentes esféricas convencionais são refrativamente similares ao cristalino adulto, apresentam aberração esférica positiva, ou seja, além de não compensarem a aberração esférica corneal (em média +0.27mm), mantém a mesma indução adicional de aberração positiva do cristalino maduro. Entretanto, os pacientes, em geral, não se queixam, pois era a aberração óptica que eles, por muito tempo, já apresentavam devido à catarata. Porém, com implante de LIOs esféricas, são privados da oportunidade, teórica, de se melhorar ainda mais a visão, após a facectomia.

A solução proposta para compensar a aberração esférica é o implante da LIO asférica (aberração negativa), que corrigirá, ao menos parcialmente, a direção dos raios incidentes periféricos (aberração positiva)⁽¹³⁻³⁷⁾.

Para avaliação do comprometimento visual pela catarata, assim como do benefício clínico das LIOs asféricas em relação às LIOs convencionais, o teste de Snellen, embora seja o instrumento mais utilizado para a avaliação da acuidade visual, apresenta limitações, pois mede a visão utilizando-se do contraste máximo (letras pretas em fundo branco). No mundo real a maioria dos objetos a serem visualizados não se encontra com tanto contraste, assim, a acuidade visual medida no consultório por meio deste teste não corresponde, necessariamente, a dificuldade de visão percebida pelo paciente no seu dia a dia. Deste modo, uma pessoa com catarata de componente nuclear predominante pode, por exemplo, enxergar 20/25 na tabela de Snellen e ter dificuldade para dirigir. Se o oftalmologista só considerar a visão medida com máximo contraste talvez não compreenda a queixa do paciente, provavelmente, em situações de menor contraste, como ao entardecer. Por outro lado, caso o paciente ou seu acompanhante se lembre de qual era a medida da visão no teste de Snellen antes da cirurgia, pode não se maravilhar com o resultado visual pós-operatório, que será, neste caso, provavelmente, de melhora de uma linha, mesmo que a dificuldade visual tenha sido corrigida.

Para se estimar mais precisamente a dificuldade visual pela catarata e para avaliar o desempenho visual com LIOs asféricas, o teste mais indicado é o de sensibilidade ao contraste, que mede a acuidade visual sob diferentes níveis de contraste. É por isso que a maioria dos estudos utiliza o teste de sensibilidade ao contraste (ETDRS) em condições mesópicas e fotópicas, além da avaliação objetiva da qualidade óptica por meio de exames de aberrometria ("frente de onda")⁽³⁸⁾.

A maioria dos estudos que compararam LIOs asféricas e esféricas não demonstraram diferenças em relação a melhor acuidade visual corrigida, medida pela tabela de Snellen ou pela do ETDRS, em condições fotópicas, exceto dois estudos^(13,17), que apresentaram resultados de melhor acuidade visual corrigida em pacientes com LIO Tecnis (AMO), se comparado aos pacientes com LIOs esféricas SA60AT (Alcon Labs) e SI40 (Alergan)^(12-15,17,20-22,25,28,29,33,34,39).

O resultado da maioria dos artigos nos leva a concluir que não há diferença entre LIOs asféricas e esféricas em relação a melhor acuidade visual, corrigida em condições de alta luminosidade, ou que, este tipo de teste não apresenta condições de detectar tal diferença.

Em condições mesópicas, as vantagens visuais das LIOs asféricas em relação às esféricas, quando avaliadas pelo teste do ETDRS, passam a ser mais evidentes. Nos trabalhos com a LIO Tecnis (AMO), apenas dois não encontraram diferenças, estatisticamente significa-

tivas, quando comparadas a LIO Stabibag (Zeiss)⁽²⁰⁾ e AR40e (AMO)^(20,22). A maioria das pesquisas apresentou resultados superiores com a LIO asférica em frequências espaciais que variaram de 1.5 a 30 ciclos por grau. Todos os estudos que avaliaram a LIO Acrysof IQ (Alcon labs) em condições mesópicas, demonstraram o melhor desempenho desta, quando comparada a diferentes LIOs esféricas^(21,28,31,32,34,36). Um estudo⁽²⁸⁾, avaliou a LIO asférica SofPort (Bausch & Lomb), e demonstraram valores estatisticamente significativos, comparado às LIOs esféricas SN60AT (Alcon labs) e AR40e (AMO).

As lentes asféricas variam em relação a asfericidade, de forma que, as LIOs mais utilizadas, Tecnis (AMO), Acrysof IQ (Alcon labs) Akreos AO (Bausch & Lomb), apresentam diferentes potenciais para compensação da aberração esférica da córnea. A aberração esférica corneal na média populacional é de 0.27mm positivos; teoricamente, em condições de diâmetro pupilar de 6 mm, a LIO Akreos AO (Bausch & Lomb) apresenta 0.0mm de aberração esférica residual, ou seja são livres de aberração; a LIO Tecnis (AMO) possui asfericidade de -0.27mm, tentando compensar totalmente a aberração corneal considerando a média populacional e a LIO Acrysof IQ (Alcon labs) -0.20mm, que deixa, se considerada a média populacional, um residual de aberração positiva de 0,07mm.

Estudo publicado recentemente⁽⁴⁰⁾ que comparou duas LIOs asféricas, a Akreos AO (Bausch & Lomb) e a Tecnis (AMO), não demonstrou diferenças estatisticamente significativas, na acuidade visual, tanto em condições fotópicas, quanto em mesópicas, porém, por meio do exame de aberrometria (frente de onda) confirmou valores residuais maiores de aberração esférica com a LIO Akreos AO (Bausch & Lomb), sugerindo, assim, que o exame da acuidade visual avalia o desempenho do Sistema Visual total (globo ocular e córtex cerebral, incluindo a neuroadaptação), enquanto que o exame de frente de onda avalia apenas a porção óptica do olho (Sistema Óptico), ou seja, a qualidade da imagem que chega na retina.

Em determinados casos, a aberração esférica positiva residual pode ser benéfica, pois embora possa diminuir a visão de longe no escuro, aumenta a profundidade de foco, facilitando a visão de perto. Artigo recente⁽²⁷⁾ demonstrou que a LIO esférica SN60AT (Alcon labs) apresenta maior profundidade de foco comparado a LIO asférica Acrysof IQ (Alcon labs), analisando visão intermediária e de perto, em pacientes corrigidos para longe.

Considera-se também que a tolerância ao “defocus”, pequenos erros refracionais esféricos, parece ser maior em pacientes com LIOs esféricas e/ou com

residual de aberração esférica positiva. Esse seria um benefício teórico da LIO asférica livre de aberração, como a Akreos AO (Bausch & Lomb), que deixaria aberração residual. Estudo⁽⁴⁰⁾ que comparou a profundidade de foco em pacientes com LIOs asféricas livres de aberração, Akreos AO (Bausch & Lomb) e LIOs asféricas com aberração negativa, Tecnis (AMO) que tendem a compensar totalmente a aberração esférica positiva da córnea, concluiu que, a profundidade de foco é maior no grupo com LIOs asféricas livres de aberração.

Atualmente se tem estudado as LIOs asféricas, com objetivo de se personalizar a cirurgia de catarata, obtendo-se valores de aberração esférica residuais finais em torno de 0.10 mm, com possível melhora na qualidade óptica e acuidade visual⁽⁴¹⁻⁴⁶⁾. Artigo recente⁽⁴⁷⁾ sugere que para pacientes com aberração esférica corneana entre -0.15 e +0.15 poderia ser implantada uma LIO asférica livre de aberração, como a Akreos AO (Bausch & Lomb), em pacientes com valores entre +0.16 e +0.33 Acrysof IQ (Alcon labs), e para pacientes com valores acima de +0.33, a LIO Tecnis (AMO).

Na indicação de LIOs asféricas, alguns fatores individuais também devem ser considerados, como diâmetro pupilar e histórico de cirurgia refrativa à laser.

Embora consideremos que o sistema visual dispõe de um mecanismo compensatório de aberrações ópticas, que é a neuroadaptação, capaz de, em muitos casos, resolver o problema da aberração esférica, bem como de outras deficiências ópticas, por si só, existe a tendência para personalizar a cirurgia de catarata, a fim de se obter resultados visuais ainda melhores^(43,48). No futuro, assim como é feita a biometria para se determinar o valor dióptrico da LIO a ser implantada, a fim de se corrigir os erros refrativos esféricos (aberrações de baixa ordem) e, em certos casos, realizado a topografia para se estimar o astigmatismo corneal (aberração de baixa ordem), objetivando-se compensá-lo com incisões relaxantes limbares ou LIOs tóricas, talvez também possa ser realizado, rotineiramente, o exame de “frente de onda”, para se estimar a aberração esférica da córnea, a fim que esta possa ser compensada com determinada LIO asférica.

ABSTRACT

With aspherical intraocular lens (IOL), phakectomy could be more than removal of cataract, it also could means an improvement in optical quality of the eye. In this article, recently published studies on aspherical IOLs and exams to access optical quality were reviewed.

Keywords: Lenses, intraocular; Cataract; Visual acuity/physiology

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4 ARTIGOS CIENTÍFICOS

4.1: Artigo sobre aberrações de maior ordem, sensibilidade ao contraste e profundidade de foco.

Wavefront Analysis, Contrast Sensitivity, and Depth of Focus After Cataract Surgery With Aspherical Intraocular Lens Implantation

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• **PURPOSE:** To determine whether implantation of an aspherical intraocular lens (IOL) results in reduced ocular aberrations and improved contrast sensitivity after cataract surgery without critical reduction of depth of focus.

• **DESIGN:** Double-blinded, randomized, prospective study.

• **METHODS:** In an intraindividual study of 25 patients with bilateral cataract, an aspherical IOL (Akreos Advanced Optic [AO]; Bausch & Lomb, Inc., Rochester, New York, USA) was implanted in one eye and a spherical IOL (Akreos Fit; Bausch & Lomb, Inc) in the fellow eye. Higher-order aberrations with a 5- and 6-mm pupil were measured with a dynamic retinoscopy aberrometer at 1 and 3 months after surgery. Uncorrected and best-corrected visual acuity and contrast sensitivity under mesopic and photopic conditions also were measured. Distance-corrected near and intermediate visual acuity were studied as a measurement of depth of focus.

• **RESULTS:** There was no statistically significant difference between eyes in uncorrected and best-corrected visual acuity at 1 and 3 months after surgery. There was a statistically significant between-group difference in contrast sensitivity under photopic conditions at 12 cycles per degree and under mesopic conditions at all spatial frequencies. The Akreos AO group obtained statistically significant lower values of higher-order aberrations and spherical aberration with 5- and 6-mm pupils compared with the Akreos Fit group ($P < .05$). There was no significant difference in distance-corrected near and intermediate visual acuity between both groups.

• **CONCLUSIONS:** Aspherical aberration-free Akreos AO IOL induced significantly less higher-order aberrations and spherical aberration than the Akreos Fit. Contrast sensitivity was better under mesopic conditions with the Akreos AO with similar results of depth of focus. (Am J Ophthalmol 2010;149:383–389. © 2010 by Elsevier Inc. All rights reserved.)

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ASPHERIC TREATMENTS WITH MODIFIED PROLATE surface intraocular lenses (IOLs) recently have become popular and have been studied extensively worldwide.^{1,2} Reduction of ocular spherical aberrations with aspherical IOLs theoretically may improve contrast sensitivity and may reduce the patient's perception of halos and glare.^{3–13}

Clinical aberrometers provide an objective measurement of optical aberrations beyond sphere and cylinder, such as spherical aberration, coma, trefoil, and other higher-order aberrations (HOAs).^{14–21} Commercially available aspherical IOLs present different amounts of spherical aberration in attempt to balance positive spherical aberrations of the cornea.^{1–13} The aspherical IOL Akreos Advanced Optic (AO; Bausch & Lomb, Inc., Rochester, New York, USA) is considered aberration free because its anterior and posterior prolate surfaces generate, theoretically, no negative spherical aberration.^{22–25}

The aim of this prospective, randomized clinical study was to determine whether implantation of an IOL with a modified anterior and posterior aspherical surface (Akreos AO) results in reduced spherical aberration and improved contrast sensitivity without critical reduction of depth of focus. The patient's quality of vision after Akreos AO implantation also was assessed and compared with that after spherical IOL (Akreos Fit; Bausch & Lomb, Inc) implantation. The Akreos AO is one of the aspherical IOL less studied in the peer-reviewed literature. To the authors' knowledge, this is the first study of the aspherical aberration-free IOL Akreos AO implanted in one eye compared with a spherical IOL made with the same material by the same manufacturer implanted in the fellow eye.

METHODS

THIS PROSPECTIVE, RANDOMIZED, BILATERAL, DOUBLE-masked clinical study included 50 eyes of 25 patients with visually significant bilateral cataracts. Patients randomly received an aspherical IOL Akreos AO in one eye (25 eyes) and a spherical IOL Akreos Fit (25 eyes) in the fellow eye. Table 1 shows the characteristics of the 2 IOLs.

Patients with visually significant bilateral cataract and corneal astigmatism lower than 2.0 diopters (D) were

TABLE 1. Characteristics of Akreos AO and Akreos Fit Intraocular Lenses Used in the Study

Characteristics	Akreos AO	Akreos Fit
Type	Single piece	Single piece
Overall length	10.7	11.5
Optic diameter	6.0	5.7
Optic material	Hydrophilic acrylic with UV blocker	Hydrophilic acrylic with UV blocker
Refractive index	1.458	1.458
Optic shape	Biconvex, aspherical anterior and posterior surface	Biconvex
Estimated A constant	118.0	118.0

IOLs = intraocular lenses; UV = ultraviolet.
Both Akreos IOLs have a 360-degree double-squared edge.

eligible for inclusion in the study. Exclusion criteria included any ocular disease, such as corneal opacities or irregularity, dry eye, amblyopia, anisometropia, glaucoma, retinal abnormalities, surgical complications, IOL tilt, IOL decentration of more than 0.4 mm (estimated by retroillumination), or incomplete follow-up. The primary outcome measures of the study were contrast sensitivity and wavefront data.

Patients were examined before surgery and at 1, 7, 30, and 90 days after surgery. At 30 and 90 days after surgery, the best-corrected visual acuity (BCVA) and distance uncorrected visual acuity (UCVA) were measured as well as HOA values. At 90 days, contrast sensitivity test was performed under photopic and mesopic conditions in all patients.

Visual acuity was measured using the Early Treatment Diabetic Retinopathy Study charts under photopic conditions (target luminance of 85 cd/m²). The visual acuity values were converted to the logarithm of the minimal angle resolution units for statistical analysis. All eyes were targeted for emmetropia. Distance-corrected, near (33.3 cm), and intermediate (100 cm) visual acuity were studied as a measurement of depth of focus.

Wavefront analysis was carried out using the OPD-Scan aberrometer (Nidek Co, Gamagori, Japan), which uses dynamic retinoscopy technology to obtain wavefront data. All aberrations were measured up to the sixth Zernike order. Measurements were repeated at least 3 times to obtain a well-focused and aligned image of the eye. Measurements were analyzed for 5- and 6-mm pupils. Pupils were dilated with 2 drops of cyclopentolate 1% given 15 minutes apart. Measurements were obtained 45 minutes after the last cyclopentolate drop was instilled. Pupil diameter was measured using the Colvard pupillometer (Oasis Medical, Glendora, California, USA).

Contrast sensitivity was measured with VCTS 6000 (Vistech Consultants Inc, Dayton, Ohio, USA) with best

TABLE 2. Pupil Size Measured in Millimeters of Eyes Implanted with Akreos AO and Akreos Fit under Different Light Conditions

Light Conditions	Akreos AO	Akreos Fit	P Value
Scotopic 1.5 cd/m ²	4.48 ± 0.46	4.54 ± 0.40	.180
Mesopic 3 cd/m ²	4.01 ± 0.45	4.04 ± 0.41	.066
Photopic 85 cd/m ²	3.48 ± 0.42	3.42 ± 0.40	.083

spectacle correction under photopic (85 cd/m²) and mesopic (3 cd/m²) conditions. Light conditions were controlled with a luxometer (Gossen-Starlite, Nürnberg, Germany). The log base 10 contrast sensitivity values were used to construct a graphic for each spatial frequency tested and then presented in the original test scale. At the same visit, the Pelli-Robson contrast sensitivity test (Pelli-Robson chart; Clement Clarke International, London, United Kingdom) was performed using a distance of 1 m (corresponding to a spatial frequency of approximately 1 cycle/degree) and a luminance of 85 cd/m². Pupil size (in millimeters) was measured under scotopic (1.5 cd/m²), mesopic (3 cd/m²), and photopic (85 cd/m²) conditions (Table 2). Pupil diameter in millimeters was measured using the same Colvard pupillometer mentioned before.

At 90 days after surgery, a subjective questionnaire also was applied. It was the same as that used in a previous study conducted by Tester and associates.²⁶ All interviews were conducted by the same masked investigator (A.P.C.G.). The questionnaire is targeted to evaluate patient perception of overall bilateral vision, and therefore it is not specific about how each eye is deemed to be working.

All surgeries were performed by the same experienced surgeon (M.R.S.) with standardized small-incision phacemulsification with IOL implantation in the capsular bag. Continuous curvilinear capsulorhexis with an approximate 5.0-mm diameter was created. No adverse event has occurred.

Statistical analysis was performed using SPSS for Windows (version 115; SPSS, Inc, Chicago, Illinois, USA). For primary outcome measures, the statistical tests were conducted at an α level of 0.05. For the remaining analyses, a Bonferroni correction was applied and the *P* value therefore was reduced to .003. For statistical analysis of visual acuity, the logarithm of the minimal angle of resolution acuity value was used. The analysis was based on a nonnormal distribution of the data. The 2 IOLs were compared between eyes intraindividually. The nonparametric Wilcoxon paired test was used to compare data between the 2 IOL groups. For our analysis, a sample size of at least 21 eyes per group allowed effect size of 0.85 and also the sample sizes took into account a significance level of 5% and a power of 95% for the Wilcoxon test.

TABLE 3. Mean Distance-Corrected Visual Acuity for Distance, Intermediate, and Near Vision of Eyes Implanted with Akreos AO and Akreos Fit at 3 Months^a

	Akreos AO	Akreos Fit	P Value
Distance	0.00 ± 0.12	0.02 ± 0.07	.431
Intermediate	0.30 ± 0.06	0.29 ± 0.07	.083
Near	0.37 ± 0.07	0.36 ± 0.08	.102

^aData are logarithm of the minimal angle of resolution units.

FIGURE 1. Graph showing contrast sensitivity under photopic conditions in the Akreos AO group and the Akreos Fit group. The difference between the aspherical intraocular lens (IOL; Akreos AO) and the spheric IOL (Akreos Fit) was statistically significant only at 12 cycles per degree.

RESULTS

FIFTY EYES OF 25 PATIENTS (12 MEN [48.0%] AND 13 WOMEN [52.0%]) were enrolled in this study. Mean age of the patients was 56.80 ± 6.48 years. No significant difference was found between IOLs groups for mean IOL power in diopters ($P = .736$) and mean axial length in millimeters ($P = .431$). No significant difference was found between groups for mean preoperative corneal spherical aberration ($P = .321$). There was also no statistical difference between groups in mean best spectacle-corrected visual acuity, spherical equivalent, and corneal curvature before surgery.

No eye had intraoperative complications. At 3 months after surgery, all the lenses were well centered and there was no evidence of posterior capsule opacity. There were no problems with follow-up with any patients.

At 1 month after surgery, all eyes showed improvement in UCVA. The spherical equivalent was 0.02 ± 0.38 in the Akreos AO group and 0.07 ± 0.43 in the Akreos Fit group ($P = .197$). The mean distance UCVA was 0.07 ± 0.07 in the Akreos AO group and 0.09 ± 0.08 in the Akreos Fit group. There was no significant difference between the IOL groups for distance UCVA ($P = .289$). The mean distance BCVA was 0.00 ± 0.12 in the Akreos AO group and 0.02 ± 0.07 in the Akreos Fit group. There

FIGURE 2. Graph showing contrast sensitivity under mesopic conditions in the Akreos AO group and the Akreos Fit group. The difference between the aspherical intraocular lens (IOL; Akreos AO) and the spheric IOL (Akreos Fit) was statistically significant at all spatial frequencies.

TABLE 4. Wavefront Data of Eyes Implanted with Akreos AO and Akreos Fit

Wavefront Data	Akreos AO (Mean ± SD)	Akreos Fit (Mean ± SD)	P Value
5-mm pupil, 1 mo			
HOA RMS	0.81 ± 0.35	1.27 ± 0.68	.005 ^a
Coma	0.50 ± 0.19	0.57 ± 0.42	.342
Spherical aberration	0.21 ± 0.42	0.37 ± 0.16	.040 ^a
6-mm pupil, 1 mo			
HOA RMS	0.89 ± 0.18	1.34 ± 0.39	.007 ^a
Coma	0.51 ± 0.18	0.59 ± 0.26	.483
Spherical aberration	0.28 ± 0.07	0.47 ± 0.17	<.001 ^a
5-mm pupil, 3 mos			
HOA RMS	0.79 ± 0.18	1.24 ± 0.39	.015 ^a
Coma	0.49 ± 0.21	0.55 ± 0.43	.366
Spherical aberration	0.20 ± 0.07	0.37 ± 0.17	.002 ^a
6-mm pupil, 3 mos			
HOA RMS	0.96 ± 0.19	1.39 ± 0.39	.004 ^a
Coma	0.51 ± 0.19	0.57 ± 0.28	.412
Spherical aberration	0.26 ± 0.08	0.45 ± 0.17	<.001 ^a

HOA = higher-order aberration; mo(s) = month(s); RMS = root mean square; SD = standard deviation.

^aStatistically significant.

was no significant difference between the IOL groups for distance BCVA ($P = .431$). Table 3 shows the results of mean distance-corrected near and intermediate visual acuity. No significant difference was found between the Akreos AO and Akreos Fit groups for distance-corrected near ($P = .083$) and intermediate ($P = .102$) visual acuity.

Figures 1 and 2 show contrast sensitivity results under photopic and mesopic conditions. Under photopic conditions, the Akreos AO IOL presented statistically better contrast sensitivity than the Akreos Fit IOL only at 12 cycles per degree (cpd) spatial frequency ($P = .028$). Under mesopic conditions, the Akreos AO IOL presented

statistically better contrast sensitivity than the Akreos Fit IOL at all spatial frequencies (1.5, 3, 6, 12, and 18 cpd; $P = .004$, $P = .042$, $P = .017$, $P = .0017$, and $P < .001$, respectively). Mean pupil diameter was similar between the groups under photopic, mesopic, and scotopic conditions (Table 2). Mean contrast sensitivity values, measured by the Pelli-Robson test, were 1.57 ± 0.03 in the Akreos AO group and 1.56 ± 0.03 in the Akreos Fit group ($P = .041$).

Table 4 shows wavefront data at 1 and 3 months after cataract surgery. At 1 month after surgery, the Akreos AO group had statistically significantly lower values of mean HOA compared with the Akreos Fit group with 5.0- and 6.0-mm pupil diameters ($P = .005$ and $P = .007$, respectively).

When analyzing HOAs separately after 1 month, no statistically significant difference of coma values was found between groups with 5.0-mm ($P = .342$) and 6.0-mm ($P = .483$) pupils. The Akreos IOL obtained significantly lower values of spherical aberration when compared with the Akreos Fit IOL with 5.0- and 6.0-mm pupils ($P = .040$ and $P < .001$, respectively).

At 3 months after surgery, the Akreos AO group had statistically significant lower values of mean HOA compared with the Akreos Fit group with 5.0- and 6.0-mm pupil diameters ($P = .015$ and $P = .004$, respectively). When analyzing HOAs separately after 3 months, no statistically significant difference of coma values was found between groups with 5.0-mm ($P = .366$) and 6.0-mm ($P = .412$) pupils. The Akreos AO IOL obtained significant lower values of spherical aberration when compared with the Akreos Fit IOL with 5.0- and 6.0-mm pupils ($P = .002$ and $P < .001$, respectively).

A subjective questionnaire was applied to analyze patient visual perception after both types of IOL implantation. Eighty percent (20 patients) were very satisfied with the visual improvement in both eyes; 16.0% (4 patients) were satisfied, and 4% (1 patient) were neutral. Some type of visual disturbance (light-caused glare, increase in eye sensibility, unwanted images) was reported by 56% of the patients.

DISCUSSION

THIS CONTRALATERAL EYE STUDY WAS CONDUCTED TO analyze the theoretical benefits of aspherical IOL implantation in reducing spherical aberration and its potential benefits in functional vision. The IOL Akreos AO is one of the aspherical IOLs less studied in peer-reviewed literature.¹ Different IOLs from the same manufacturer were used to minimize bias from different IOL materials.

Both IOLs achieved satisfactory UCVA and BCVA. The in-focus performance of the aspherical Akreos AO was similar to the spheric Akreos Fit. Previous studies that compared aspherical and spheric IOLs also showed similar

values for distance BCVA. A study conducted by Mester and associates and another conducted by Bellucci and associates showed better in-focus performance in eyes implanted with aspherical IOLs compared with those with spheric IOLs.^{5,7}

In addition to visual acuity measurements, wavefront analysis and contrast sensitivity tests provide important information on visual optics. Despite remaining controversial,^{1,2} reduction of ocular spherical aberrations may lead to improvements in contrast sensitivity and visual quality.³⁻¹³

Our study confirms previous findings that aspherical IOLs lead to a significant decrease in spherical aberrations. We found statistically significant lower values of spherical aberration with the aspherical IOL Akreos AO compared with the spheric IOL Akreos Fit.

Previous studies comparing aspherical and spheric IOLs showed lower values of spherical aberration in the aspherical group. Bellucci and associates, in a study with the aspherical IOL Tecnis (Advanced Medical Optics, Inc, Santa Ana, California, USA), which has negative spherical aberration, showed lower values of spherical aberration compared with the other 4 spheric IOLs in 4.0- and 6.0-mm pupil size.¹⁴ Kasper and associates, in a study to evaluate HOA as a function of pupil diameter, also showed lower values of spherical aberration in eyes implanted with aspheric IOL Tecnis compared with the spheric IOL AR40e in 3.0-, 3.5-, 4.0-, 5.0-, and 6.0-mm pupil size.²⁷ Marcos and associates showed lower values of spherical aberration in Tecnis group compared with the spheric SA60AT in a 4.5-mm pupil.²⁸ Rocha and associates also analyzed spherical aberration in eyes implanted with an aspherical IOL, which has negative spherical aberration as well.²⁹ In that study, the authors compared AcrySof IQ (Alcon Laboratories, Inc, Fort Worth, Texas, USA) with 2 spheric IOLs, the SN60AT (Alcon Laboratories, Inc) and AR40e (Advanced Medical Optics), and also showed lower values of aspherical aberration in the aspherical IOL group. Tzelikis and associates showed lower values of spherical aberration in the AcrySof IQ group compared with the spheric IOL SN60AT group at 5 and 6 mm.⁹ In our study, eyes implanted with the aspherical IOL Akreos AO showed lower values of spherical aberration compared with eyes implanted with the spheric IOL Akreos Fit.

Because we study an aspherical IOL that theoretically does not present negative spherical aberration, a higher amount of total ocular spherical aberration was found in our study compared with those previous studies that analyzed other types of aspherical IOLs, which have residual negative spherical aberration.

Caporossi and associates conducted a study that compared an aspherical IOL that also does not generate internal negative spherical aberration, the Sofport AO (Bausch & Lomb, Inc), with a spheric IOL and also found lower values of spherical aberration with the aspherical IOL.⁸ Johansson and associates compared the

aspherical IOL Akreos AO to aspherical IOL Tecnis and showed significantly lower values of spherical aberration in favor of the Tecnis group.²² Nabh and associates compared 3 aspherical IOLs (Akreos AO, Tecnis, and AcrySof IQ) and showed lower values of spherical aberration in eyes implanted with the AcrySof IQ compared with eyes implanted with the Akreos AO; however the Akreos AO group had lower values of spherical aberration compared with the aspherical IOL Tecnis group.²³

The mean ocular spherical aberration values after 3 months at 5.0 mm ($0.20 \pm 0.07 \mu\text{m}$) and at 6.0 mm ($0.26 \pm 0.08 \mu\text{m}$) with the Akreos AO IOL in our study were higher than those of Johansson and associates at 5.0 mm ($0.17 \pm 0.06 \text{ mm}$) and lower at 6.0 mm ($0.35 \pm 0.13 \text{ mm}$).²² Different devices to obtain wavefront data and corneal aberration induced by surgeons may explain these differences. In our study, both groups had low values of decentration, and there was no statistically significant difference in coma values between the aspherical and spheric IOL groups.

Dietze and Cox suggested that more coma aberration is induced when an aspherical IOL is decentered.³⁰ It is possible that our lower decentration rates justify the lower levels of coma aberration measured in both IOL groups. However, a longer follow-up is required because an asymmetric contraction of a fibrotic capsule may develop and decenter the implanted IOL, as demonstrated by several authors.^{31–33}

Under mesopic conditions, postoperative VCTS contrast sensitivity testing showed significant differences between the 2 groups at all spatial frequencies, indicating that the Akreos AO IOL group performed better than the Akreos Fit group in larger pupil sizes. However, under photopic conditions, the Akreos AO IOL performed better than Akreos Fit only at 12 cpd.

Johansson and associates²² showed similar results under mesopic and photopic conditions in the aspherical Akreos AO IOL group compared with aspherical Tecnis IOL group. However, the authors found statistically significantly lower values of spherical aberration in the Tecnis group. They suggested that the Akreos AO IOL could have a better performance compared with a corresponding spherical IOL, which was confirmed in our study.

Surprisingly, the Pelli-Robson test performed under photopic conditions showed a statistically significant difference between the 2 IOLs, favoring the aspherical IOL group. These results point out that the benefits of Akreos AO are clearer under mesopic conditions with higher pupil diameter, whereas its benefits under photopic conditions remain unclear.

It is important to keep in mind that the methods used to measure contrast sensitivity varied between studies^{1,2} and could not be sensitive enough to detect differences in contrast vision under photopic or mesopic conditions, although these differences may be significant.³⁴ A review by Montés-Micó and associates emphasized discrepant

results with aspherical IOLs under photopic conditions.¹ However, under mesopic conditions, the outcomes seem to be less contradictory. Munóz and associates and Kasper and associates showed that although they found lower values of spherical aberration in the aspherical IOL group, they found similar results under mesopic conditions between aspherical and spherical IOLs.^{35,36}

Rocha and associates,²⁹ in a study of the AcrySof IQ aspherical IOL, showed lower values of spherical aberration and reached statistical significance in contrast sensitivity test results under mesopic conditions only at 3 cpd. The results of our study suggest that the lower values of spherical aberration resulted in a better visual performance in mesopic conditions.

In our study, depth of focus in patients implanted with the aspherical Akreos AO was similar to that in patients implanted with spheric IOLs. It should be noted that both IOLs studied generated a considerable amount of spherical aberration if compared with the results of previous studies.

Johansson and associates,²² in a study of the Akreos AO and Tecnis, showed that a higher amount of spherical aberration results in a better depth of focus. In their study, the Akreos AO resulted in better depth of focus compared with the aspherical IOL Tecnis. Marcos and associates analyzed the depth of focus and concluded that tolerance to defocus tended to be lower with aspherical IOLs with negative spherical aberration compared with spheric IOLs.²⁸

Rocha and associates studied the depth of focus in patients implanted with aspherical AcrySof IQ and spheric IOLs.³⁷ They concluded that the reduction in spherical aberration with aspherical IOL may degrade distance-corrected near and intermediate visual acuity. They also showed that residual spherical aberration can improve depth of focus in eyes with spherical IOLs.

Our results confirm those findings. Although there was a significantly different amount of spherical aberration between the 2 IOLs studied, the depth of focus was similar. After implantation of an aspherical IOL that does not generate negative spherical aberration to compensate for the positive spherical aberration of the cornea, we found a higher amount of spherical aberration in the optical system. With that value of spherical aberration, it seems that there will be no critical reduction of depth of focus.

Favorable objective results, as reported by previous studies, do not necessarily correlate with better perceived visual quality by patients.^{1,2} In our study, most of the patients were very satisfied with their visual quality in both eyes, which is probably because of the significant visual acuity improvement after cataract removal.

IOL design and IOL material may play a role in results comparing different IOLs. In our study, we used IOLs of the same material. One limitation of our study is the number of eyes included. We also did not perform a separate analysis of corneal aberrations after surgery. However, the design of our study, with bilateral randomized

surgery, makes it unlikely that surgically induced differences in the cornea contributed significantly to the results. In addition, values of corneal spherical aberration were similar before surgery. Moreover, because the total aberrations of the eye directly affect the image quality, it is relevant to measure them from the patient's perspective.

Senile miosis may be a limiting factor of the benefits of aspherical IOLs. Mean values of pupil diameter under mesopic conditions are lower than the pharmacologic dilated pupils used to obtain reliable wavefront data. Further intraindividual studies of optical quality with different pupil diameters would give more appropriate data and would be more realistic of daily activities.

In summary, the aspherical IOL studied should be considered an option to improve the patient's optical quality and functional vision after cataract surgery. Although most of the patients were satisfied with their visual improvement in both eyes, the aspherical Akreos AO IOL induced lower values of spherical aberration, with better performance in the contrast sensitivity test under mesopic conditions and similar depth of focus compared with the spheric IOL Akreos Fit. Our results lead us to suggest that the aspherical IOL studied, if implanted in an eye, will provide better spherical aberration and contrast sensitivity parameters compared with the spheric IOL. Further studies with a larger sample size are necessary.

THE AUTHORS INDICATE NO FINANCIAL SUPPORT OR FINANCIAL CONFLICT OF INTEREST. INVOLVED IN DESIGN OF THE study (M.R.S., M.V.N.); Conduct of the study (M.R.S.); Collection (M.R.S., B.A.F.G., A.P.C.G., A.M.), management (M.R.S., M.V.N., J.B.), and analysis and interpretation (M.R.S., M.V.N., J.B., N.K.-J.) of the data; and Preparation (M.R.S.), review (M.R.S., M.V.N., J.B., N.K.-J.), and approval (M.R.S., M.V.N., N.K.-J.) of the manuscript. The research was approved by the review board (Comissão de Ética para Análise de Projetos de Pesquisa) of University of São Paulo, São Paulo, Brazil. Written informed consent was obtained from all patients before surgery. The study followed the tenets of the Declaration of Helsinki. *ClinicalTrials.gov* identifier: NCT00863759.

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4.2: Artigo sobre parâmetros de qualidade de imagem.

Optical Quality in Eyes Implanted With Aspheric and Spherical Intraocular Lenses Assessed by NIDEK OPD-Scan: A Randomized, Bilateral, Clinical Trial

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ABSTRACT

PURPOSE: To determine whether implantation of an intraocular lens (IOL) with an aspheric surface (Akreos AO, Bausch & Lomb Inc) results in reduced ocular aberrations (spherical aberration) and improved Strehl ratio and modulation transfer function (MTF) after cataract surgery.

METHODS: In an intraindividual, randomized, double-masked, prospective study of 50 eyes (25 patients) with bilateral cataract, an IOL with modified anterior and posterior surfaces (Akreos AO) was implanted in one eye and a biconvex IOL with spherical surfaces (Akreos Fit, Bausch & Lomb Inc) implanted in the fellow eye. Ocular aberrations, Strehl ratio, and MTF curve with 4.5-, 5.0-, and 6.0-mm pupils were measured with a NIDEK OPD-Scan dynamic retinoscopy aberrometer 3 months after surgery. Uncorrected and corrected distance visual acuity (UDVA and CDVA, respectively) were also measured.

RESULTS: No statistically significant difference was noted between eyes in postoperative UDVA and CDVA at 1 month. At 3 months, the Akreos AO IOL group obtained statistically significant lower values of higher order and spherical aberrations with 4.5-, 5.0-, and 6.0-mm pupil diameters than the Akreos Fit IOL group ($P < .05$). The value of Strehl ratio was statistically significantly higher in eyes with the Akreos AO IOL for 4.5- and 6.0-mm pupils ($P < .05$). The MTF curve was better in the Akreos AO IOL group in 4.5-, 5.0-, and 6.0-mm pupils ($P < .05$).

CONCLUSIONS: The aspheric Akreos AO IOL induced significantly less spherical aberration than the Akreos Fit IOL for 4.5-, 5.0-, and 6.0-mm pupils. Modulation transfer function and Strehl ratio were also better in eyes implanted with the Akreos AO IOL than the Akreos Fit. [*J Refract Surg.* 2011;27(4):287-292.] doi:10.3928/1081597X-20100714-01

Because optical quality decreases with aging,¹⁻⁵ replacement of the crystalline lens with an artificial intraocular lens (IOL) attempts to restore it. Aspheric IOLs with modified prolate surfaces reduce higher order aberration and improve functional vision, especially contrast sensitivity under mesopic conditions.

Clinical aberrometers provide an objective measurement of optical aberrations beyond sphere and cylinder, such as spherical aberration, coma, trefoil, and other higher order aberrations. Wavefront sensors also provide image quality metrics, such as the modulation transfer function (MTF) and point spread function (PSF) expressed as Strehl ratio.⁶⁻¹¹

The aim of this prospective, randomized clinical study is to determine whether implantation of an IOL with aspheric surface (Akreos AO; Bausch & Lomb Inc, Rochester, New York) results in better optical quality parameters, such as lower values of spherical aberration and higher MTF and Strehl ratio, compared to a spherical IOL (Akreos Fit, Bausch & Lomb Inc). To our knowledge, this is the first study with the aspheric aberration-free Akreos AO IOL implanted in one eye compared to a spherical IOL of the same material by the same manufacturer implanted in the fellow eye.

PATIENTS AND METHODS

This prospective, randomized, bilateral, double-masked clinical study included 50 eyes (25 patients) with visually significant bilateral cataracts. Patients randomly received an aspheric Akreos AO IOL in one eye (25 eyes) and a spherical Akreos Fit IOL in the fellow eye. The first patient recruited was asked to pick one of two cards to decide the type of IOL (aspheric or spherical) and to pick one of two cards to decide

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TABLE 1

Characteristics of Aspheric Akreos AO and Spherical Akreos Fit IOLs

	Akreos AO	Akreos Fit
Type	Single piece	Single piece
Overall length (mm)	10.7	11.5
Optic diameter (mm)	6.0	5.7
Optic material	Hydrophilic acrylic with UV blocker	Hydrophilic acrylic with UV blocker
Refractive index	1.458	1.458
Optic shape	Biconvex; aspheric anterior and posterior surface	Biconvex
Estimated A constant	118.0	118.0

IOLs = intraocular lens, UV = ultraviolet
Note. Both IOLs have a 360° double-squared edge.

the eye in which the selected IOL would be implanted. The other type of IOL was subsequently implanted in the fellow eye. The next patient enrolled received the opposite of the previous patient. Table 1 shows characteristics of each IOL. The study was approved by the institutional review board. An informed consent was obtained from all patients, and the study followed the tenets of the Declaration of Helsinki.

Patients with visually significant bilateral cataract and corneal astigmatism <2.00 diopters were eligible for inclusion in the study. Exclusion criteria were any ocular disease, such as corneal opacities or irregularity, dry eye, amblyopia, anisometropia, glaucoma, retinal abnormalities, surgical complications, IOL tilt, IOL decentration >0.4 mm (estimated by retroillumination), or incomplete follow-up.

To calculate IOL power, immersion ultrasound biometry (OcuScan RxP, Alcon Laboratories Inc, Ft Worth, Texas) was performed in all cases by a single experienced examiner (M.R.S.). All eyes were targeted for emmetropia.

Visual acuity was measured using the Early Treatment of Diabetic Retinopathy Study charts under photopic conditions (target luminance of 85 cd/m²). Visual acuity values were converted to the logarithm of the minimal angle resolution scale (logMAR) for statistical analysis.

Patients were examined preoperatively and at 1, 7, 30, and 90 days after surgery. At 30 days postoperatively, corrected and uncorrected distance visual acuity (CDVA and UDVA, respectively) were measured. At 90 days postoperatively, higher order aberration values, MTF, and Strehl ratio were measured.

Higher order aberrations were obtained using the

TABLE 2

Pupil Size Under Different Light Conditions for the Aspheric Akreos AO and Spherical Akreos Fit IOLs

Light Conditions	Mean ± SD (Range) (mm)		P Value
	Akreos AO	Akreos Fit	
Scotopic (1.5 cd/m ²)	4.48 ± 0.46 (4.00 to 5.50)	4.54 ± 0.40 (4.00 to 5.50)	.180
Mesopic (3 cd/m ²)	4.01 ± 0.45 (3.00 to 5.00)	4.04 ± 0.41 (3.00 to 5.00)	.066
Photopic (85 cd/m ²)	3.48 ± 0.42 (2.50 to 4.00)	3.42 ± 0.40 (2.50 to 4.00)	.083

OPD-Scan aberrometer (NIDEK Co Ltd, Gamagori, Japan), which employs dynamic skiascopy-based ocular aberrometry using 1440 points and Placido-disk corneal topography to obtain wavefront data. The OPD-Scan references the wavefront aberrations on the corneal vertex, not the line of sight. The OPD-Station software (NIDEK Co Ltd) was used to obtain the MTF and PSF expressed as Strehl ratio values. The Strehl ratio is the ratio between the intensity of the real PSF by the intensity of the perfect PSF.

The MTF and Strehl ratio were calculated based on the effect of higher order aberrations. We measured what we term the mean MTF value, which corresponds to the area under the curve. The mean MTF values were calculated in a logarithmic plot.

All aberrations were measured up to the 6th Zernike order. The coma values reported are for 3rd order aberration total coma terms (Z_3^{-1} and Z_3^1), and the values of spherical aberration comprise the spherical aberration Z_4^0 term. Measurements were repeated at least three times to obtain a well-focused, aligned image of the eye. Measurements were analyzed for 4.5-, 5.0-, and 6.0-mm pupils. Pupil diameter was measured using the Colvard pupillometer (Oasis Medical, Glendora, California). Pupils were dilated with two drops of cyclopentolate 1% administered 15 minutes apart. Measurements were taken 45 minutes after the last cyclopentolate drop was instilled.

Pupil size (mm) was also measured under scotopic (1.5 cd/m²), mesopic (3 cd/m²), and photopic (85 cd/m²) conditions (Table 2).

All surgeries were performed by the same experienced surgeon (M.R.S.) with standardized small-incision phacoemulsification with IOL implantation in the capsular bag. Continuous curvilinear capsulorhexis with an approximate 5.0-mm diameter was created. No adverse events occurred.

TABLE 3
Strehl Ratio and Wavefront Data of Eyes Implanted With the Aspheric Akreos AO and Spherical Akreos Fit IOLs at 3 Months for Different Pupil Diameters

	Mean±Standard Deviation (Range)		P Value
	Akreos AO	Akreos Fit	
4.5-mm pupil			
Strehl ratio	0.28±0.23 (0.02 to 0.62)	0.22±0.16 (0.01 to 0.33)	.040*
HOA RMS	0.77±0.15 (0.21 to 1.15)	1.18±0.38 (0.48 to 2.12)	.017*
Coma	0.48±0.21 (0.10 to 0.79)	0.54±0.33 (0.12 to 1.71)	.466
Spherical aberration	0.18±0.08 (0.01 to 0.30)	0.35±0.19 (0.05 to 0.53)	.004*
5.0-mm pupil			
Strehl ratio	0.26±0.33 (0.05 to 0.69)	0.21±0.13 (0.01 to 0.43)	.757
HOA RMS	0.79±0.18 (0.24 to 1.28)	1.24±0.39 (0.60 to 2.60)	.015*
Coma	0.49±0.21 (0.14 to 1.03)	0.55±0.43 (0.15 to 1.74)	.366
Spherical aberration	0.20±0.07 (0.02 to 0.33)	0.37±0.17 (0.07 to 0.73)	.002*
6.0-mm pupil			
Strehl ratio	0.19±0.12 (0.01 to 0.49)	0.11±0.11 (0.01 to 0.33)	.037*
HOA RMS	0.96±0.19 (0.60 to 1.29)	1.39±0.39 (0.48 to 1.97)	.004*
Coma	0.51±0.19 (0.17 to 0.77)	0.57±0.28 (0.21 to 1.22)	.412
Spherical aberration	0.26±0.08 (0.09 to 0.44)	0.45±0.17 (0.21 to 0.90)	<.001*

IOL = intraocular lens, HOA = higher order aberration, RMS = root-mean-square

*Indicates statistical significance.

Statistical analysis was performed using SPSS for Windows version 11.5 (SPSS Inc, Chicago, Illinois). All statistical tests were conducted at an alpha level of 0.05. For statistical analysis of visual acuity, logMAR acuity values were used. The two IOLs were compared between eyes intraindividually. Normality was checked, and the data did not fulfill the criteria for normal distribution. The analysis was therefore based on a nonnormal distribution of the data. The nonparametric, Wilcoxon paired test was used to compare data between IOL groups. To maintain an overall level of significance <5%, a Bonferroni correction was applied.

RESULTS

Fifty eyes of 25 patients (12 men [48%] and 13 women [52%]) were enrolled in the study. Mean patient age was 56.80 $\pm$ 6.48 years (range: 45 to 68 years). No significant difference was found between groups for mean IOL power ($P=.736$) and mean axial length ($P=.431$). No significant difference was found between groups for mean preoperative total corneal higher order aberration ($P=.421$). Postoperative values of total corneal higher order aberration were also statistically similar ($P=.423$).

No statistical difference was noted between groups in mean CDVA, spherical equivalent refraction, and corneal

curvature before surgery. No eye had intraoperative complications. At 3 months postoperatively, all IOLs were well centered, and there was no evidence of posterior capsule opacification. All patients completed follow-up.

At 1 month postoperative, all eyes showed improvement in UDVA. Spherical equivalent refraction was 0.02 $\pm$ 0.38 (range: -0.50 to 0.50) in the Akreos AO IOL group and 0.07 $\pm$ 0.43 (range: -0.50 to 0.50) in the Akreos Fit IOL group ($P=.197$). Mean UDVA was 0.07 $\pm$ 0.07 (range: 0.00 to 0.18) (20/23) in the Akreos AO IOL group and 0.09 $\pm$ 0.08 (range: 0.00 to 0.20) (20/24) in the Akreos Fit IOL group. No significant difference between groups for UDVA was noted ($P=.289$). Mean CDVA was 0.00 $\pm$ 0.12 (range: -0.10 to 0.18) (20/20) in the Akreos AO IOL group and 0.02 $\pm$ 0.07 (range: 0.00 to 0.18) (20/20) in the Akreos Fit IOL group. No significant difference between groups for CDVA was noted ($P=.431$).

At 3 months postoperatively, wavefront measurement of higher order aberrations root-mean-square (RMS) for a 4.5-mm pupil was 0.77 $\pm$ 0.15 μ m and 1.18 $\pm$ 0.38 μ m, 0.79 $\pm$ 0.18 μ m and 1.24 $\pm$ 0.39 μ m for a 5.0-mm pupil, and 0.96 $\pm$ 0.19 μ m and 1.39 $\pm$ 0.39 μ m for a 6.0-mm pupil for the Akreos AO and Akreos Fit IOL groups, respectively. The Akreos AO IOL group

Figure 1. Modulation transfer function curve according to intraocular lens (IOL) group obtained with a 5.0-mm pupil diameter at different spatial frequencies. Three months postoperatively, eyes implanted with aspheric Akreos AO IOLs had statistically significantly higher values compared to eyes implanted with spherical Akreos Fit IOLs at all spatial frequencies studied.

Figure 2. Modulation transfer function curve according to intraocular lens (IOL) group obtained with a 6.0-mm pupil diameter at different spatial frequencies. Three months postoperatively, eyes implanted with aspheric Akreos AO IOLs had statistically significantly higher values compared to eyes implanted with spherical Akreos Fit IOLs at all spatial frequencies studied.

had statistically significantly lower values of higher order aberrations than the Akreos Fit IOL group for 4.5-, 5.0-, and 6.0-mm pupil diameters ($P=.017$, $P=.015$, and $P=.004$, respectively) (Table 3).

When analyzing higher order aberrations separately, coma for a 4.5-mm pupil was $0.48 \pm 0.21 \mu\text{m}$ and $0.54 \pm 0.33 \mu\text{m}$, $0.49 \pm 0.21 \mu\text{m}$ and $0.55 \pm 0.43 \mu\text{m}$ for a 5.0-mm pupil, and $0.51 \pm 0.19 \mu\text{m}$ and $0.57 \pm 0.28 \mu\text{m}$ for a 6.0-mm pupil for the Akreos AO and Akreos Fit IOL groups, respectively. No statistically significant difference was found between groups for 4.5-, 5.0-, and 6.0-mm pupils ($P=.466$, $P=.366$ and $P=.412$, respectively). Spherical aberration for a 4.5-mm pupil was $0.18 \pm 0.08 \mu\text{m}$ and $0.35 \pm 0.19 \mu\text{m}$, $0.20 \pm 0.07 \mu\text{m}$ and $0.37 \pm 0.17 \mu\text{m}$ for a 5.0-mm pupil, and $0.26 \pm 0.08 \mu\text{m}$ and $0.45 \pm 0.17 \mu\text{m}$ for a 6-mm pupil for the Akreos AO and Akreos Fit IOL groups, respectively. The Akreos AO IOL obtained significantly lower values of spherical aberration when compared to the Akreos Fit IOL for 4.5-, 5.0-, and 6.0-mm pupils ($P=.004$, $P=.002$, and $P<.001$, respectively).

At 3 months postoperatively, mean MTF for a 4.5-mm pupil was 0.225 ± 0.102 (range: 0.102 to 0.356) and 0.142 ± 0.072 (range: 0.040 to 0.250) ($P<.001$), 0.205 ± 0.114 (range: 0.080 to 0.340) and 0.121 ± 0.060 (range: 0.040 to 0.220) for a 5.0-mm pupil diameter ($P<.001$), and 0.122 ± 0.043 (range: 0.080 to 0.310) and 0.120 ± 0.145 (range: 0.040 to 0.200) for a 6.0-mm pupil diameter ($P=.019$) in the Akreos AO and Akreos Fit IOL groups, respectively.

We also evaluated the mean values of MTF for different spatial frequencies (5, 10, 15, 20, 25, and 30 cycles per degree) for 4.5-, 5.0- (Fig 1), and 6.0-mm (Fig 2) pupil diameters. Eyes with the Akreos AO IOL performed better for 4.5-mm pupils ($P<.05$ at all spatial frequencies), 5.0-mm pupils ($P<.05$ at all spatial frequen-

cies), and 6.0-mm pupil diameters ($P<.05$ at all spatial frequencies) compared to eyes with the Akreos Fit IOL.

At 3 months postoperatively, Strehl ratio analysis with a 4.5-mm pupil revealed values of 0.28 ± 0.23 and 0.22 ± 0.16 ($P=.040$); 0.26 ± 0.33 and 0.21 ± 0.13 for a 5.0-mm pupil diameter ($P=.757$); and 0.19 ± 0.12 and 0.11 ± 0.11 for a 6.0-mm pupil ($P=.037$) in the Akreos AO and Akreos Fit IOL groups, respectively (Fig 3).

DISCUSSION

To investigate the optical quality of eyes implanted with aspheric Akreos AO and spherical Akreos Fit IOLs, we analyzed three specific indicators of optical quality—spherical aberration, PSF, and MTF.⁹⁻¹¹ To minimize bias, we used two different IOLs of the same material and manufacturer. To our knowledge, the Akreos AO IOL is one of the least studied aspheric IOLs in the peer-reviewed literature.

Optical distortions can be analyzed in eyes implanted with aspheric and spherical IOLs through the study of wavefront aberrations. Secondary measurements of optical quality, such as MTF and PSF can be derived from wavefront data.⁹ Barreto et al¹² showed that the aberrometer device used in this study provides wavefront data with acceptable repeatability.

The results of our study confirm the theoretical advantages of an aspheric IOL in reducing postoperative spherical aberrations. Eyes implanted with the aspheric Akreos AO IOL showed statistically significant lower values of spherical aberration compared to eyes implanted with the spherical IOL with 5.0- and 6.0-mm pupil diameters.

Previous studies comparing aspheric and spherical IOLs showed lower values of spherical aberration in the aspheric IOL group. Bellucci et al,¹³ in a study with the aspheric Tecnis IOL (Abbott Medical Optics [AMO],

Santa Ana, California), which has negative spherical aberration, showed lower values of spherical aberration compared to four other spherical IOLs in 4.0- and 6.0-mm pupil sizes. Tzelikis et al¹⁴ and Rocha et al¹⁵ showed lower values of spherical aberration in eyes with the AcrySof IQ IOL (Alcon Laboratories Inc, Ft Worth, Texas) compared to the spherical SN60AT IOL (Alcon Laboratories Inc) at different pupil sizes. Marcos et al¹⁶ showed lower values of spherical aberration in eyes with the aspheric Tecnis IOL compared to the spherical SA60AT IOL (Alcon Laboratories Inc) for a 4.5-mm pupil. Ohtani et al¹⁷ also showed that eyes with the aspheric IOL (Tecnics) presented significantly lower values of spherical aberrations compared to the spherical IOL in the fellow eye.

Johansson et al¹⁸ compared the aspheric Akreos AO IOL to the aspheric Tecnis IOL and showed significantly lower values of spherical aberration in favor of the Tecnis group. Mean ocular spherical aberration after 3 months at 5.0-mm ($0.20 \pm 0.07 \mu\text{m}$) and 6.0-mm ($0.26 \pm 0.08 \mu\text{m}$) pupil diameters with the Akreos AO IOL in our study were higher than those of Johansson et al¹⁸ at 5.0 mm ($0.17 \pm 0.06 \mu\text{m}$) and lower at 6.0 mm ($0.35 \pm 0.13 \mu\text{m}$). Different devices to obtain wavefront data and corneal aberration induced by surgeons could explain these differences.

It should be emphasized that the reported higher order aberration RMS values for a 5-mm pupil are higher than in the normal phakic population. We believe higher values of coma and spherical aberration as well as other higher order aberrations contribute to those values, but our study did not include a control group of phakic patients to definitively confirm this. Although the spherical IOL studied seems to induce a considerable amount of spherical and higher order aberrations, the neutral aspheric IOL used in this study does not induce negative spherical aberration, thereby compensating for positive corneal spherical aberration. We suggest that those values contributed to the reported higher order aberration RMS values, which were higher than the normal phakic population.

The MTF defines how optical systems modulate contrast sensitivity as a function of spatial frequency. In our study, we reported the mean MTF value and mean curve. The aspheric Akreos AO IOL performed better for 4.5-, 5-, and 6-mm pupil diameters. Mencucci et al¹⁹ showed that with a 5-mm pupil diameter, IOLs with aspheric surfaces effectively compensated for the spherical aberration of the cornea and had a significantly higher MTF.

It should be emphasized that the aberrometer device used in the current study performs monochromatic measurements, and the results cannot be directly compared to human polychromatic vision. Franchini²⁰

Figure 3. Point spread function expressed as Strehl ratio of eyes examined with a 5.0- and 6.0-mm pupil 3 months after surgery. Eyes implanted with aspheric Akreos AO intraocular lenses (IOLs) had statistically significant higher values of Strehl ratio with a 6.0-mm pupil compared to eyes implanted with spherical Akreos Fit IOLs.

studied the theoretical benefits of aspheric IOLs. He showed differences in the monochromatic MTF curve in favor of the aspheric IOL. However, he did not find a significant difference in the results of polychromatic MTF compared to a spherical IOL.

Point spread function can theoretically be expressed through measurements derived from the width (blur circle diameter) or height (Strehl ratio) of the intensity distribution.^{8,9}

The Strehl ratio parameter theoretically evaluates IOLs over the whole frequency spectrum and is independent from the refractive power of the tested IOL.^{8,11} In our study, eyes implanted with the Akreos AO IOL had higher Strehl ratio values compared to eyes implanted with the Akreos Fit IOL. However, it was statistically significant only with a 6.0-mm pupil diameter.

Bellucci et al²¹ compared PSF and MTF as optical quality parameters (4.0-mm pupil). They found statistically significantly better values in eyes implanted with the aspheric Tecnis IOL compared to eyes with the spherical CeeOn Edge 911 IOL (Pharmacia & Upjohn, Bridgewater, New Jersey) in age-matched patients. Marcos et al¹⁶ showed that best corrected optical quality was statistically better in eyes implanted with an aspheric IOL, but the tolerance to defocus tended to be lower.

Ligabue and Giordano²² studied optical quality in cataract and refractive surgery patients. They showed that PSF is a clinically valuable metric to evaluate the patient's visual quality postoperatively. Bühren et al²³ studied how optical quality metrics based on optical transfer function, such as higher order aberration and visual Strehl ratio, can predict subjective visual quality after refractive surgery. They showed retinal image quality should be kept as high as possible to provide good subjective quality of vision.

Rawer et al¹¹ assessed image quality through Strehl ratio and MTF. They showed that the imaging quality of different IOL designs and manufacturers varied significantly and should be considered when choosing an IOL.

One limitation of our study is the number of eyes included. We also did not perform a separate analysis of postoperative corneal aberrations. However, with the design of the study, it is unlikely that surgically induced differences or even previous values of spherical aberration in the cornea contributed significantly to the results. In addition, pre- and postoperative values of corneal higher order aberrations were statistically similar. Moreover, because the total aberrations of the eye directly affect the image quality, it is relevant to measure them from the patient's perspective.

Senile miosis may be a limiting factor of the benefits of aspheric IOLs. Mean values of pupil diameter under mesopic conditions are lower than the pharmacologically dilated pupils used to obtain wavefront data. Further studies of optical quality with different pupil diameters would give more appropriate data and would be more realistic of daily activities.

Aspheric IOLs can be considered an option to improve optical quality after cataract surgery. Optical quality parameters, such as spherical aberration, MTF, and Strehl ratio, seem to be better in eyes implanted with aspheric Akreos AO IOLs compared to eyes with spherical Akreos Fit IOLs.

AUTHOR CONTRIBUTIONS

Study concept and design (M.R.S., M.V.N., N.K.J.); data collection (M.R.S., B.A.F.G., C.D.O., N.K.J.); analysis and interpretation of data (M.R.S., M.V.N., J.B., B.A.F.G., N.K.J.); drafting of the manuscript (M.R.S., M.V.N., J.B., B.A.F.G., C.D.O., N.K.J.); critical revision of the manuscript (M.R.S., J.B., N.K.J.); statistical expertise (M.R.S.); supervision (M.R.S.)

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5 COMENTÁRIOS CONCLUSIVOS

Para analisar os potenciais benefícios da LIO asférica Akreos AO em reduzir aberração esférica, melhorar a qualidade de visão e melhorar a sensibilidade ao contraste sem reduzir criticamente a profundidade de foco, conduziu-se este estudo comparativo duplo-cego randomizado. Para minimizar possíveis vieses escolheu-se implantar uma LIO asférica em um olho e uma LIO esférica produzida pelo mesmo laboratório e do mesmo material no olho contralateral do paciente.

Parâmetros objetivos de qualidade óptica, como aberração esférica, razão Strehl, função de transferência de modulação e sensibilidade ao contraste foram utilizados para investigar a degradação da qualidade de imagem.

A LIO asférica neutra investigada demonstrou-se capaz de produzir menores valores de aberrações de maior ordem e subsequente melhores valores de qualidade óptica. Mesmo apresentando maiores valores de aberração esférica residual por não gerar aberração esférica negativa, o presente estudo confirma publicações prévias que mostram que olhos onde foram implantadas LIOs asféricas apresentam significativa redução dos valores de aberração esférica, comparado a olhos com LIOs esféricas.⁹

O teste de sensibilidade ao contraste em condições mesópicas apresentou diferenças significativas entre os dois grupos em todas as frequências espaciais estudadas, indicando melhor performance da LIO Akreos AO em condições de maior diâmetro pupilar. Entretanto, em condições fotópicas, encontrou-se diferença em favor da LIO asférica apenas na frequência espacial de 12 ciclos por grau. Este resultado indiretamente nos mostrou que os benefícios das LIOs asféricas, relacionados ao teste de sensibilidade ao contraste, parecem ser mais claros em condições de pupila com maior diâmetro.

No presente estudo não encontrou-se diferença significativa na profundidade de foco entre o grupo de LIOs esféricas e esféricas. Deve ser notado que em ambos os grupos estudados uma quantidade considerável de aberração esférica foi encontrada, embora significativamente menor no grupo de LIOs esféricas. Provavelmente há um valor de aberração esférica acima do qual a profundidade de foco se mantém a mesma. O ideal seria portanto identificar a faixa de valores de aberração esférica onde se mantém o ganho de qualidade de imagem sem que ocorra redução crítica da profundidade de foco. Sugerimos novos estudos com este objetivo específico e será uma de nossas linhas de pesquisa no futuro.

Este estudo conclui portanto, que a LIO esférica neutra estudada, é capaz de produzir melhores valores de qualidade óptica, tais como aberração esférica, função de transferência de modulação, razão Strehl e sensibilidade ao contraste quando comparada à LIO esférica. Identificamos ainda que os benefícios descritos acima ocorrem sem que haja redução significativa da profundidade de foco.

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