The Analysis of Corneal Asphericity and its Related Factors in Cataract Patients

Chen Li
the First Affiliated Hospital of Soochow University
Peirong Lu (lupeirong@suda.edu.cn)
the First Affiliated Hospital of Soochow University

Research Article

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Abstract

Purpose: To determine the corneal asphericity and its related factors in cataract patients.

Methods: This study enrolled 121 eligible eyes of 121 cataract patients. The corneal Q values of anterior and posterior surface were measured in the central 3.0, 4.0, 5.0, and 6.0 mm zone using the Sirius System. Age, gender, and corneal higher-order aberrations (HOAs) were recorded. Comparison of preoperative and postoperative Q value was conducted in 103 eyes of 103 patients three months after surgery.

Results: The Q value of the anterior corneal surface at 6.0 mm zone and the posterior surface in 3.0, 4.0, 5.0, and 6.0 mm zone were statistically significant across the different age groups. The Q value of the posterior surfaces in 3.0, 4.0, 5.0, and 6.0 mm zone was statistically significant between the male and the female groups. The Q values of the anterior corneal surface in the 6.0 mm zone were positively correlated with $Z4^{0}$ cornea, $Z4^{0}$ CF, $Z3^{3,-3}$ CF, and total corneal HOAs; While the Q value of the posterior surface in the 6.0 mm zone were negatively correlated with $Z3^{1,-1}$ cornea, $Z3^{3,-3}$ cornea, $Z3^{3,-3}$ CF, $Z3^{1,-1}$CB, $Z4^{0}$ CB, and total corneal HOAs. Besides, no significant change was found in corneal Q value 3 months after surgery.

Conclusion: There were great individual differences between the corneal asphericity of the cataract patients. Age, sex, and HOAs seemed to be correlated with the corneal asphericity. The preoperative Q value can be used as one of the parameters for personalized selection of intraocular lens.

Introduction

The cornea is the most significant refractive component in the eye, contributing a major share of around 70% of the refractive power. Previous researches demonstrated that the cornea could be described as a quadric surface having asphericity on the surface.[1,2] The radial variation from the center towards the periphery of the quadric surface determines the Q value, the quantified aspherical degree indicator. The Q value, being the crucial parameter of the mathematical cornea model, is reflective of the shape of the cornea and its optical properties. [3] Today, the corneal Q value along with its distribution properties have garnered the focus of attention of the relevant studies, besides the manner in which the optical properties are impacted in the eye. [4,5]

Alongside the popularization and application of aberration theory in ophthalmology, the influence of corneal Q value on spherical aberrations following corneal refractive surgery and intraocular refractive surgery is garnering an increasing amount of attention from ophthalmologists. Corneal Q value provides an essential reference for personalized intraocular refractive surgery and aspheric intraocular lens (IOL) implantation. Although corneal Q value in elderly populations is an essential factor in the design of IOL procedures and for the treatment of refractive errors, there is little formal studies have been conducted to evaluate its relevance for cataract patients.

The Q value of different corneal surface areas is disparate, and a single value does not accurately reflect the shape of the cornea. [6] It is crucial to examine the Q value of different ranges to improve the visual acuity of cataract patients following aspheric IOL implantation. Many different factors affect corneal Q value. Previous studies have focused on the relationships among Q value, age, refractive error[7], refractive status[8], and spherical aberrations[9], while studies concerning Q value and other high-order aberrations (HOAs) of the cornea are limited at present. In addition, the majority of previous studies focus on the Q value of the anterior corneal surface, little attention has been paid to the posterior corneal surface, but it does affect the optical properties of the eye.[10] Previous studies have confirmed that LASIK can significantly change the asphericity of the anterior corneal surface and this morphological change have a negative impact on visual quality. As a result, personalized keratotomy guided by topographic maps came into being to reduce the negative effect. However, little is known about whether phacoemulsification affects corneal asphericity. This study aims to determine the Q value of anterior and posterior corneal surface in cataract patients and its characteristics and correlations with corneal HOAs. At the same time, we observed the changes of Q value between preoperative and postoperative.

Method

Study population

This retrospective study recruited patients scheduled for cataract surgery, from July 31st, 2020 to May 31st, 2021, at the First Affiliated Hospital of Soochow University, Suzhou, China. The grade of cataract was assessed using a slit-lamp microscope and classified using the Lens Opacities Classification System III (LOCS III). A total of 121 eyes of 121 cataract patients including 58 males and 63 females were enrolled in the study after excluding patients who underwent ocular surgery or had corneal disease, glaucoma, uveitis, dry eye or had worn contact lenses in the last 2 weeks, as well as patients with incomplete topographical mapping, and/or poor repeated measurements during preoperative examination. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board of the First Affiliated Hospital of Soochow University. Consenting to allow their clinical data to be retrospectively evaluated, all the patients endorsed the consent letter with their signature.

Surgical Technique

All operations were performed by one experienced surgeon (P.R.L), and using the centurion phacoemulsification platform (Alcon Laboratories, Inc., Lake Forest, CA, USA) at the Cataract Center of the First Affiliated Hospital of Soochow University. The phacoemulsifications were performed through a 2.2 mm corneal limbus incision, and all the patients underwent IOL implantation in the capsular bag. No stitches were required in any of the patients in this study. Postoperative treatment consisted of 0.3% Lavofloxacin (Cravit, Santen Pharmaceutical Co, Ltd, Osaka, Japan) eye drops four times a day for 2 weeks and TobraDex (tobramycin 0.3%, dexamethasone 0.1%; Alcon, Fort Worth, TX, USA) eye drops four times a day for 4 weeks.

Method

Corneal topography measurement was repeated three times for all patients using Sirius (Sirius, CSO Inc, Florence, Italy) system. The data were analyzed for the full topographic map measurements in the central 3.0, 4.0, 5.0, and 6.0 mm zones. All examinations were done by the first author (C.L.), the corneal reflex rings were clear, and the tear film rupture was not disturbed during the examinations. The Q value in the central 3.0, 4.0, 5.0, and 6.0 mm zone was calculated by the Sirius system. The analysis of the correlation between the HOAs and Q value, along with the mean corneal Q value (mean ± SD) having varying diameters on the anterior and posterior surfaces were included in the results. The HOAs in pupillary areas of 6.0 mm analyzed included the root mean square (RMS) values of primary spherical aberration ($Z4^{0}$), primary coma aberration ($Z3^{1,-1}$), primary trefoil aberration ($Z3^{3,-3}$) of the total cornea, corneal front surface, and corneal back surface and total corneal HOAs. The statistical analysis was conducted using high centrality, high repeatability, and high quality aberration values. A classification of the device signal according to the composite index of the keratoscopic and Scheimpflug images with fixation states, described high quality. The high-quality images with the coverage of Scheimpflug tomographic images over 98% were used for analysis. The anterior and posterior difference of elevation < 5 mm and the difference of the tangential anterior corneal curvature < 0.5D explained high repeatability. A percentage-based signal of the device, according to a keratoscopic image of > 90% described high centrality. Three months after the operation, 103 patients were examined again with the same method and the corresponding data were recorded.

Statistical analysis

The SPSS software (version 25.0) was used for data analysis. The average Q value (mean ± SD) for varying diameters was determined using descriptive statistics. Variance analysis (One-way ANOVA) was used to compare the Q value for different diameters. Kruskal-Wallis H test was used to compare the Q value for three age groups. T-test was performed to compare Q value between the male and female groups, and to compare Q value before and 3 months after operation. Pearson's correlation was used to explore the relationship between corneal Q value and HOAs. We considered a p-value of < 0.05 to be statistically significant.

Results

Subject's age distribution

In a range of 38–92 years, 67.44 ± 10.66 years was the average age. 5.79% of the subjects belonged to the group aged 38 to 50 years, 51.24% belonged to the 50–70 years group, while 42.97% of the study population was accounted for by persons aged 70 years and above. In this study, around 94.21% of the population was composed of persons aged 50 years and above, the period was considered most prone to develop senile cataract.

Corneal Q values

The anterior surface indicated, respectively, the mean corneal Q values as: 0.09 (± 0.42), 0.02 (± 0.27), -0.04 (± 0.20) and − 0.11 (± 0.17) in 3.0, 4.0, 5.0 and 6.0 mm zone. The mean Q values of the posterior corneal surface were: 0.02 (± 0.81), -0.28 (± 0.56), -0.37 (± 0.43) and − 0.41 (± 0.30) in 3.0, 4.0, 5.0 and 6.0 mm zone, respectively (Table 1). The corneal Q value of anterior and posterior corneal surfaces decreased with the enlargement of the measurement range (Table 1). The negative Q values of anterior surfaces were 37.19%, 49.59%, 59.50%, and 76.86% of the total eyes. The negative corneal Q values of 3.0, 4.0, 5.0, and 6.0 mm zone on the posterior surface were 44.63%, 69.42%, 80.99% and 95.04% of the total eyes. It can be seen that the corneal Q values of most cataract patients were negative at the 6.0 mm diameter zone of the cornea. That is to say, the anterior and posterior corneal surface of most cataract patients was prolate.

Table 1
Corneal Q values.

diameter (mm)	Q value (anterior)		Q value (posterior)	
	Mean ± SD	**Negative constituent ratio**	**Mean ± SD**	**Negative constituent ratio**
3.0	0.09 ± 0.42	37.19%	0.02 ± 0.81	44.63%
4.0	0.02 ± 0.27*	49.59%	-0.28 ± 0.56*	69.42%
5.0	-0.04 ± 0.20**	59.50%	-0.37 ± 0.43**	80.99%
6.0	-0.11 ± 0.17***	76.86%	-0.41 ± 0.30***	95.04%
F	27.085		44.861	
p	**< 0.001**		**< 0.001**	

Note: "*" means compared with 3.0 mm diameter $p < 0.05$; "**" means compared with 4.0 mm diameter $p < 0.05$; "***" means compared with 5.0 mm diameter $p < 0.05$.

Corneal Q value distribution at large zone of 6.0mm

In 121 eyes, the mean Q value of anterior corneal surface was: -0.11 ± 0.17, 95% confidence interval (95% CI): -0.07 ~ -0.14 (Fig. 1A), and that of posterior corneal surface was: -0.41 ± 0.30, 95% CI: -0.36 ~ -0.46 (Fig. 1B).

Corneal Q value of different age groups

Table 2 showed the distribution of the Q value at various stages of age. The study participants were divided into three groups according to their ages: 38–49 years old; 50–69 years old; and ≥ 70 years old. The one-way ANOVA analysis results indicate that the anterior corneal surface Q values of the ≥ 70 years old group (in 6.0 mm zone) was significantly higher than those of the 38–49 years old group; posterior corneal surface Q values (in 4.0 mm and 5.0 mm zone) of the ≥ 70 years old group were significantly lower than those of the 50–69 years old group; and the posterior corneal surface Q value (in 6.0 mm zone) of the ≥ 70 years old group were significantly lower than those of the 38–49 years old and 50–69 years old groups. It was quite evident that with increasing age, the Q value of the anterior surface of the cornea also increased. Nevertheless, as indicated in Table 2, with an increase in the age, the posterior surface Q value seemed to decrease.

Table 2
Corneal Q values for different age groups.

diameter (mm)	Age Group (years old)				
	38–49	**50–69**	**≥ 70**	χ^2	***p***
3.0 (Anterior)	0.04(-0.09-0.34)	0.07(-0.09-0.24)	0.08(-0.14-0.24)	0.657	0.720
4.0 (Anterior)	-0.06(-0.16-0.08)	0.03(-0.10-0.14)	-0.02(-0.15-0.10)	1.072	0.585
5.0 (Anterior)	-0.16(-0.21-0.01)	-0.06(-0.16-0.09)	-0.04(-0.17-0.06)	1.176	0.556
6.0 (Anterior)	-0.22(-0.31-0.18)	-0.10(-0.21-0.02)	-0.10(-0.20-0.03)*	6.569	**0.037**
3.0 (Posterior)	0.14(-0.26-0.38)	0.24(-0.24-0.58)	-0.06(-0.57-0.47)	4.376	0.112
4.0 (Posterior)	-0.08(-0.16-0.01)	-0.06(-0.28-0.21)	-0.46(-0.68-0.12)#	15.702	**< 0.001**
5.0 (Posterior)	-0.23(-0.27-0.08)	-0.19(-0.39-0.02)	-0.51(-0.77-0.32)#	20.448	**< 0.001**
6.0 (Posterior)	-0.21(-0.39-0.17)	-0.29(-0.44-0.18)	-0.46(-0.68-0.38)*#	20.277	**< 0.001**
Note: "*" means compared with 38–49 $p < 0.05$; "#" means compared with 50–69 $p < 0.05$.					

Corneal Q value in male and female groups

The mean Q value (mean ± SD) at varying diameters for both the female and male groups was determined as indicated in Table 3. There was no significant difference in Q values of anterior surface in 3.0, 4.0, 5.0, and 6.0 mm zone between female and male groups, whereas, for the posterior surface with zone of 3.0, 4.0, 5.0, and 6.0 mm, the Q values were found to be significant ($p < 0.05$) statistically.

Table 3
Corneal Q values for male and female groups.

diameter (mm)	Male	Female	t	*p*
3.0 (Anterior)	0.11 ± 0.39	0.07 ± 0.45	0.397	0.692
4.0 (Anterior)	0.04 ± 0.28	-0.01 ± 0.25	1.131	0.260
5.0 (Anterior)	-0.02 ± 0.21	-0.06 ± 0.19	0.944	0.347
6.0 (Anterior)	-0.10 ± 0.17	-0.11 ± 0.17	0.377	0.707
3.0 (Posterior)	-0.17 ± 0.87	0.19 ± 0.71	-2.505	**0.014**
4.0 (Posterior)	-0.40 ± 0.59	-0.17 ± 0.51	-2.336	**0.021**
5.0 (Posterior)	-0.47 ± 0.46	-0.28 ± 0.38	-2.404	**0.018**
6.0 (Posterior)	-0.47 ± 0.33	-0.35 ± 0.26	-2.303	**0.023**

The correlations of corneal Q value and HOAs

Next, correlations between corneal Q values and HOAs were investigated. A linear correlation analysis revealed that the Q value of the anterior surface (in 6.0 mm zone) positively correlated with total corneal primary spherical aberration ($Z4^0$ cornea) (Pearson correlation = 0.796, $p < 0.001$); with primary spherical aberration of the corneal front surface ($Z4^0$ CF) (Pearson correlation = 0.840, $p < 0.001$); with primary trefoil aberration of the corneal front surface ($Z3^{3,-3}$ CF) (Pearson correlation = 0.236, $p = 0.009$) and with total corneal HOAs (Pearson correlation = 0.305, $p < 0.001$) (Fig. 2). However, negative correlations were found to exist between the Q value of the posterior surface (in 6.0mm zone) and total corneal primary coma aberration ($Z3^{1,-1}$ cornea) (Pearson correlation=-0.212, $p = 0.019$); total corneal primary trefoil aberration ($Z3^{3,-3}$ cornea) (Pearson correlation=-0.179, $p = 0.049$); primary trefoil aberration of the corneal front surface ($Z3^{3,-3}$ CF) (Pearson correlation=-0.190, $p = 0.037$); primary coma aberration of the corneal back surface ($Z3^{1,-1}$ CB) (Pearson correlation=-0.534, $p < 0.001$); primary spherical aberration of the corneal back surface ($Z4^0$ CB) (Pearson correlation=-0.878, $p < 0.001$); and total corneal HOAs (Pearson correlation=-0.220, $p = 0.015$) (Fig. 3).

However, no correlation was found to exist between the Q value of the anterior surface (in 6.0mm zone) and total corneal primary coma aberration ($Z3^{1,-1}$ cornea); total corneal primary trefoil aberration ($Z3^{3,-3}$ cornea); primary coma aberration of the corneal front surface ($Z3^{1,-1}$ CF); primary coma aberration of the corneal back surface ($Z3^{1,-1}$ CB); primary trefoil aberration of the corneal back surface ($Z3^{3,-3}$ CB); or primary spherical aberration of the corneal back surface ($Z4^0$ CB). Similarly, no significant correlation was found to exist between the Q value of the posterior surface (in 6.0 mm zone) and total corneal primary spherical aberration ($Z4^0$ cornea); primary coma aberration of the corneal front surface ($Z3^{1,-1}$ CF); primary spherical aberration of the corneal front surface ($Z4^0$ CF); or primary trefoil aberration of the corneal back surface ($Z3^{3,-3}$ CB).

The comparison of corneal Q value before and after operation

Three months after surgery, a total of 103 patients were recorded, the Q value (in 6.0 mm zone) and visual acuity due to 18 patients was lost to follow-up. As shown in Table 4, there was no significant change in Q values of anterior and posterior corneal surface at 3 months after operation. The results showed that our phacoemulsification did not change the corneal Q value.

Table 4
Comparison of corneal Q values before and after operation.

Q value	eyes	Pre	Post 3M	t	*p*
Anterior (6mm)	103	-0.10 ± 0.17	-0.11 ± 0.17	1.815	0.072
Posterior (6mm)	103	-0.40 ± 0.31	-0.40 ± 0.30	-1.677	0.097

Discussion

The cornea is the first surface of light gateway to the retina, representing two-thirds of the dioptric power of the human eye, making it the most important refractive element. The parameter most used to describe how the curvature of a parabola differs from the curve of a circle is the asphericity,Q value is one of the most common and important parameters for describing the asphericity of the cornea. The Q value characterizes the change on cornea curvature from the center to the periphery. When Q = 0, it represents a circle, but if Q < 0 or Q > 0, it represents a prolate or oblate ellipse, respectively. [11] The anterior and posterior surface corneal Q value with a zone of 6.0 mm were observed to be -0.11 ± 0.17 and − 0.41 ± 0.30, respectively in this study, whereas, in some earlier studies the corneal mean Q values were reported as -0.22 (Cheung (Chinese), [12] -0.08 (Horner (Indian)), [13] -0.20 (Fuller (American Caucasian)) [4] and − 0.19 (Read (Australian)). [14] The subtle differences between our study and the earlier studies could have been possibly due to the impact of various factors like age, race, sample size, and the differences in testing equipment.

The anterior and posterior corneal surfaces were separately calibrated using the Sirius system in the study, which we had used for a related study before.[15] While some other studies had utilized varying methods, like: Pentacam HR system, TMSI mapping system, and the EyeSys corneal topography. Sirius system was routinely employed in research and clinical use, and preceding studies that measured anterior segment parameters have demonstrated the system’s high degree of repeatability and reproducibility. The system’s repeatability is akin to that reported for the Pentacam tomographers.[16, 17]

Regarding the study of Q values across different ages, Dubbleman et al.[18] investigated corneal asphericity in 114 cases (aged between 18–65 years old), finding that the Q values increased with age. Age-related changes in corneal thickness and asphericity are believed to be due to the increase in the number of patients with corneal arcus senilis with age. Guirao et al.,[19] examined changes in corneal curvature across three groups, namely, young people (between 20–30 years old), middle-aged people (between 40–50 years old), and elderly people (between 60–70 years old), finding that corneal asphericity progressed and became increasingly circular (from oblate to round) with age. Out of the 1,991 subjects in the study conducted by Davis [20] for the children in the age group of 6 to 15 years old, the mean Q value they determined was found to be -0.346. The subjects in Zhang's [5] studies were Chinese youngsters at an average age of 25.4 years old with − 0.30 as the Q value. In our study, the average age of the subjects was 67.44 years, the corneal Q value of the anterior surface with 6.0 mm zone was found to be much higher in the group with an age above 70 years than in the group ranging from 38–49 years, which is consistent with the previous study conducted by Dubbleman. However, few studies have measured the Q values of the posterior corneal surface. Our results have shown that the Q value decreased significantly with age across the zone of 4.0 mm, 5.0 mm, and 6.0 mm. A correlation between sex and the Q value was aptly established in our study. Scholz[21] and Chan[22] arrived at similar conclusions. For the anterior surface in our study, the female group was found to have a smaller Q value than the male group. For the posterior surface, the opposite was found and the difference was statistically significant. However, sex was found to be an irrelevant factor for the corneal Q value in the study conducted by Fuller [4], it may be attributed to the difference in the subject's age and race.

Wavefront aberration refers to the optical path difference between wavefront and ideal wavefront at each point on the imaging plane of the eye. Some aberrations are the primary causes of glare, halos, and decreased night vision in patients following cataract surgery, including total HOAs, spherical aberration, coma, and trefoil aberration.[23] The corneal Q value is a morphological parameter representing the geometric shape of the cornea, whereas corneal aberration (e.g., spherical aberration) describes the optical quality of the cornea and is representative of the degree of corneal optical error. However, few studies have investigated the correlation between Q values and HOAs. Calossi[11] analyzed the relationship between asphericity and the degree of spherical aberration of the anterior corneal surface. It was found that, as long as the corneal refractive index and the pupil diameter remained constant, the flatter corneal surfaces from the center to the periphery (negative Q value), the lesser degree of spherical aberration, and steeper corneal surfaces from the center to the periphery (positive Q value) equated to greater degrees of spherical aberration. Our results indicated that both the anterior and posterior surfaces of the cornea correlate significantly with the degree of spherical aberration of the corresponding ranges. That is to say that, alongside higher Q value, the degree of spherical aberration increases accordingly, which is consistent with previous studies. Coma and trefoil were both third-order aberrations, which reflected the asymmetry of refractive characteristics of the eye and were the representation of irregularity, inclination, eccentricity, and other symmetry of the eye. Related studies have indicated that spherical and coma aberration is associated with decreased visual acuity and contrast sensitivity in healthy people. In this study, a positive correlation was found to exist between Q value and the degree of trefoil aberration of the front corneal surface, while a negative correlation exists between Q value and total coma aberration, coma aberration of the corneal back surface, total trefoil aberration, and trefoil aberration of the front corneal surface. These findings suggest that evaluation of corneal Q-value before cataract surgery may have certain significant to the postoperative recovery of visual function and enhancing patients’ visual quality.

There was no significant change in Q value before and after surgery, which indicated that the surgery did not cause corneal morphology change. The possible reason may be that all patients underwent limbal incision with a length of 2.2 mm. Firstly, the incision was small enough and relatively far away from the cornea. Secondly, the change of corneal vertical diameter was limited by the outer edge of the large curved tunnel, so the change of corneal morphology was limited. It is important that the phacoemulsification did not change the corneal Q value, because it is meaningful to observe whether the preoperative corneal Q value can be used as a parameter for personalized selection of IOL, only when there is no significant change in the corneal Q value before and after surgery.

The present study differs from the previous studies in that the corneal Q values for 3.0mm, 4.0mm, 5.0mm, and 6.0 mm zone were tallied separately. It was found that the Q value relates to aperture size and that the average values vary statistically across different diameters. Meanwhile, the Q values of the posterior corneal surface were also examined. Although the posterior corneal surface is seldom relevant in the design of refractive products, it does affect the optical properties of the eye. Prior research around the Q value of the posterior corneal surface is limited. In conclusion, there were great individual differences between the corneal Q values of the cataract patients. Age, sex, and HOAs seemed to be correlated with the Q value. The preoperative Q value can be used as one of the parameters for personalized selection of intraocular lens.

Abbreviations

HOAs: higher-order aberrations; IOL: intraocular lens; LOCS III: Lens Opacities Classification System III; RMS: root mean square; CI: confidence interval; CF: corneal front surface; CB: corneal back surface

Declarations

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Not applicable.

Authors' contributions

LC was involved in the study design, data collection, statistical analysis, and drafted the manuscript. LPR was involved in the analysis and interpretation of study data. Both authors read and approved the final manuscript.

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Availability of data and materials

The datasets analyzed during the current study are not publicly available for confidentiality reasons; nevertheless, the corresponding author will provide them on reasonable request.

Ethics approval and consent to participate

This non-interventional retrospective chart-review study was approved by the ethics committee of the First Affiliated Hospital of Soochow University, and the committee waived the need for informed consent from the patients because the data were anonymized.

Consent for publication

Not applicable.

Competing interests

The author declares no competing interests.

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Figures

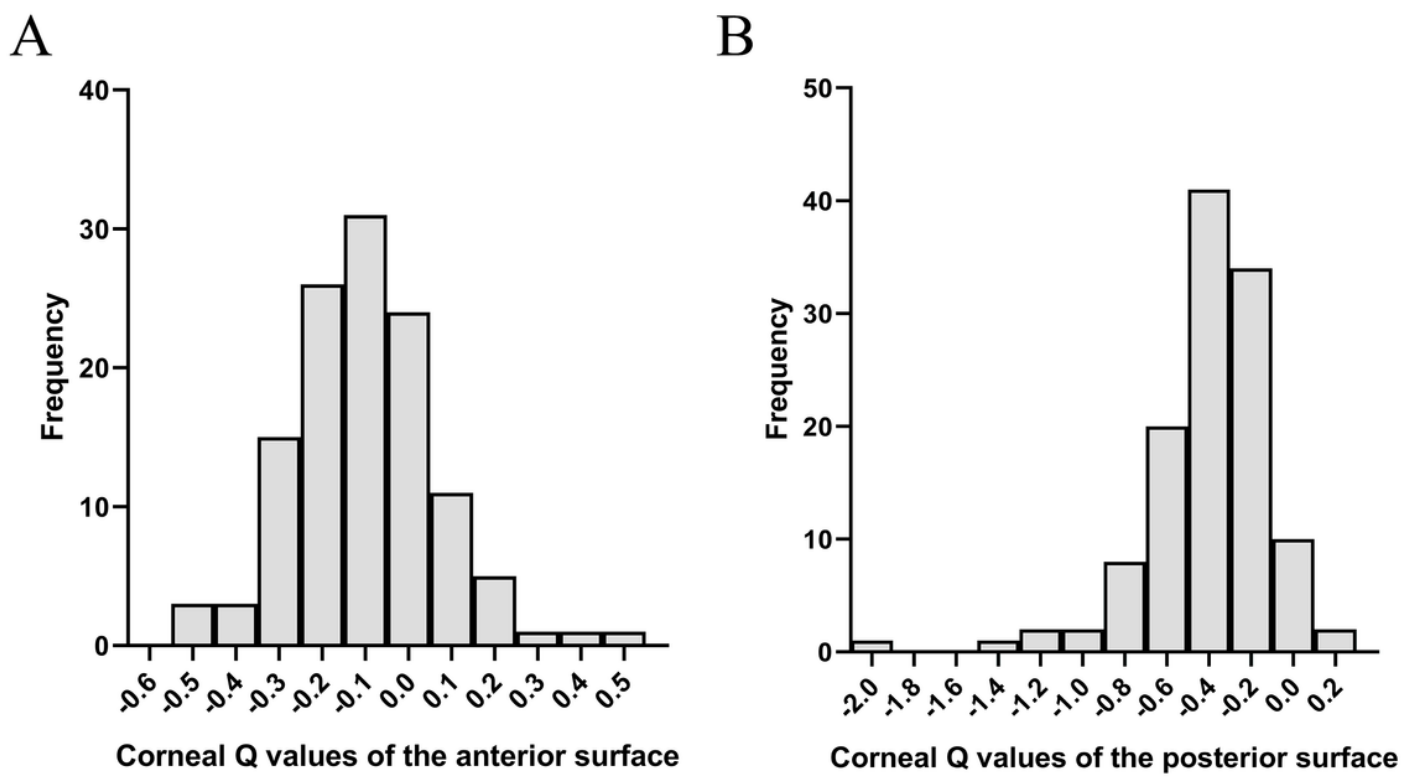

Figure 1

Corneal Q values distribution of the anterior (A) and posterior corneal surface (B).

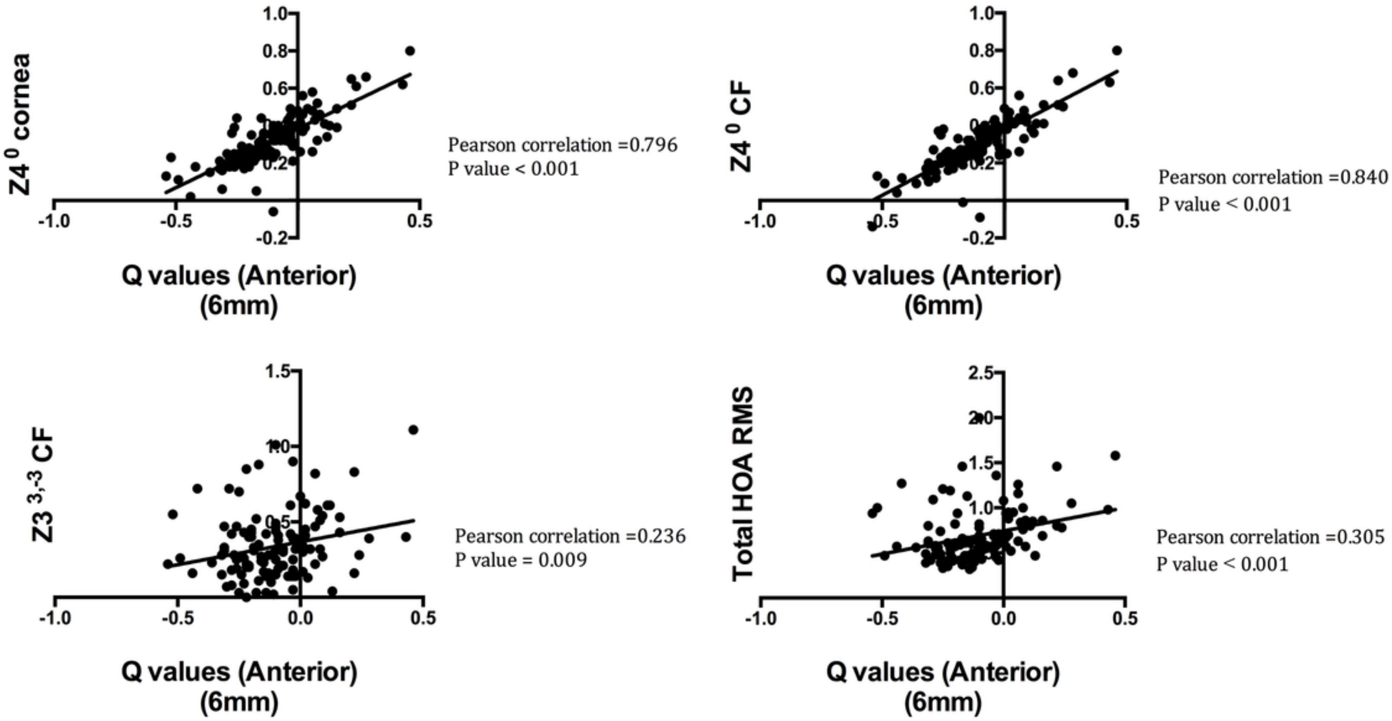

Figure 2

Correlations between Q value of anterior corneal surface and HOAs. (cornea=total cornea; CF=front corneal surface; Z33, -3=primary trefoil aberration; Z40=primary spherical aberration; Total HOA RMS=total corneal HOAs)

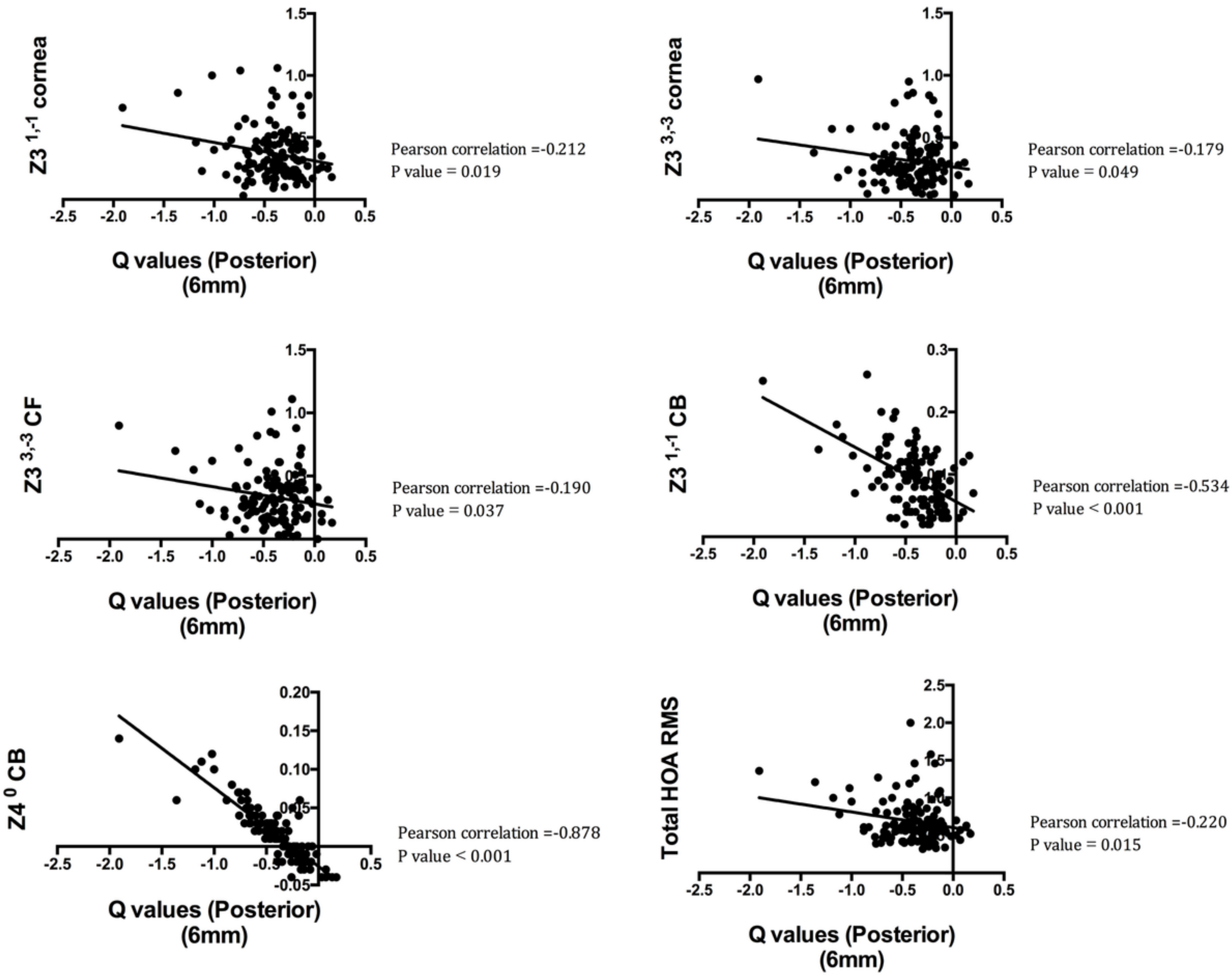

Figure 3

Correlations between Q value of posterior corneal surface and HOAs. (cornea=total cornea; CF=front corneal surface; CB=back corneal surface; Z33, -3=primary trefoil aberration; Z40=primary spherical aberration; Z31, -1=primary coma aberration; Total HOA RMS=total corneal HOAs)