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Higher-order aberrations and spherical aberration in various age groups after LASIK and cataract surgery

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Abstract

Objective To evaluate higher order aberrations and spherical aberration in various age groups after corneal and lenticular treatments.

Methods Two hundred forty untreated eyes across various age groups and 182 eyes post-corneal or lenticular treatment were included and iTrace (Tracey Technologies, Houston, Texas) aberrometry measurements were gathered. Treated patients were classified into 2 groups according to treatment administered: eyes that underwent different algorithms of laser in situ keratomileusis (Lasik) demonstrating quantifiable differences in corneal aberrations, and eyes that underwent uncomplicated phacoemulsification with in-the-bag implantation of aspheric neutral EnVista MX60 (Bausch & Lomb, USA), negative aspheric Tecnis ZCB00 (Johnson and Johnson, USA), or spherical Akreos Adapt (Bausch & Lomb, USA) intraocular lens (IOL) showing differences in internal spherical aberrations.

Results Aging was associated with less myopic refractions ($p = 0.0001$) and an increase in internal spherical aberration ($p = 0.0001$). Following corneal refractive surgery, the corneal spherical aberration measured through 3 mm pupils for Standard LASIK, Zyoptix wavefront-aspheric Lasik, Supracor Myopic Lasik, and Supracor Hyperopic Lasik, were +0.054 *um*, +0.074 *um*, -0.013 *um*, and −0.032 *um*, respectively. ($p = 0.001$) Following cataract surgery and measured through 5 mm pupils, the internal spherical aberration were significantly lower in the neutral aspheric EnVista and negative aspheric Tecnis compared to spherical Akreos Adapt IOLs, calculated to be +0.022 *um*, -0.150 *um*, and +0.094 *um*, respectively. ($p = 0.00$)

Conclusion The study indicated a trend of increasing internal spherical aberration with age. In Lasik surgery, manipulating spherical aberration in the corneal periphery improves overall vision while in the central cornea provides presbyopic treatment. In cataract surgery, patients with larger scotopic pupil sizes may benefit more from aspheric IOLs.

Keywords Higher order aberration, Spherical aberration, iTrace aberrometer, Asphericity, Wavefront-optimized Lasik, Aspheric IOL

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Introduction

The advent of wavefront technology has revolutionized the way by which vision can be measured and allowed for a more comprehensive quantitative analysis of the optical qualities of the eye. Wavefront measurement works by shining multiple rays of infrared light into the pupil. These rays reach the retina and are reflected back out as scattered beams of light. These beams are bent as they encounter structures such as the lens and cornea when they exit the eye, and are captured by lenses in the wavefront device. The term wavefront pertains to how these light rays reach the measuring device at different time points, similar to how waves reach the shore at different times.

Wavefront technology measures all optical conditions including lower order (hyperopia, myopia, and astigmatism) and higher order aberrations (coma, spherical aberration, trefoil, quadrafoil, and pentafoil) [1]. These are depicted as a set of Zernike polynomials that lend shape and form to each type of aberration. Conventional refraction measurements such as sphere and cylinder are lower-order aberrations. The application of wavefront knowledge to modern refractive and cataract surgery has given surgeons and engineers the ability to better understand optics, improve therapeutic interventions, refine intraocular lens design, expand options in presbyopia correction, and understand sources of dissatisfaction in surgical outcomes.

Historically, standard laser in situ keratomileusis (Lasik) addressed spherical and cylindrical refractive errors by ablating tissue to a predetermined depth to achieve the desired amount of diopteric correction [2]. While the desired refraction is achieved in majority of low to moderate myopes and hyperopes [3–5], up to 60% of patients tested poorly for contrast sensitivity following surgery [6]. This has been attributed to the large increase in spherical aberration induced by standard Lasik algorithms. To address this problem, wavefront-optimized Lasik treatments, like Zyoptix wavefront-aspheric Lasik, were conceptualized [7]. Zyoptix wavefront-aspheric Lasik (Aspheric in 217 model lasers and Proscan in Teneo II model lasers, Bausch and Lomb, Munich, Germany) incorporates corneal topography with wavefront aberrometry in treating sphere and cylinder and adds an aspheric treatment to the periphery to counteract any induced positive spherical aberration (Fig. 1) [8]. Supracor presbyopic Lasik (Supracor Lasik, 217 and Teneo II model lasers, Bausch and Lomb, Munich, Germany) simultaneously treats presbyopia and refractive error by creating a negative aspheric zone in the central cornea to extend depth of focus and adding a peripheral aspheric optimized zone to improve distance vision (Fig. 2a and b) [9].

Data from wavefront analysis has also revolutionized the way cataract surgery is performed. Research has shown that the human cornea has a spherical aberration (SA) of approximately + 0.27 um, which changes minimally throughout life [10, 11]. In young eyes, this aberration is compensated for by the negative SA of the lens. As the lens ages, its SA becomes more positive, resulting in a higher overall SA and poorer vision [12]. Conventional spherical intraocular lenses (IOL) have positive spherical aberration, producing submaximal vision postoperatively [13]. The application of wavefront science to current IOL development and design has allowed for the creation of aspheric IOLs with neutral (EnVista, Bausch and Lomb, USA) and negative (Tecnis ZCB00, Abbot Medical Optics, USA) spherical aberrations that are able to counteract the positive spherical aberration of the cornea [14, 15]. Patients who received aspheric IOLs reported better contrast sensitivity and postoperative visual function [15].

While the concept of wavefront technology has existed since 1978, its incorporation into optical metrics is fairly recent. Data gathered by initial optical wavefront aberrometers utilized Shack-Hartmann sensors and differential skiascopy. However, these methods were unable to isolate unique retinal points, measure higher-order aberrations such as quadrafoil and pentafoil, or quantify corneal aberrations, resulting in inadequate measurements of ocular aberrations [1]. The introduction of iTrace (Tracey Technologies, Houston, Texas) ray tracing technology addressed these limitations by analyzing ocular aberrations point-by-point. It is a device that acquires both wavefront aberrometry and corneal topography data simultaneously, allowing us to more accurately determine whether measured ocular aberrations are corneal or internal in origin [1].

This study aims to describe the types and magnitudes of total, corneal, and internal aberrations in the natural and treated eye using iTrace data. The rationale of this study is to describe differences in higher order and spherical aberrations that can be measured after specific types of surgical treatment. Exploring how these values contribute to vision is important prior to initiating any type of treatment to correct visual problems.

Patients and methods

This is a cross-sectional, comparative study that reviewed all iTrace data taken under a single surgeon in a single institution. The Ethics Review Committee of St. Frances Cabrini Medical Center-Asian Eye Institute (SCMC-AEI) has reviewed and approved the study protocol, waiving the requirement for obtaining informed consent from participants, as per institutional guidelines governing research involving human subjects. This decision was made in consideration of the retrospective nature

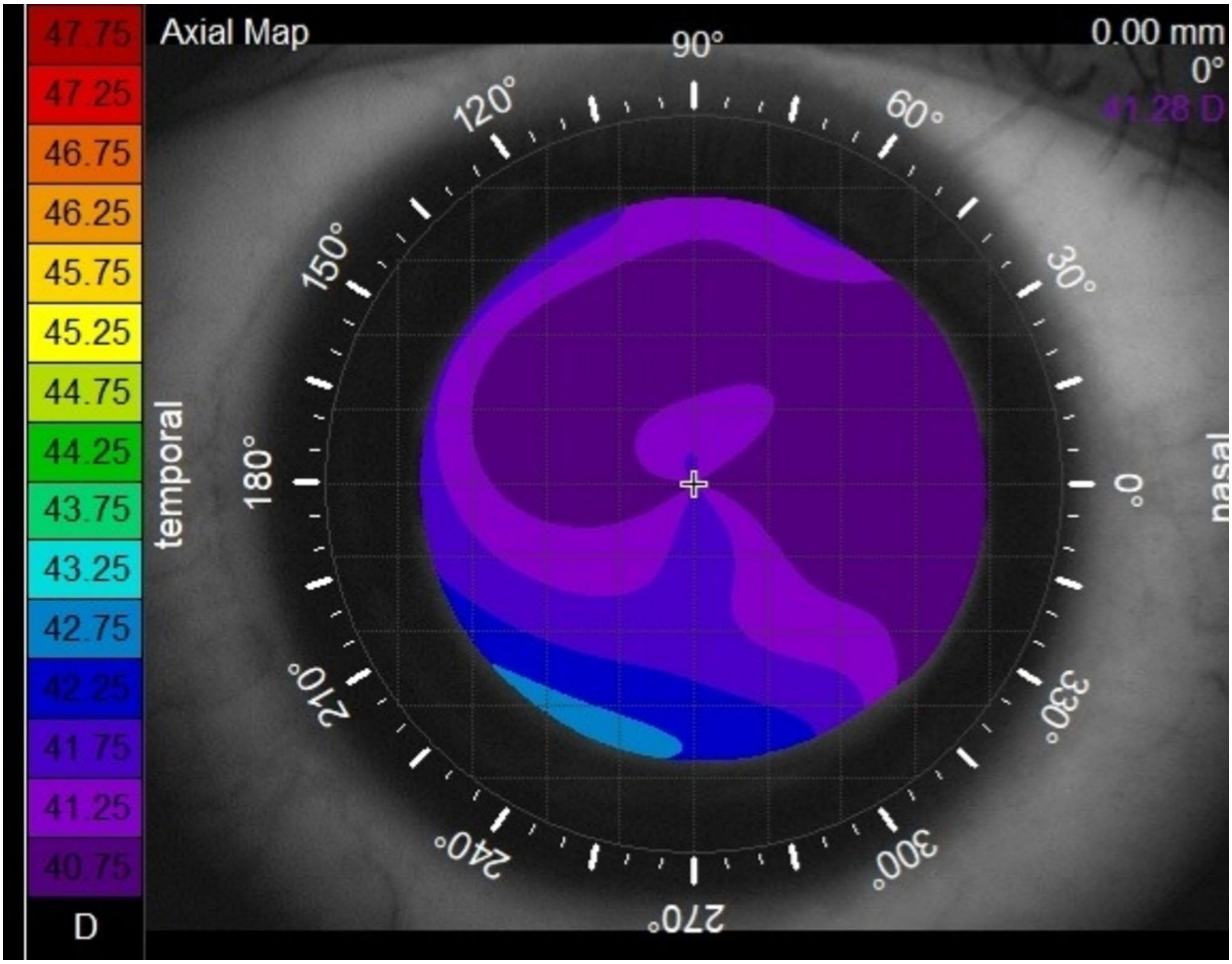

Fig. 1 iTrace axial map showing corneal topography following Zyoptix Lasik treatment

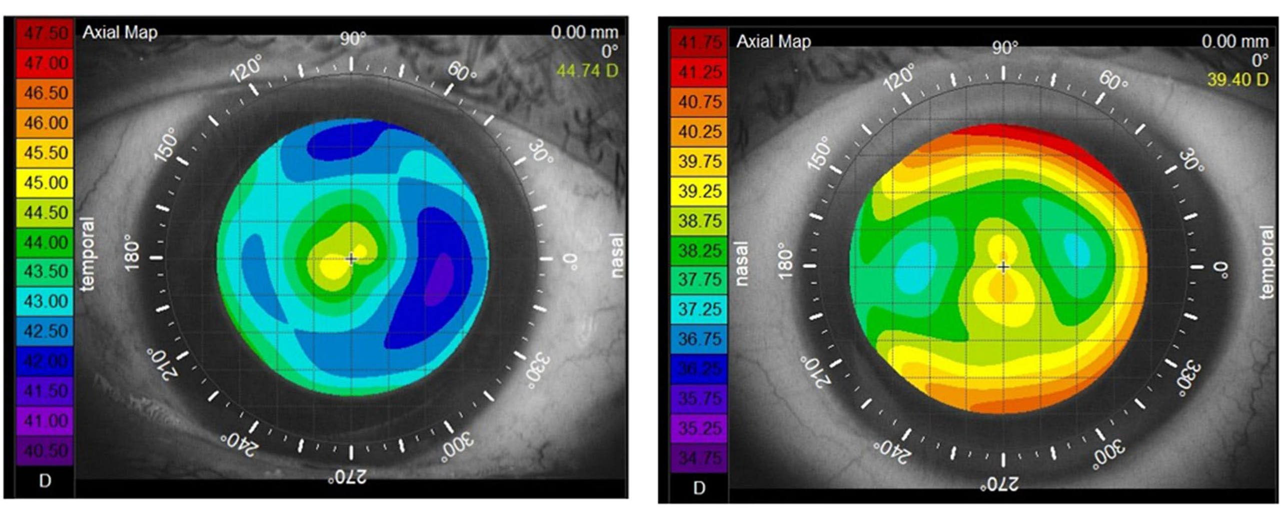

Fig. 2 **a** iTrace axial map showing Supracor central bump following presbyopic myopic Lasik treatment; **b** iTrace axial map showing Supracor central bump following presbyopic hyperopic Lasik treatment

of the study, the minimal risk involved, and the utilization of anonymized data. The approval was granted following a thorough assessment of the study protocol and ethical considerations aimed at safeguarding participant rights and welfare. All procedures were conducted in strict adherence to established ethical standards and guidelines.

Patients from the first group were gathered from January 2009 to December 2017, while patients from the second and third group were recruited from April to July 2019. Eyes with corneal, iris, pupillary, retinal, or optic nerve abnormalities, history of previous ocular surgery or ocular trauma, and corneal astigmatism of more than 1.0 diopter for the IOL group, were excluded from this study. For the first group, all eyes of patients aged 18 to 80 years old were included and were subsequently grouped according to decade of life (18–29 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years, 70–80 years). Based on a similar study on wavefront aberrometry by Amano [16], a minimum of 81 eyes are required to achieve a 95% level of confidence and precision of 5% to estimate the spherical changes among different parameters.

The iTrace machine combines ray-tracing aberrometry with Placido corneal topography to accurately and precisely measure ocular aberrations [1]. Aberrometry measurements are taken in dim light conditions with the patient gazing at infinity to remove the effect of accommodation. Once the patient is placed in the correct position, the machine's Data Acquisition Unit (DAU) software aligns the patient's visual axis with the laser. Wavefront aberrometry and corneal topography data were captured and calculated simultaneously (Fig. 3).

Demographics (age, gender) and iTrace measurements such as total ocular aberration, total lower order aberration (LOA), total higher order aberration (HOA), total spherical aberration (total SA), corneal spherical aberration (corneal SA) and internal spherical aberration (internal SA) were manually collected, tabulated using Microsoft Excel, and analyzed. Three groups of patients were identified. Group 1 consisted of eyes from patients 18–80 years old who never had any corneal or lenticular treatment. Group 2 comprised of eyes that underwent Lasik. These eyes were further subdivided depending on the type of Lasik treatment received (Standard Lasik, Zyoptix wavefront-aspheric Lasik, Supracor myopic presbyopic Lasik, and Supracor hyperopic presbyopic Lasik). All eyes were tested at 3 mm, which corresponded to the presbyopic treatment zone for Supracor Lasik, and at 6 mm, which corresponded to the treatment zones for correction of distance vision in all types of Lasik. Postoperative aberrometry data taken at least 3 months after surgery were analyzed to determine how surgery affected ocular aberrations. Group 3 comprised of eyes that underwent uncomplicated phacoemulsification with in-the-bag implantation of an intraocular lens (IOL), either

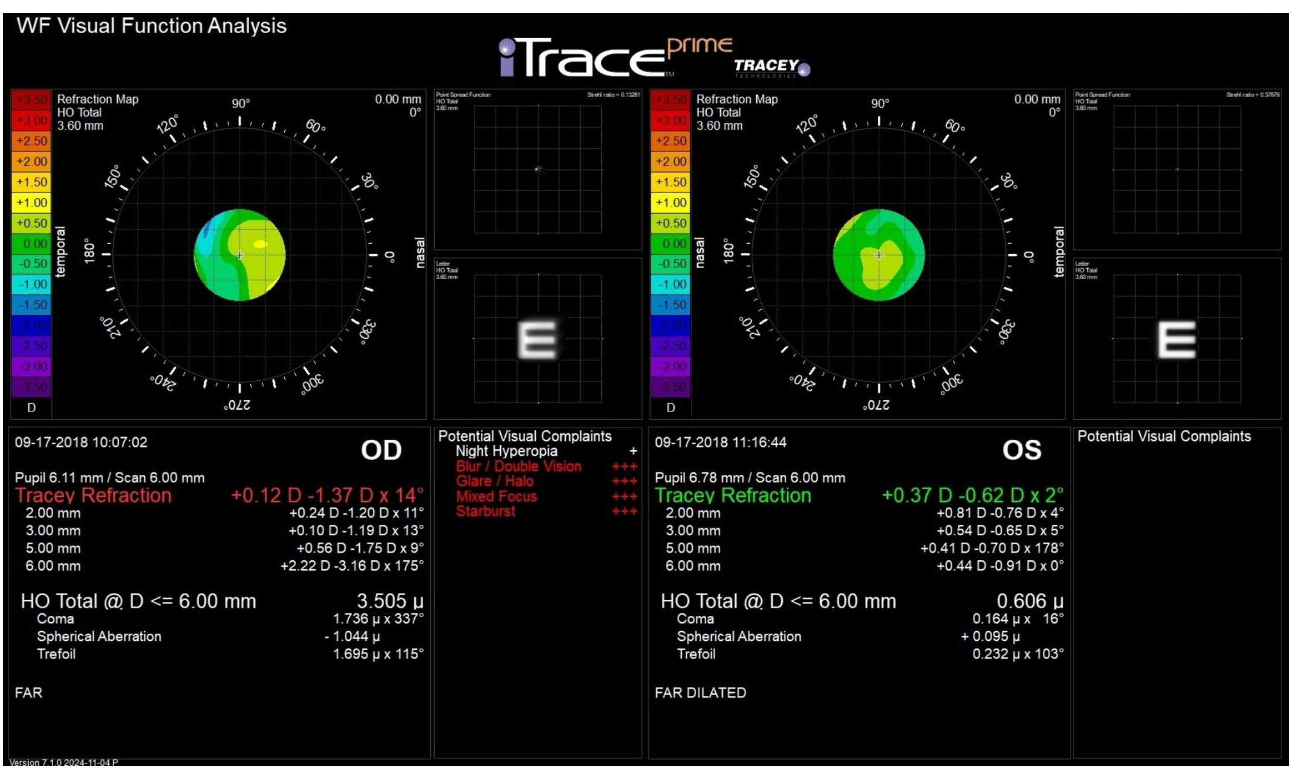

Fig. 3 iTrace wavefront visual function analysis

Table 1 Demographics of the population that did not undergo any type of surgery (Group 1)

Age Group (*n*)	18–29 *n* = 40	30–39 *n* = 40	40–49 *n* = 40	50–59 *n* = 40	60–69 *n* = 40	70–80 *n* = 40
Gender						
Male (%)	20 (50%)	18 (45%)	18 (45%)	23 (58%)	11 (28%)	11 (28%)
Female (%)	20 (50%)	22 (55%)	22 (55%)	17 (42%)	29 (72%)	29 (72%)
Laterality						
OD (%)	20 (50%)	22 (55%)	25 (63%)	27 (68%)	19 (48%)	22 (55%)
OS (%)	20 (50%)	18 (45%)	15 (37%)	13 (32%)	21 (52%)	18 (45%)
Refraction						
Myope (%)	40 (100%)	40 (100%)	36 (90%)	25 (63%)	11 (28%)	17 (43%)
Emmetrope (%)	0	0	2 (5%)	3 (7%)	6 (15%)	4 (10%)
Hyperope (%)	0	0	2 (5%)	12 (30%)	23 (57%)	19 (47%)
Mean Pupil Size	4.67 mm	4.94 mm	4.05 mm	3.88 mm	3.34 mm	3.07 mm

Table 2 Mean values for total ocular, lower order, and higher order aberrations per decade of life

Age Group	Sphere (D)	Cylinder (D)	Spherical Equivalent (D)	Total Ocular Aberration (um)	Lower Order Aberration (um)	Higher Order Aberration (um)
18–29 years	-4.095	-2.098	-4.908	4.353	4.302	0.299
30–39 years	-4.394	-1.151	-4.969	4.266	4.221	0.302
40–49 years	-3.770	-0.898	-4.219	2.762	2.686	0.296
50–59 years	-1.752	-1.129	-2.316	2.046	2.038	0.256
60–69 years	0.843	-1.550	0.068	1.185	1.049	0.284
70–80 years	1.437	-1.904	0.486	1.303	1.243	0.313

the aspheric neutral EnVista MX60 (Bausch + Lomb, USA), the negative aspheric Tecnis ZCB00 (Johnson & Johnson, USA), or the spherical IOL Akreos Adapt (Bausch & Lomb, USA). Post-operative iTrace data were taken at follow-up from cataract surgery, 21 months post-op after for the neutral aspheric group, 13 months post-op for the negative aspheric group, and 74 months post-op for the spherical group. Aberrometry data were taken at a pharmacologically dilated pupil size of 5 mm.

Statistical analysis

Descriptive analysis was recorded using the mean and standard deviation. Categorical data were presented as frequency and percentage, while discrete data such as age and continuous data such as total ocular aberration, total lower order aberration, total higher order aberration, total spherical aberration, corneal spherical aberration, and internal spherical aberration were analyzed using mean and median. A one-way analysis of variance (ANOVA) was performed to determine differences among 3 different subgroups. A p-value < 0.05 was considered statistically significant. The statistical computations were performed using MedCalc Statistical Software, version 19.2.6 (MedCalc Software bv, Ostend, Belgium; https://www.medcalc.org; 2020).

Results

This study included 240 eyes of different age groups that did not undergo any type of surgery and 182 eyes that underwent corneal and lenticular treatment. Demographics of the population that did not undergo any type of surgery and mean natural pupil size per decade of life are presented in Table 1. Total ocular aberration is composed of total lower order aberration and total higher order aberration (Table 2). The older age groups tended to have lower refractive errors (spherical equivalent) and consequently, the total ocular ($p = 0.0001$) and total lower order aberrations ($p = 0.0001$) were lower as well. No correlation was found between age and higher order aberration ($p = 0.563$).

Higher order aberrations are comprised mostly of spherical aberration, coma, trefoil and other higher order aberrations of lesser magnitudes. (Table 3). No significant correlation was found between age and total spherical aberration ($p = 0.639$), total coma ($p = 0.910$), and total trefoil ($p = 0.570$). Total spherical aberration can be subdivided into corneal spherical aberration and internal spherical aberration. Corneal spherical aberration was similar among different age groups ($p = 0.411$) whereas internal spherical aberration increased significantly with age ($p = 0.0001$).

This study included 2 groups of treated eyes (Lasik and cataract surgery). Eyes that underwent different algorithms of laser in situ keratomileusis (Lasik) were

Table 3 Mean higher order aberrations of group 1

Age Group	Higher Order Aberration (um)	Total Spherical Aberration (um)	Corneal Spherical Aberration (um)	Internal Spherical Aberration (um)	Total Coma (um)	Total Trefoil (um)
18–29	0.299	0.044	0.251	-0.085	0.178	0.154
30–39	0.302	0.039	0.248	-0.100	0.159	0.147
40–49	0.296	0.024	0.277	-0.051	0.142	0.132
50–59	0.256	0.055	0.292	-0.027	0.144	0.134
60–69	0.284	0.060	0.281	0.017	0.131	0.157
70–80	0.313	0.025	0.293	0.000	0.156	0.125
p-value	0.865	0.639	0.224	0.0001	0.910	0.570

Table 4 Demographic and clinical characteristics of the participants according to LASIK subgroup

Characteristics	LASIK Subgroup ($N=120$)				*p*-value (Two-Tailed)
	Standard LASIK ($n=30$)	Zyoptix LASIK ($n=30$)	Supracor Myopic LASIK ($n=30$)	Supracor Hyperopic LASIK ($n=30$)	
Age (Years; $\bar{x}$, SD)	51.87 (5.56)	31.57 (5.67)	51.33 (5.43)	53.00 (4.09)	0.001[†]
Sex (*f*, %)					0.960
Male	9 (30.00%)	10 (33.33%)	10 (33.33%)	11 (36.67%)	
Female	21 (70.00%)	20 (66.67%)	20 (66.67%)	19 (63.33%)	
Post-Operative Tracey Spherical Equivalent (D; $\bar{x}$, SD)	−0.017 (2.52)	−0.782 (0.71)	−1.243 (1.60)	−0.361 (1.44)	0.037[*]

Note: Summary statistics are presented as mean (standard deviation).

[*]Significant at 0.05

[†]Significant at 0.01

Table 5 Demographics according to IOL subgroups

Characteristics	IOL Subgroup ($N=62$)			
	EnVista ($n=22$)	Tecnis ($n=24$)	Akreos ($n=16$)	*p*-value
Age (Years; $\bar{x}$, SD)	67 (6.4)	65 (4.7)	78 (2.9)	0.00
Sex (*f*, %)				
Male	8 (36%)	10 (42%)	6 (37%)	
Female	14 (64%)	14 (76%)	10 (63%)	
Interval from phacoemulsification (months)	13	21	74	0.00

composed of 30 eyes for standard Lasik (Subgroup 1), 30 eyes for zyoptix aspheric Lasik (Subgroup 2), 30 eyes for Supracor myopic Lasik (Subgroup 3), and 30 eyes for Supracor hyperopic Lasik (Subgroup 4). Eyes that underwent uncomplicated phacoemulsification with in-the-bag implantation of monofocal IOLs included 22 eyes with the EnVista MX60 IOL (Subgroup 5), 24 eyes with the Tecnis ZCB00 IOL (Subgroup 6) and 16 eyes with the Akreos Adapt IOL (Subgroup 7). Demographics of these 2 groups are seen in Tables 4 and 5.

Post-operatively, at the 6 mm diameter measurement, Zyoptix wavefront-aspheric Lasik had a lower corneal spherical aberration at +0.237 *u*m compared to standard Lasik at +0.307 *u*m. At the 3 mm measurement, Supracor Lasik induced negative spherical aberration compared to standard and aspheric LASIK. Supracor hyperopic Lasik showed the lowest values in total and corneal spherical aberration at the 3 mm zone. Supracor hyperopic Lasik had lower corneal spherical aberration value of -0.032 *u*m compared to Supracor myopic Lasik with −0.013 *u*m. Corneal spherical aberration differences at both 3 mm ($p=0.001$) and 6 mm ($p=0.002$) zone sizes were statistically significant (Table 6).

In the IOL group, when measured through a pharmacologically dilated pupil size of 5 mm, mean internal spherical aberration for the EnVista, Tecnis and Akreos IOLs were +0.022 *u*m, -0.150 *u*m, and +0.094 *u*m, respectively, with a statistically significant difference ($p=0.00$). Mean total spherical aberration followed a similar pattern, with Tecnis IOLs exhibiting the lowest value ($p=0.00$). (Table 7).

Discussion

Initial studies measured aberrations of the entire ocular system alone and were unable to determine whether corneal or lenticular changes were responsible for worsening vision [17]. Studies that followed attempted to refine this by utilizing two machines: a wavefront aberrometer to measure total ocular aberrations, and a corneal topographer to measure corneal aberrations [12]. The measurement from one device was subtracted from the measurement of the other device and assumed to represent the internal aberrations of the natural eye. However, discrepancies in machine algorithm and design meant

Table 6 Mean post operative aberration values according to LASIK subgroups at 3 mm and 6 mm pupil size

Characteristics	LASIK Subgroup (*N* = 120)				*p*-value (Two-Tailed)
	Standard LASIK (*n* = 30)	Zyoptix LASIK (*n* = 30)	Supracor Myopic LASIK (*n* = 30)	Supracor Hyperopic LASIK (*n* = 30)	
Total Higher Order Aberration (um; $\bar{x}$, SD)	0.236 (0.24)	0.263 (0.14)	0.241 (0.12)	0.281 (0.22)	0.775
Total Spherical Aberration (um; $\bar{x}$, SD)	0.025 (0.11)	−0.007 (0.07)	−0.026 (0.04)	−0.049 (0.20)	0.123
Corneal Spherical Aberration at 3 mm (um; $\bar{x}$, SD)	0.054 (0.07)	0.074 (0.09)	−0.013 (0.02)	−0.032 (0.06)	0.001†
Corneal Spherical Aberration at 6 mm (um; $\bar{x}$, SD)	0.307 (0.18)	0.237 (0.09)	0.208 (0.13)	0.167 (0.14)	0.002†

*Significant at 0.05; †Significant at 0.01

Table 7 Mean post operative aberration values according to IOL subgroups at 5 mm pupil size

Characteristics	IOL Subgroup (*N* = 62)			
	EnVista (*n* = 22)	Tecnis (*n* = 24)	Akreos (*n* = 16)	*p*-value
Total Higher Order Aberration (um; $\bar{x}$, SD)	0.436 (0.12)	0.279 (0.06)	0.452 (0.19)	0.04
Total Spherical Aberration (um; $\bar{x}$, SD)	0.164 (0.05)	0.007 (0.05)	0.205 (0.07)	0.00
Internal Spherical Aberration (um; $\bar{x}$, SD)	0.022 (0.08)	-0.150 (0.06)	0.094 (0.03)	0.00

each value was not necessarily related to and comparable with the other.

We believe this study is relevant because we obtained and analyzed the measurements of a ray-tracing wavefront aberrometer and corneal topographer incorporated into a single device. Ray-tracing technology is superior to older wavefront principles because it measures aberrations as light enters the eye, mimicking real visual conditions, whereas the older wavefront devices measure aberrations after the light reflects from the retina and exits the eye. In ray tracing, each ray of light is made up of 256 beams that measure unique retinal points, resulting in a more detailed depiction of ocular aberrations. Moreover, wavefront and corneal topography data are taken at the same line of sight using a laser tracking system unique to the iTrace machine. Wavefront aberrometry data are then analyzed with corneal topography data to produce values that measure and calculate the internal optics of the eye (Fig. 4) [1].

To our knowledge, this study is the first of its kind to map out total, corneal, as well as internal ocular aberrations in eyes of different treatment groups.

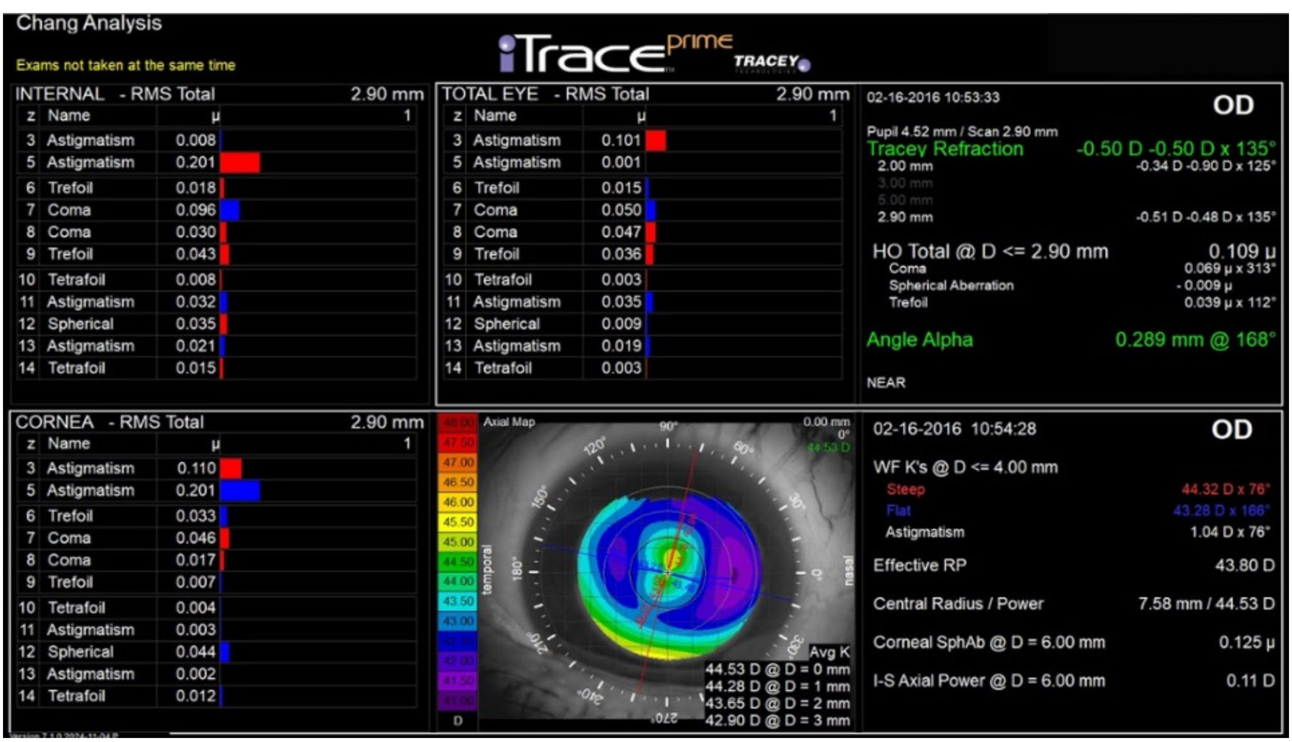

Fig. 4 iTrace wavefront analysis using Chang method for corneal, internal, and total eye aberrations

Understanding how aberrations change in response to surgical intervention may help refine therapeutic options and aid in decision-making in terms of Lasik algorithm to use and type of monofocal IOL to select. Total ocular aberration is composed of lower-order, as well as higher order aberrations. Lower-order aberrations are comprised of sphere (defocus) and cylinder (astigmatism). Higher-order aberrations include spherical aberration, coma, trefoil, quadrafoil, and pentafoil. Mean values for total and lower order aberrations are closely correlated because most aberrations in the optical system are caused by sphere and cylinder. This supports current literature that demonstrates up to 90% of ocular aberrations are lower order in nature [18]. Lower-order aberrations, composed of sphere and cylinder, are measured by manifest refraction and are correctable with eyeglasses, contact lens, or standard Lasik algorithms. There is no consensus from published literature whether aberrations increase or decrease with aging [19–21]. Higher-order aberrations (HOAs) constitute about 10% of total ocular aberrations and cannot be measured by manifest refraction but by aberrometers alone. Among the HOAs, spherical aberration is by far the only type of HOA that can be manipulated through surgical intervention – either by applying laser refractive procedures to the cornea to modify corneal spherical aberration or implanting intraocular lenses to modify internal spherical aberration.

Spherical aberration has been shown to have a significant influence on quality of vision and can either be corneal or internal (lenticular) in origin. Mean corneal spherical aberration at 6 mm across all age groups for our study population was calculated to be + 0.274 *u*m and is consistent with previously published data that reports average corneal spherical aberration to be + 0.27 *u*m ± 0.10 *u*m [10, 22]. While corneal spherical aberration remained stable throughout different ages ($p = 0.224$), internal spherical aberration increased significantly with age ($p = 0.0001$). Cataractous lenses have been shown to be associated with high degrees of spherical aberration [23, 24].

Spherical aberrations play a significant role in patient satisfaction following corneal refractive surgery. Using the iTrace aberrometer, we analyzed the corneal spherical aberration properties of different types of Lasik procedures. Standard Lasik algorithms have been shown to increase positive spherical aberration while wavefront-aspheric or wavefront-optimized algorithms reduce or minimize the induction of positive spherical aberration to improve quality of vision [25]. Mean post-operative spherical aberration measurements taken at 6 mm for Standard and Zyoptix Lasik were + 0.307 *u*m and + 0.237 *u*m, respectively. These results are consistent with previous publications, which showed that the increase in corneal spherical aberration is higher in Standard Lasik than Zyoptix wavefront-aspheric Lasik [8, 25, 26]. Studies on wavefront-optimized Lasik also propose that changes in HOAs are influenced by both treatment zone size and scotopic pupil diameter [27]. It has been suggested that planned laser optical zone sizes should overlap the pupil by at least 15% to minimize the induction of excess HOAs. While wavefront-optimized algorithms are superior, knowledge of scotopic pupil size prior to surgery is important to allow surgeons to optimize non-presbyopic Lasik treatments. Supracor Lasik, on the other hand, is a presbyopia-correcting Lasik algorithm that combines two aspheric treatments for simultaneous correction of refractive error and astigmatism. Supracor induces negative spherical aberration in the central 3 mm cornea to extend depth of focus and provide up to + 2.00 D of near addition while creating an aspheric optimized zone towards the 6 mm corneal periphery to improve distance vision [28]. Mean post-operative spherical aberration measurements for both Supracor myopic and Supracor hyperopic Lasik treatments were – 0.013 *u*m and – 0.032 *u*m, respectively. This is consistent with the intent of the Supracor software to induce negative spherical aberration in the central cornea, whether it is for myopic or hyperopic presbyopic treatments [29].

High positive spherical aberration values have been correlated with poor contrast sensitivity [30]. Initial spherical IOLs, such as the Akreos Adapt (Bausch & Lomb) spherical IOL, have positive spherical aberration values and when implanted, added to the naturally-existing positive spherical aberration of the cornea. This overall increase in positive total spherical aberration worsened quality of vision and reduced patient satisfaction [13]. Newer aspheric IOLs were developed to bring total ocular spherical aberration as close to zero as possible by inducing no additional positive spherical aberration with zero-aberration/aberration-neutral lenses or counteracting the positive spherical aberration of the cornea with negative-aspheric lenses. The Tecnis negative-aspheric IOL pioneered aspheric IOL technology by creating a lens that induced – 0.27 *u*m of internal spherical aberration [31]. Proponents of the Tecnis IOL believed in fully neutralizing the average corneal spherical aberration of + 0.27 *u*m with a -0.27 *u*m aspheric IOL, thereby bringing the resulting total spherical aberration to zero which would result in the best visual outcomes. Other lenses that followed, such as Bausch and Lomb's EnVista [32], which has zero microns of spherical aberration, and Alcon's Acrysof IQ [33], which has – 0.2 *u*m of spherical aberration, proposed that leaving a very low but slightly positive total ocular spherical aberration may be more beneficial as this mimics natural ocular aberrations. On the whole, targeting zero or near-zero total spherical aberration post-operatively has been shown to be associated with increased contrast sensitivity and better low-light vision [34].

Using the aberrometer, we were able to measure and verify the spherical aberration properties of the EnVista, Tecnis, and Akreos IOLs. At a pupil size of 5 mm, the Akreos Adapt spherical IOL has a positive internal spherical aberration of + 0.094 um, followed by the neutral aspheric EnVista IOL with + 0.022 um, and the negative aspheric Tecnis IOL with − 0.150 um. It appears logical that the difference in asphericity is found at the IOL periphery because spherical aberration increases in dim light or large pupil conditions [35–37]. Therefore, patients with larger scotopic pupil sizes may benefit more from aspheric IOLs [35], particularly when driving in low-light conditions [38]. Our findings show that the aspheric design of the Tecnis IOL has effectively negated the corneal spherical aberration of a 5 mm pupil. It is our belief that knowledge about internal spherical aberrations of different IOLs and measuring the scotopic pupil size preoperatively will allow surgeons to customize IOL options for patients undergoing cataract surgery.

This study has the following limitations: The first set of aberration measurements were taken from eyes across various age groups but not necessarily from eyes that underwent cataract or refractive surgery. This serves as an indirect control group that can represent virgin eyes. The second set of data came from eyes that underwent corneal laser refractive or cataract surgery. Not having the preoperative data of treated eyes limited our ability to directly compare eye to eye the aberrations induced or changed by the treatments. What we have is an indirect comparison of virgin eyes and postoperative eyes which we believe is still useful to describe the corneal and lenticular aberrations present. We therefore refined our objective to state that we are evaluating the aberrations present but we are not evaluating changes in aberrations from preoperative to postoperative values.

Conclusion

Our study demonstrates the evaluation of higher-order and spherical aberrations across different age groups and following corneal and lenticular treatments. The findings highlight the impact of these aberrations on optical quality, emphasizing the importance of understanding age-related [39] and post-operative changes in aberrations because it may allow us to customize treatments and manipulate aberrations in order to achieve our desired outcomes.

In corneal treatments, HOA aberrations, specifically spherical aberration can be modified in different areas on the cornea to produce a specific visual outcome. Manipulating the spherical aberration in the Lasik treatment periphery (specifically at 4 mm or beyond) reduces the induction of spherical aberration, whereas manipulating the spherical aberration in the central 2 mm creates a varifocal cornea that addresses presbyopic correction. In cataract surgery, different types of monofocal IOLs have different spherical aberration treatments in the IOL periphery. Using aberrometers that have internal aberrometry measurements can help distinguish between spherical (positive), zero aspheric or negative aspheric IOLs.

By understanding which diameter the measurements should be taken leads surgeons to understand the intended visual effect. We therefore recommend that all patients scheduled to undergo corneal treatments such as laser refractive surgery and lens treatments such as cataract surgery acquire pre-operative iTrace measurements to better guide treatment planning as well as optimize and evaluate visual outcomes.

Abbreviations

LOA	Lower order aberrations
HOA	Higher order aberrations
SA	Spherical aberration
Lasik	Laser in situ keratomileusis
IOL	Intraocular lens

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Author contributions

Design and conduct of the study (RTA); collection (PLL, RST, MQA, MMT); management (RTA); analysis (RTA, PLL, RST, MQA, MMT); interpretation of the data (RTA, PLL, RST, MQA, EMC); manuscript preparation (PLL, RST, MQA, MMT); manuscript review (RTA, PLL, RST, MQA, MMT, EMC); and manuscript approval (RTA, PLL, EMC).

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to compliance with the National Data Privacy Law. However, they are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The St. Frances Cabrini Medical Center-Asian Eye Institute (SCMC-AEI) Ethics Review Committee has officially approved the study protocol and waived the necessity of obtaining informed consent from participants in accordance with institutional guidelines pertaining to research involving human subjects. This decision was rendered based on the retrospective nature of the study, its minimal risk to participants, and the utilization of anonymized data. The decision was reached following a thorough review of the study protocol and ethical considerations, with paramount emphasis on safeguarding participant rights and welfare. All procedures were conducted in strict adherence to ethical standards and guidelines.

Consent for publication

Not applicable.

Competing interests

Consultant/advisory positions: RTA: Staar Surgical, Acevision, Acufocus, Bausch and Lomb, Johnson & Johnson, Physiol BVI. PLL, RST, MQA, EMC, MMT: none.

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