ORIGINAL ARTICLE/KLİNİK ÇALIŞMA

Comparison of Scleral-Fixated Intraocular Lens Implanted Patients in Terms of High-Order Wavefronts Aberrations

Skleral Fiksasyonlu Intraoküler Lens Yerleştirilen Hastalarda Yüksek Sıralı Aberrasyonların Karşılaştırılması

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ABSTARCT

Purpose: To study and compare the effects of the foldable scleral-fixated intraocular lens implantation surgery and unfoldable scleral-fixated intraocular lens implantation surgery on the optical quality characterized in terms of aberrations with a wavefront sensor.

Materials and Methods: In total, 20 eyes of 20 patients (11 women, 9 men) who had undergone scleral-fixated IOL implantation surgery to correct aphakia between January 2004 and September 2009 were included in the study. All of the surgeries were conducted by same surgeon in the Cerrahpasa Faculty of Medicine, Department of Ophthalmology at Istanbul University. The average age of the patients was 55.05, and patients ranged in age from 11 to 78 years. Patients were divided two groups.Group 1 (11 eyes): Patients had foldable scleral-fixated intraocular lens,group 2 (9 eyes): Patients had unfoldable scleral-fixated intraocular lens. Informed consent was obtained from each of the patients included in the study.

Detailed biomicroscopy and fundus examinations were performed. A Keratron Scout videokeratoscope was used to measure corneal topography, and ORK wavefront device was used to measure optical aberrations.

Results: There is no significant difference for Coma (µ), Trefoil (µ) and Spherical aberrations (µ) between two groups (p values are respectively 0.370; 0.199 and 0.503).

Conclusions: Foldable or unfoldable scleral-fixated intraocular lens implantation surgery induces High-order aberrations. This information may provide better understanding of the optical performance of eyes implanted with scleral-fixated IOLs The weakness of this retrospective study is that various types of IOLs were used and The number of patients were limited in our study. Further studies are warranted.

Key Words: Wavefront aberrations,scleral-fixated lens,cataract.

ÖZ

Amaç: Katlanabilir skleral fiksasyonlu lens ve katlanmayan skleral fiksasyonlu lens yerleştirilen hastaları optik kalite bakımından karşılaştırmak için Wave front aberrometre ile ölçülen optik aberasyonların karşılaştırılması.

Gereç ve Yöntem: Çalışmaya alınan hastalar Ocak 2004-Eylül 2009 tarihleri arasında İstanbul Üniversitesi Cerrahpaşa Tıp Fakültesi Göz Hastalıkları Anabilim dalında afaki tashihi için skleral fiksasyonlu intraoküler lens implantasyonu ameliyatı yapılmış olgular arasından seçildi. Dokuz erkek 11 kadın toplam 20 hastanın 20 gözünü kapsayan çalışmamızda tüm hastaların ortalama yaşı 55.05 (11-78) idi. Hastalar 2 gruba ayrıldı. 1. Grup (11 hasta) katlanabilir skleral fiksasyonlu lens yerleştirilen, 2. Grup (9 hasta) katlanmayan skleral fiksasyonlu lens yerleştirilen hastalar. Çalışma kapsamına alınan tüm olgulardan çalışma kapsamı ve amacı açıklanarak izin belgesi alındı. Ameliyat sonrası en az bir yılını doldurmuş olan hastaların detaylı biomikroskopi ve indirekt oftalmoskopi ile göz dibi muayeneleri yapıldı.

Hastaların kornea topoğrafileri Keratron Scout videokeratoskop (Optikon 2000 İtaly) cihazı ile çekildi. Optik aberasyon ölçümleri için ORK Wavefront (SCHWİND eye-tech-solutions Gmbh&Co-KG) cihazı kullanıldı.

Bulgular: İki gurup arasında Coma (µ), Trefoil (µ) and Sferik (µ) aberasyonlar açısından anlamlı fark bulunamadı (p değerleri 0.370; 0.199 ve 0.503 sırasıyla).

Sonuç: Katlanabilir ve katlanmayan skleral fiksasyonlu lens yerleştirilen hastalarda yüksek sıralı aberasyonlar artar. Ancak iki gurup arasında anlamlı fark bulunamadı. Çalışmamızda hasta sayısının az olması dezavantaj oluşturmaktadır.Daha fazla hastayı kapsayan çalışmalar gereklidir.

Anahtar Kelimeler: Wavefront aberasyonlar, skleral fiksasyonlu lens, katarakt.

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INTRODUCTION

Scleral suture fixation of a posterior chamber IOL is one of the surgical procedures used to visual rehabilitation when an IOL cannot be implanted due to the absence of capsular or/and zonular support.[1,2] Other possible methods of visual rehabilitation include using eyeglasses and contact lenses, anterior chamber IOL implantation and iris claw IOL implantation.[3,4] Wavefront aberration analysis are non-invasive, non-contact, sensitive, and repeatable techniques, and wavefront analysis has recently become more commonly used in the field of refractive surgery.[5,6] These patients, had undergone complicated surgical procedures, which included primary or secondary scleral suture fixation of the IOL, and many of them have other ocular pathologies that affect visual functions. Thus, such evaluation is difficult in this study population. Corneal refractive changes following cataract surgery are related to the location and size of the corneal incision. Therefore, smaller incision can manipulate the cornea more gently with minimal stress and injury to the surrounding tissues providing better optical outcomes, through having a corneal incision of a good quality, both optically and morphologically.[7-11] A significantly better control of astigmatism has been demonstrated related to the reduction of corneal incision size for over 3 mm to less than 2 mm, resulting in a reduction of surgically induced astigmatism (SIA) and corneal aberrations.[8-10] The aim of this study is to investigate the effects of the foldable scleral-fixated intraocular lens implantation surgery and unfoldable scleral-fixated intraocular lens implantation surgery on the optical quality of the cornea characterized in terms of corneal aberrations with a wavefront sensor

MATERIALS AND METHODS

In total, 20 eyes of 20 patients (11 women, 9 men) who had undergone scleral-fixated IOL implantation surgery to correct aphakia between January 2004 and September 2009 were included in the study.Patients were divided two groups.

Table 1: *Demographic data and lens types used for each patient.*

Patient	Age	Gender	Cause of Aphakia	Type of Corneal incision	Type of scleral-fixated lens used
1.	68	M	Comp. Phaco	3.5 mm Corneal Incision	FH:1000
2.	55	M	Comp. Phaco	3.5 mm Corneal Incision	FH:1000
3.	33	M	Lens Lux	3.5 mm Corneal Incision	FH:1000
4.	11	F	Cong. Cat	3.5 mm Corneal Incision	FH:1000
5.	78	F	Comp. Phaco	3.5 mm Corneal Incision	FH:1000
6.	60	F	Comp. Phaco	3.5 mm Corneal Incision	ACRIVA
7.	58	M	Comp. Phaco	3.5 mm Corneal Incision	ACRIVA
8.	54	M	Comp. Phaco	3.5 mm Corneal Incision	ACRIVA
9.	63	F	Comp. Phaco	3.5 mm Corneal Incision	FH:1000
10.	52	F	Comp. Phaco	3.5 mm Corneal Incision	FH:1000
11.	60	M	Comp. Phaco	3.5 mm Corneal Incision	FH:1000
12.	65	F	Comp. Phaco	6.5 mm Corneal Incision	Schmidt
13.	63	M	Comp. Phaco	6.5 mm Corneal Incision	CZ 70 BD
14.	57	F	Comp. Phaco	6.5 mm Corneal Incision	CZ 70 BD
15.	60	M	Comp. Phaco	6.5 mm Corneal Incision	Schmidt
16.	53	F	Comp. Phaco	6.5 mm Corneal Incision	CZ 70 BD
17.	28	M	Lens Lux	6.5 mm Corneal Incision	Schmidt
18.	65	F	Comp. Phaco	6.5 mm Corneal Incision	Schmidt
19.	69	F	Comp. Phaco	6.5 mm Corneal Incision	Schmidt
20.	49	F	Comp. Phaco	6.5 mm Corneal Incision	Schmidt

Comp. Phaco: Complicated Phacoemulsification, Cong. Cat: Congenital Cataract, Lens Lux: Lens Luxation, FH:1000: Lenstec, Florida, USA, ACRIVA: VSY Biotechnology, Istanbul, Turkey, CZ 70 BD: Alcon, Texas, USA, Schmidt: Dr. Schmidt intraocularlinsen GmbH-Sankt Augustin, Deutschland.

***Table 2:** Topography, astigmatism, and visual acuity values for each patient.*

Patient	SimK1	SimK2	Astigmatism	Uncorrected visual acuity	Corrected visual acuity
1.	45.8	43.8	-1.25	0.6	0.85
2.	44.5	41.7	-2.25	0.2	0.7
3.	44.6	42.7	-1.75	0.4	0.9
4.	39.1	37.9	-1.00	0.2	0.8
5.	44.8	42.9	-1.75	0.4	0.9
6.	48.4	47.0	-1.00	0.6	1.0
7.	43.7	41.8	-2.75	0.5	1.0
8.	45.7	42.0	-3.25	0.5	1.0
9.	46.8	45.7	-1.75	0.6	1.0
10.	44.4	43.3	-1.00	0.5	0.8
11.	42.8	41.5	-1.25	0.35	0.75
12.	45.2	43.0	-1.75	0.3	0.6
13.	41.9	41.2	-1.75	0.1	0.7
14.	46.3	43.2	-1.75	0.2	0.8
15.	44.1	42.3	-4.00	0.3	1.0
16.	45.1	41.1	-3.25	0.3	0.9
17.	44.8	42.3	-2.00	0.4	0.85
18.	46.7	42.5	-3.25	0.35	1.0
19.	44.2	42.5	-2.50	0.4	0.8
20.	44.5	42.9	-1.50	0.2	0.6

Group 1 (11 eyes): Patients had foldable scleral-fixated intraocular lens, group 2 (9 eyes): Patients had unfoldable scleral-fixated intraocular lens. All of the surgeries were conducted by same surgeon in the Cerrahpasa Faculty of Medicine, Department of Ophthalmology at Istanbul University. The average age of the patients was 55.05, and patients ranged in age from 11 to 78 years. Informed consent was obtained from each of the patients included in the study. Information regarding the demographic and medical history data of each patient, including his/her age, gender, cause of aphakia, corneal incision type, and scleral-fixated implanted IOL, are presented in table 1.

Criteria for participation in the study

Patients whose ocular media were not transparent (due to corneal opacity, corneal edema, vitreous hemorrhage, vitritis, or endophthalmitis), those who presented with ocular pathology (such as retinal detachment, macular diseases, optic disc anomalies, optic disc edema, glaucoma, and uveitis), and those whose pupils did not sufficiently dilate were excluded from the study due to the potential for inaccuracies in their wavefront measurements.

Methods

The visual acuity of each patient included in the study was determined with and without correction using the Snellen scale, and refractive errors were determined using a Topcon KR-8800 autorefractometer (Topcon corporation, Tokyo, Japan). All participants had undergone scleral-fixated intraocular lens (IOL) implantation surgery at least 1 year prior to participating in the study. Their intraocular pressures were measured with a Topcon CT80 non-contact tonometer (Topcon corporation, Tokyo, Japan). Detailed biomicroscopy and fundus examinations were performed. A Keratron Scout videokeratoscope (Optikon 2000 Industrie, Rome, Italy) was used to assess the corneal topography of each patient. Both the simK1 and simK2 corneal topography measurements were repeated three times to determine an average value for each. The measurements obtained from the topographic maps were recorded for further evaluation in the study. Measurements of optical aberrations were obtained using an (ORK) wavefront device (SCHWIND eye-tech-solutions Gmbh&Co-KG, Kleinostheim, Germany).

Table 3: *Aberrations of Group 1.*

Patient	Coma (μ)	Trefoil (μ)	Spherical Aberrations (μ)
1.	0.294	0.292	0.201
2.	0.204	0.035	0.109
3.	0.06	0.14	0.037
4.	0.08	0.105	0.017
5.	0.058	0.143	0.034
6.	0.061	0.146	0.01
7.	0.285	0.512	0.453
8.	0.218	0.855	0.109
9.	0.604	0.471	0.575
10.	0.585	0.672	0.494
11.	0.297	0.474	0.061

The corneal aberrations were obtained for a pupil 6 mm in diameter. The obtained data were expanded into the set of orthogonal Zernike polynomials. The root-mean squares of third-order Zernike components (Z_3^{-3} to Z_3^{3}) were used to represent trefoil,coma-like aberration and root-mean squares of fourth-order Zernike components (Z_4^{-4} to Z_4^{4}) were used to represent spherical-like aberrations.[12-14]

Wavefront aberrations were measured three times for each patient by fixing the patient's eye in the fixation point of the device, and coma, trefoil, and spherical aberration values were determined using the averages of these three measurements.

Statistical Method

"SPSS 13.0 for Windows (Chicago, IL)" used for statistical analysis. Numerical variables (Coma, Trefoil and Spherical aberrations) are given with mean, standart deviation, median, minimum and maximum values. Shapiro-Wilk test is used for normality tests. For nonparametric variables, Mann Whitney U test used for two group comparions. For all statistical analysis with p value under 0.05 is assumed as there is a statistical significance.

Table 4: *Aberrations of Group 2.*

Patient	Coma (μ)	Trefoil (μ)	Spherical Aberrations (μ)
12.	0.19	0.711	0.16
13.	0.195	0.65	0.18
14.	0.32	0.985	0.256
15.	0.302	0.175	0.084
16.	0.21	0.84	0.102
17.	0.311	0.355	0.156
18.	0.267	0.264	0.184
19.	0.311	0.643	0.243
20.	0.292	0.079	0.106

RESULTS

The corneal topography findings, degrees of astigmatism, and visual acuities of the patients who participated in the study are presented in Table 2.The mean astigmatism values of group 1 greater than group 2 (-1.73±0.75 and -2.42±0.88 respectively) but there is no significant difference statisticaly.There is no significant difference between The mean Sim K1 values of group 1 and group 2 (44.60±2.37 and 44.76±1.39 respectively). There is no significant difference betveen The mean Sim K2 values of group 1 and group 2 (42.75±2.36 and 42.33±0.74 respectively).

Optical aberration measurements are presented in are presented in tables 3 and 4. The mean RMS values of group 1 for coma-like aberrations,spherical aberrations,trefoil aberrations were 0.25 μm,0.19 μm and 0.35 μm respectivly and mean RMS values of group 2 for coma-like aberrations,spherical aberrations,trefoil aberrations were 0.27 μm,0.16 μm and 0.52 μm respectivly. Statistical analysis are presented in table 5. Foldable and unfoldable scleral-fixated intraocular lens implantation surgery induces High-order aberrations. There is no significant difference for Coma (μ), Trefoil (μ) and Spherical aberrations (μ) between two groups (p values are respectively 0.370; 0.199 and 0.503).

Table 5: *Statistical analysis.*

		Group 1 (n=11)	Group 2 (n=9)	p
Coma (μ)	Mean±SD Median (Min-Max)	0.250±0.196 0.218 (0.058 - 0.604)	0.266±0.053 0.292 (0.190-0.320)	0.370
Trefoil (μ)	Mean±SD Median (Min-Max)	0.350±0.266 0.292 (0.035 - 0.855)	0.522±0.315 0.643 (0.079-0.985)	0.199
Spherical aberrations (μ)	Mean±SD Median (Min-Max)	0.191±0.212 0.109 (0.010 - 0.575)	0.163±0.060 0.160 (0.084-0.256)	0.503

DISCUSSION

Spherical aberrations are important for determining contrast sensitivity, visual acuity and focal depth. As the degree of spherical aberration increases, night vision and especially contrast sensitivity decrease, and the amounts of glare and halo experienced by a patient increase.

Coma, the second most important aberration, is important in determining contrast sensitivity, visual acuity, and accommodation.[15]

Tzelikis and colleagues[16] reported that decreases in ocular spherical aberration result in increases in contrast sensitivity and visual acuity.

Optical outcomes after cataract surgery depend on two main factors combined together to produce the fine retinal image, which are the eye's aberrations (modified by the surgery) and IOL-induced aberrations. Incision size has the greatest impact on the optical aberrations induced by surgery, and the smaller the incision, the lower the aberrations, the better the optical quality.[17,18]

Implantation of the spherical PMMA IOL led to a slight reduction in total wavefront aberration compared to phakic eyes. AcrySof IOLs induced more aberrations, especially spherical aberration. Corneal-based incisions for IOL implantation compounded this increase. Studies of the optical performance of IOLs in vivo should use wavefront sensing as the main outcome measure rather than visual measures, which are readily confounded by multiple factors.[19]

An increase in IOL high-order aberrations contributed to the decline in retinal image quality. An IOL modifies the entire aberration pattern of the eye. There was a statistically significant increase in aberrations in patients with an acrylic IOL compared to those with a silicone or PMMA IOL. The exact mechanism is uncertain.[20]

Ocular, corneal, and internal optic higher-order wavefront aberrations are correlated significantly with visual function in eyes with a spherical monofocal IOL. The spherical aberration of the internal optics and coma of the cornea vary between eyes with different types of IOL.[21]

Artiflex pIOL implantation decreased spherical aberration, while Artisan pIOL implantation increased spherical aberration. Trefoil-y increased in both groups. These changes might be explained by incision size differences in relation to trefoil and differences in optic design in relation to spherical aberration.[22]

There is a possibility that the differences in IOL design and material resulted in different amount and pattern of ocular wavefront aberrations.

Bellucci et al[23] have reported, however, that ocular coma-like aberrations did not differ significantly among various types of IOLs, whereas ocular spherical-like aberrations were largely affected by the style of IOLs.

A new class of IOLs designed to offset corneal spherical aberration has been recently introduced, making the relative alignments of IOLs and other optical components of the eye more important. [24-27]

In eyes with scleral-sutured posterior chamber IOL, tilting of the lens induces considerable amount of ocular coma-like aberrations.[28]

Small-incision surgery does not systematically degrade the optical quality of the anterior corneal surface. However, it introduces changes in some aberrations, especially in nonrotationally symmetric terms such as astigmatism, coma, and trefoil.

The results in the same patients before and after surgery, indicate that small 3.5 mm incision surgery produces only moderate changes and, on average, a small increase in aberrations. The larger changes occurred in the corneas with nasal incisions. However, the increase was not systematic. The incision site plays a main role in the corneal changes after surgery. temporal incisions induce less aberration than nasal incisions.[29]

Salmon and colleagues[30] were collected data from 10 laboratories that measured higher-order aberrations (HOAs) in normal, healthy adult eyes using Shack-Hartmann aberrometry (2560 eyes of 1433 subjects). Signed Zernike coefficients were scaled to pupil diameters of 6.0 mm and mean RMS values for coma-like aberrations,spherical aberrations,trefoil aberrations were 0.14 µm,0.13 µm and 0.11 µm respectivly. These values can serve as a set of reference norms.

We detected the mean RMS values of Foldable scleral-fixated intraocular lens implantated patients for coma-like aberrations,spherical aberrations,trefoil aberrations were 0.25 µm,0.19 µm and 0.35 µm respectivly and mean RMS values of unfoldable scleral-fixated intraocular lens implantated patients for coma-like aberrations,spherical aberrations,trefoil aberrations were 0.27 µm, 0.16 µm and 0.52 µm respectivly.

Foldable and unfoldable scleral-fixated intraocular lens implantation surgery induces High-order aberrations. Some data can serve as a set of reference norms which Salmon and colleagues[30] reported.

The weakness of this retrospective study is that various types of IOLs were used so the effect of İOL$_s$ aberrations were ignored and The number of patients were limited in our study. This was because of the retrospective nature of the current study. Further studies are warranted.

REFERENCES/KAYNAKLAR

1. Stark W J, Gottsch J D, Goodman D F. et al. Posterior chamber intraocular lens implantation in the absence of capsular support. Arch Ophthalmol 1989;107:1078-83.
2. Wagoner M D, Cox T A, Ariyasu R G. et al. Intraocular lens implantation in the absence of capsular support: a report by the American Academy of Ophthalmology. Ophthalmology 2003;110:840-59.
3. Yanoff M, Duker JS. Ophthalmology (2nd ed). Philadelphia; Mosby; 2004;2:241-394.
4. Aydin P, Akova YA. Göz Hastalıkları. [The basics of eye diseases.] Ankara; Gunes Kitabevi; 2001;P:191-226.
5. Boyd BF, Agarwal A. Wavefront Analysis and Corneal Topography. In: Alio JL, Krueger RR, Wilson SE eds. Wavefront Analysis, Aberrometers and Corneal Topography. Panama; Highlights of Ophthalmology; 2003;:217-42.
6. Ozdamar A. Aberometreler ve topografi aracılı laser sistemleri. [Aberrometers and topography-guided laser systems.] 24. National Ophthalmology Training, Refractive Surgery. Printed in 2004:65-8.
7. Elkady B, Piñero D, Alió JL. Corneal Incision Quality in Microincisional Cataract Surgery (MICS) vs. Microcoaxial Phacoemulsification. J Cataract Refract Surg 2009;35:466-74.
8. El Kady B, Alió J, Ortiz D. et al. Corneal aberrations after microincision cataract surgery. J Cataract Refract Surg 2008;34:40-5.
9. Yao K, Tang X, Ye P. Corneal astigmatism, high order aberrations, and optical quality after cataract surgery: Microincision versus small-incision. J Refract Surg 2006;22:1079-82.
10. Jiang Y, Le Q, Yang J. et al. Changes in corneal astigmatism and high order aberrations after clear corneal tunnel phacoemulsification guided by corneal topography. J Refract Surg 2006;22:1083-8.
11. Berdahl JP, DeStafeno JJ, Kim T. Corneal wound architecture and integrity after phacoemulsification: Evaluation of coaxial, microincision coaxial, and microincision bimanual techniques. J Cataract Refract Surg 2007;33:510-5.
12. Howland H C, Howland B. A subjective method for the measurement of monochromatic aberrations of the eye. J Opt Soc Am 1977;67:1508-18.
13. Applegate R A, Howland H C, Sharp R P. et al. Corneal aberrations and visual performance after radial keratotomy. J Refract Surg 1998;14:397-407.
14. Oshika T, Klyce S D, Applegate R A. et al. Changes in corneal wavefront aberrations with aging. Invest Ophthalmol Vis Sci 1999;40:1351-55.
15. Kuroda T, Fujikado T, Maeda N. et al. Wavefront analysis of higher-order aberrations in patients with cataract. J Cataract Refract Surg. 2002;28:438-44.
16. Tzelikis PF, Akaishi L, Trindade FC. et al. Spherical aberration and contrast sensitivity in eyes implanted with aspheric and spherical intraocular lenses: a comparative study. Am J Ophthalmol. 2008;145:827-33.
17. Guirao A, Redondo M, Geraghty E. et al. Corneal optical aberrations and retinal image quality in patients in whom monofocal intraocular lenses were implanted. Arch Ophthalmol 2002;120:1143-51.
18. Holladay JT. Optical quality and refractive surgery. Int Ophthal mol Clin 2003;43:119-36.
19. Pesudovs K, Dietze H, Stewart OG. et al. Effect of cataract surgery incision location and intraocular lens type on ocular aberrations.J Cataract Refract Surg 2005;31:725-34.
20. Vilarrodona L, Barrett GD, Johnson B. High-order aberrations in pseudophakia with different intraocular lenses.J Cataract Refract Surg 2004;30:571-5.
21. Hayashi K, Yoshida M, Hayashi H. Correlation of higher-order wavefront aberrations with visual function in pseudophakic eyes. Eye (Lond) 2008;22:1476-82.
22. Tahzib NG, MacRae SM, Yoon G. et al. Higher-order aberrations after implantation of iris-fixated rigid or foldable phakic intraocular lenses. J Cataract Refract Surg 2008;34:1913-20.
23. Bellucci R, Morselli S, Piers P. Comparison of wavefront aberrations and optical quality of eyes implanted with five different intraocular lenses. J Refract Surg 2004;20:297-306.
24. Packer M, Fine I H, Hoffman R S. et al. Prospective randomized trial of an anterior surface modified prolate intraocular lens. J Refract Surg 2002;18:692-6.
25. Mester U, Dillinger P, Anterist N. Impact of a modified optic design on visual function: clinical comparative study. J Cataract Refract Surg 2003;29:652-60.
26. Bellucci R, Scialdone A, Buratto L. et al. Visual acuity and contrast sensitivity comparison between Tecnis and AcrySof SA60AT intraocular lenses: a multicenter randomized study. J Cataract Refract Surg 2005;31:712-17.
27. Marcos S, Barbero S, Jimenez-Alfaro I. Optical quality and depth-of-field of eyes implanted with spherical and aspheric intraocular lenses. J Refract Surg 2005;21:223-35.
28. 28.Oshika T, Sugita G, Miyata K, et al. Influence of tilt and decentration of scleral-sutured intraocular lens on ocular higher-order wavefront aberration. Br J Ophthalmol 2007;91:185-8.
29. Guirao A, Tejedor J, Artal P. Corneal aberrations before and after small-incision cataract surgery.Invest Ophthalmol Vis Sci 2004;45:4312-9.
30. Salmon TO, van de Pol C. Normal-eye Zernike coefficients and root-mean-square wavefront errors. J Cataract Refract Surg 2006;32:2064-74.