

Characteristics of corneal Q value and its related factors in cataract patients before operation

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Research article

Keywords: Q value, aberrations, cataract, Sirius, Scheimpflug photography

Posted Date: October 14th, 2019

DOI: <https://doi.org/10.21203/rs.2.15989/v1>

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Abstract

Background: To determine corneal Q value and its related factors in cataract patients.

Methods: A retrospective study was conducted in the First Affiliated Hospital of Soochow University, Suzhou, China. In all, this study enrolled 121 eligible eyes of 121 cataract patients. The corneal Q values of anterior and posterior surfaces were measured in central 3.0, 4.0, 5.0 and 6.0 mm zone using the Sirius System. Age and gender were recorded. Cataract was diagnosed using slit-lamp examination.

Results: The average Q value of the anterior surface in 3.0, 4.0, 5.0 and 6.0 mm zone were 0.09 ± 0.42 , 0.02 ± 0.27 , -0.04 ± 0.20 and -0.11 ± 0.17 , respectively. The average Q value of the posterior surface in 3.0, 4.0, 5.0 and 6.0 mm zone were 0.02 ± 0.81 , -0.28 ± 0.56 , -0.37 ± 0.43 , -0.41 ± 0.30 , respectively. The Q values of the anterior 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 ($p<0.05$) across different age groups. The Q values of the posterior surfaces in 3.0, 4.0, 5.0 and 6.0 mm zone were statistically significant ($p<0.05$) between the male and the female groups. The Q values of the anterior surface in the 6.0 mm zone were positively correlated with Z40 cornea (Pearson correlation =0.796, $p<0.001$), Z40 CF (Pearson correlation =0.840, $p<0.001$), Z33,-3 CF (Pearson correlation =0.236, $p=0.009$) and total corneal higher-order aberrations (HOAs) (Pearson correlation =0.305, $p<0.001$); While the Q values of the posterior surface in the 6.0 mm zone were negatively correlated with Z31,-1 cornea (Pearson correlation =-0.212, $p=0.019$), Z33,-3 cornea (Pearson correlation =-0.179, $p=0.049$), Z33,-3 CF (Pearson correlation =-0.190, $p=0.037$), Z31,-1 CB (Pearson correlation =-0.534, $p<0.001$), Z40 CB (Pearson correlation =-0.878, $p<0.001$) and total corneal HOAs (Pearson correlation =-0.220, $p=0.015$).

Conclusions: 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 values.

Keywords: Q value; aberrations; cataract; Sirius; Scheimpflug photography

Background

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 [1–3]. 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 [4,5], which includes the aberration distribution, the spherical aberration, the refractive power, and others. 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 [6–9].

Alongside the popularization and application of aberration theory in ophthalmology, the influence of corneal Q values on spherical aberrations following corneal refractive surgery and intraocular refractive surgery is garnering an increasing amount of attention from ophthalmologists. Corneal Q values provide an essential reference for personalized corneal refractive surgery and aspheric intraocular lens (IOL) implantation. Although corneal Q values in elderly populations are essential factors in the design of IOL procedures and for the treatment of refractive errors [10,11], few formal studies have been conducted to evaluate its relevance for cataract patients.

The Q values of different corneal surface areas are disparate, and a single value does not accurately reflect the shape of the cornea [12]. It is crucial to examine the Q values of different ranges to improve the visual acuity of cataract patients following aspheric IOL implantation. Many different factors affect corneal Q values. Previous studies have focused on the relationships between Q values and age, refractive errors [13], refractive statuses [14], and spherical aberrations [15], while studies concerning Q values and other high-order aberrations (HOAs) of the cornea are limited at present. This study aims to determine the characteristics of the corneal Q value and its correlations with corneal HOAs in cataract patients, which provide a theoretical basis for treating the errors in refraction and designing IOLs.

Methods

Study population

This retrospective study recruited patients scheduled for cataract surgery, from July 31st, 2017 to May 31st, 2018, at the First Affiliated Hospital of Soochow University, Suzhou, China. A total of 121 eyes of 121 cataract patients were enrolled. Patients who had undergone ocular surgeries or had corneal diseases, glaucoma, uveitis, dry eye or had worn contact lenses in the last 2 weeks were excluded. After exclusion of the eyes with high deviation from the surface reference, incomplete topographical mapping, and/or poor repeated measurements, the study included 58 males and 63 females. 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 signatures.

Measurement

Corneal topography measurement was repeated three times for each of 121 patients' eye using Sirius (Sirius, CSO Inc, Florence, Italy) system. Data were analyzed for the full topographic map measurements in central 3.0, 4.0, 5.0 and 6.0 mm zone. The same qualified doctors examined the subjects, the focus was on eliminating examiner bias. During analysis, the corneal reflex rings were clear and the tear film rupture was not disturbed. The Q values in central 3.0, 4.0, 5.0 and 6.0 mm zone were calculated by the Sirius system. The distribution of the Q values of both the anterior and posterior surfaces with large diameters (6.0 mm zone), the analysis of the correlation between the HOAs and Q values, along with the

mean corneal Q values (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 (Z_4^0), primary coma aberration ($Z_3^1, -1$), primary trefoil aberration ($Z_3^3, -3$) 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. However, grouping was ignored by the evaluators.

Statistical analysis

The SPSS software (version 25.0) was used for data analyses. 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 values for different diameters. Kruskal-Wallis H test was used to compare the Q values for three age groups. T-test was performed to compare Q values between the male and female groups. Pearson's correlation was used to explore the relationship between corneal Q values 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 which was considered to be 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 corneal Q values of the posterior 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 values of anterior and posterior 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. It can be seen that the corneal Q values of

anterior surfaces of most cataract patients were negative. That is to say, the anterior corneal surface of most cataract patients was prolate. 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. The average Q value of 6.0 mm zone on the anterior corneal surface of 121 eyes was normal distribution.

Corneal Q value distribution at large zone of 6.0 mm

In the range -0.07 to -0.14 , CI 95% (Figure 1) the anterior surface showed a mean Q value of -0.11 ± 0.17 , whereas, on the posterior surface in the range -0.36 to -0.46 , CI 95% (Figure 2), it was -0.41 ± 0.30 .

Corneal Q values for different age groups

Figure 3 and Table 2 summarize the distribution of the Q values 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 anterior corneal surface Q values of the ≥ 70 years old group (in 6.0 mm zone) were 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 values (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 an increasing age the Q value of the anterior surface of the cornea also increased. Nevertheless, as indicated in Figure 3, with an increase in the age, the posterior surface Q value seemed to decrease.

Corneal Q values for male and female groups

The mean Q values (mean \pm SD) at varying diameters for both the female and male groups were determined as indicated in Table 3. The statistical significance ($p > 0.05$) of the Q values for both the female and the male groups in zone of 3.0, 4.0, 5.0 and 6.0 mm was insignificant or negligible, 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.

The correlations of corneal Q values and HOAs

Next, correlations between corneal Q values and HOAs were investigated. A linear correlation analysis revealed that the Q values of the anterior surface (in 6.0 mm zone) positively correlated with total corneal primary spherical aberration (Z_4^0 cornea) (Pearson correlation = 0.796, $p < 0.001$); with primary spherical aberration of the corneal front surface (Z_4^0 CF) (Pearson correlation = 0.840, $p < 0.001$); with primary trefoil aberration of the corneal front surface ($Z_3^{3,-3}$ CF) (Pearson correlation = 0.236, $p = 0.009$) and with

total corneal HOAs (Pearson correlation = 0.305, $p < 0.001$) (Figure 4). However, negative correlations were found to exist between the Q values 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 front surface ($Z4^0$ CB) (Pearson correlation = -0.878 , $p < 0.001$); and total corneal HOAs (Pearson correlation = -0.220 , $p = 0.015$) (Figure 5).

However, no correlation was found to exist between the Q values of the anterior surface (in 6.0 mm 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 values 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) (Table S1).

Discussion

The cornea is the first surface of light gateway to the retina along with the tear film, representing two-thirds of the dioptric power of the human eye, making it the most important refractive element [16]. The anterior surface of the cornea can be mathematically described into conic sections. The parameter most used to describe how the curvature of a parabola differs from the curve of a circle is the asphericity (Q value). The Q value characterizes the change on cornea curvature from the center to the periphery. When $Q = 0$, it represents a circle, but if $-1 < Q < 0$ or $Q > 0$, it represents a prolate or oblate ellipse, respectively. If $Q = -1$, the curve defines a parabola while a hyperbole is defined when $Q < -1$ [16,17]. The literature reported negative Q values ranging between -0.01 and -0.80 for a normal cornea, which indicates that cornea usually flattens toward the periphery and can be better fitted to a prolate ellipse shape [12,18]. The Q values of different corneal aperture diameters varied, with a corneal aperture diameter of 3.0 mm being the largest, and the nearer the perimeter, the smaller the value. This study is consistent with previous studies since most of the Q values in previous studies were observed at 30 degrees (or 6.0 mm zone) in the central cornea. The posterior and anterior surface corneal Q values with zone of 6.0 mm were observed to be -0.41 ± 0.30 and -0.11 ± 0.17 respectively in this pertinent study, whereas, in some earlier studies the corneal Q values were reported as -0.22 [Cheung (Chinese)] [19], -0.08 [Horner (Indian)] [20], -0.20 [Fuller (American Caucasian)] [6] and -0.19 [Read (Australian)] [21]. This substantial difference with our study and the earlier studies could have been possible due to the impact of various factors like the subject age and race, sample sizes, and the differences in testing equipment.

The anterior and posterior corneal surfaces were separately calibrated using the Sirius system in the study. The same instrument had been used by various other studies as we had used [22–27], while some other studies had utilized varying methods, like: Pentacam HR system [9], TMS-I mapping system [28] and The EyeSys corneal topography [6]. Sirius Scheimpflug-Placido tomographers are 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 [29,30]. The system's repeatability is akin to that reported for the Pentacam tomographers [31]. Datapoints such as simulated K, corneal power, the distance between the corneal endothelia, and the Q value are considered to be interchangeable between these two instruments [32].

Regarding the study of Q values across different ages, Dubbelman et al. [33] 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. [34] 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. In our study, the average age of the subjects comprising of 94.21% in the age group above 50 years was 67.44 years, while the corneal Q values of the anterior surface with a zone under 6.0 mm 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 Dubbelman. However, few studies have measured the Q values of the posterior corneal surface. Our results have shown that the Q values decrease significantly with age across the zone of 4.0mm, 5.0mm and 6.0 mm. The larger the observed area, the more obvious the change in Q values of the posterior corneal surface. It shows that the factors of posterior corneal surface morphology and pupil size should be taken into account when choosing new IOLs (multifocal IOL, aspherical IOL, etc.) for cataract patients over 70 years old. It also shows that refractive IOLs is not recommended for cataract patients over 70 years old.

A correlation between sex and the Q values was aptly established in our study. Carney [35], Scholz [36], Dubbelman [33] and Chan [8] 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. However, for the posterior surface the opposite was found to be true along with certain difference in the statistics. Sex was found to be an irrelevant factor for the corneal Q values in the studies conducted by Fuller [6] and Cheung [19], which may be attributed to the difference in the subject's race and different measuring instruments.

Corneal aspheric properties influence visual acuity. Wavefront aberration refers to the optical path difference between wavefront and ideal wavefront (from the perspective of wave optics) at each point on the imaging plane of the eye. The most relevant aberrations are total HOAs, spherical aberration, coma aberration, and trefoil aberration, which are the primary causes of glare, halos, and decreased nighttime vision in patients following cataract surgery or corneal refractive surgery [37,38]. Different corneal shapes produce different degrees of spherical aberration. 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 corneal aspheric morphology and HOAs. Philip et al. [39] examined corneal morphology and its influence on HOAs using a theoretical model. It was found that fourth-order aberration (especially spherical aberration) varied alongside corneal asphericity. Kiely et al. [40] studied corneal morphology and its influence on corneal aberration, finding that the degree of corneal aberration varied alongside corneal asphericity and the radius of the corneal apex curvature. Calossi [17] 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, flatter corneal surfaces from the center to the periphery (negative Q value) equated to lesser degrees 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 values, the degree of spherical aberration increases accordingly, which is consistent with previous studies [17,39,40]. Furthermore, this finding reflects the morphological characteristics of the cornea in optical imaging.

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. The depth of the focus gets enhanced by the aberration of the vertical coma [41]. Theoretically, coma is correctable, however, technically, it is much difficult to conduct a surgical correction under the circumstances. In certain cases Trefoil becomes unmanageable and surgery may worsen the situation. Related studies have indicated that spherical and coma aberration is associated with decreased visual acuity and contrast sensitivity in healthy people [42]. In this study, a positive correlation was found to exist between Q values and the degree of trefoil aberration of the front corneal surface, while a negative correlation exists between Q values 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 preoperative evaluation of corneal Q values before cataract surgery is hugely significant to the postoperative recovery of visual function and enhancing patients' visual acuity.

The primary feature of this study is that the corneal Q values for 3.0, 4.0, 5.0 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. This conclusion is hugely significant for product design relating to corneal shapes (e.g., contact lenses), and designers should adjust their design parameters according to different diameters. Meanwhile, according to the mathematical model, the Q value affects the degree of aberration and refractive power distribution of the cornea, thus providing a reference for the design of products related to corneal optical properties and parameters, such as IOLs. The Q values of the posterior corneal surface were also examined in this study. 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 values of the posterior corneal surface is limited. This study found that patients' age and gender affect the Q values of the posterior corneal surface under varying diameters, and a correlation was

found to exist between the Q values of the posterior corneal surface and higher-order aberrations. Consequently, attention should be paid to the morphological characteristics of the posterior corneal surface in preoperative cataract evaluation and the design of intraocular lenses.

There were some limitations to this study. Overall, the recruitment of the patients was highly restricted in number. Besides, the usage of just the Scheimpflug instruments could have led to limitations in the corneal measurements despite the reproducibility and repeatability of the Scheimpflug instruments being revealed in the earlier studies in case of measurements on the anterior segment in the normal eyes. Nevertheless, supplementary corneal topographers could have been utilized. The aberration measurements might also have been affected by the conditions of the tear film [43]. Thus, the last limitation was no measurements of ocular surface dryness, although all dry eyes diagnosed were excluded.

In conclusion, the purpose of this research was to study the factors related to the corneal Q values in cataract patients. We found that there were great individual differences in Q values. The Q values were found to have a correlation with HOAs, sex, and age. Further studies with regards to the optical properties of the human eye shall be able to access the results as ready reference, besides they could be helpful in improving the designing of the IOLs.

Abbreviations

Q value: Asphericity; HOAs: Higher-order aberrations; Z_4^0 : Primary spherical aberration; Z_4^0 cornea: Total corneal primary spherical aberration; Z_4^0 CF: Primary spherical aberration of the corneal front surface; Z_4^0 CB: Primary spherical aberration of the corneal back surface; $Z_3^{1,-1}$: Primary coma aberration; $Z_3^{1,-1}$ cornea: Total corneal primary coma aberration; $Z_3^{1,-1}$ CF: Primary coma aberration of the corneal front surface; $Z_3^{1,-1}$ CB: Primary coma aberration of the corneal back surface; $Z_3^{3,-3}$: Primary trefoil aberration; $Z_3^{3,-3}$ cornea: Total corneal primary trefoil aberration; $Z_3^{3,-3}$ CF: Primary trefoil aberration of the corneal front surface; $Z_3^{3,-3}$ CB: Primary trefoil aberration of the corneal back surface; IOL: Intraocular lens; RMS: Root mean square.

Declarations

Ethics approval and consent to participate

The study was performed in accordance with the Declaration of Helsinki and approved by the ethics committee board of the First Affiliated Hospital of Soochow University. The patients provided written informed consent for their participation in the study. A copy of the written consent is available for review by the editor of this journal.

Consent for publication

Written informed consent was obtained for publication of this manuscript and any accompanying images. A copy of the written consent is available for review by the editor of this journal.

Availability of data and materials

All data have been shared in the Figures and Tables.

Competing interests

All authors declare that they have no competing interests.

Funding

This work was supported by the National Natural Science Foundation in China (NSFC No. 81671641), Jiangsu Provincial Medical Innovation Team (No. CXTDA2017039), Jiangsu Provincial Natural Science Foundation (No. BK20151208), and the Soochow Scholar Project of Soochow University (No. R5122001).

Authors' contributions

Chen Li and Peirong Lu designed the study; Chen Li, Jianqing Li, Yihong Cao, Jiaju Zhang and Peirong Lu participated in the acquisition of data. Chen Li and Peirong Lu analyzed and interpreted the data and wrote the paper. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

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Tables

Table 1. Corneal Q values.

diameter (mm)	Q values (anterior)		Q values (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±0.2**	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	
<i>p</i>	< 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 $p < 0.05$.

Table 2. Corneal Q values for different age groups.

diameter (mm)	Age Group (years old)				
	38-49	50-69	≥70	c 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 $p < 0.05$.

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)	-0.1±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)	-0.4±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

Figures

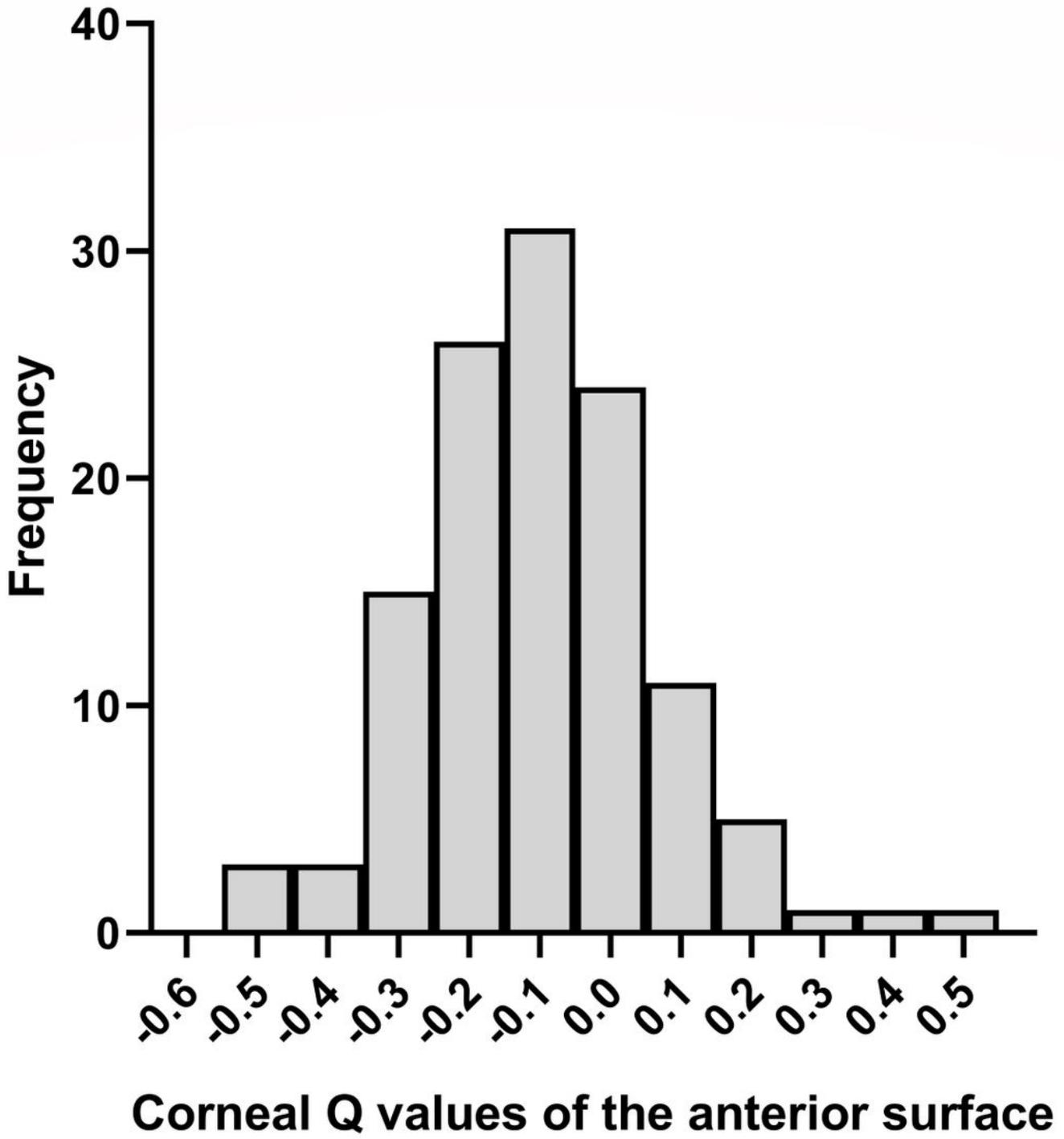


Figure 1

Corneal Q value distribution of the anterior surface.

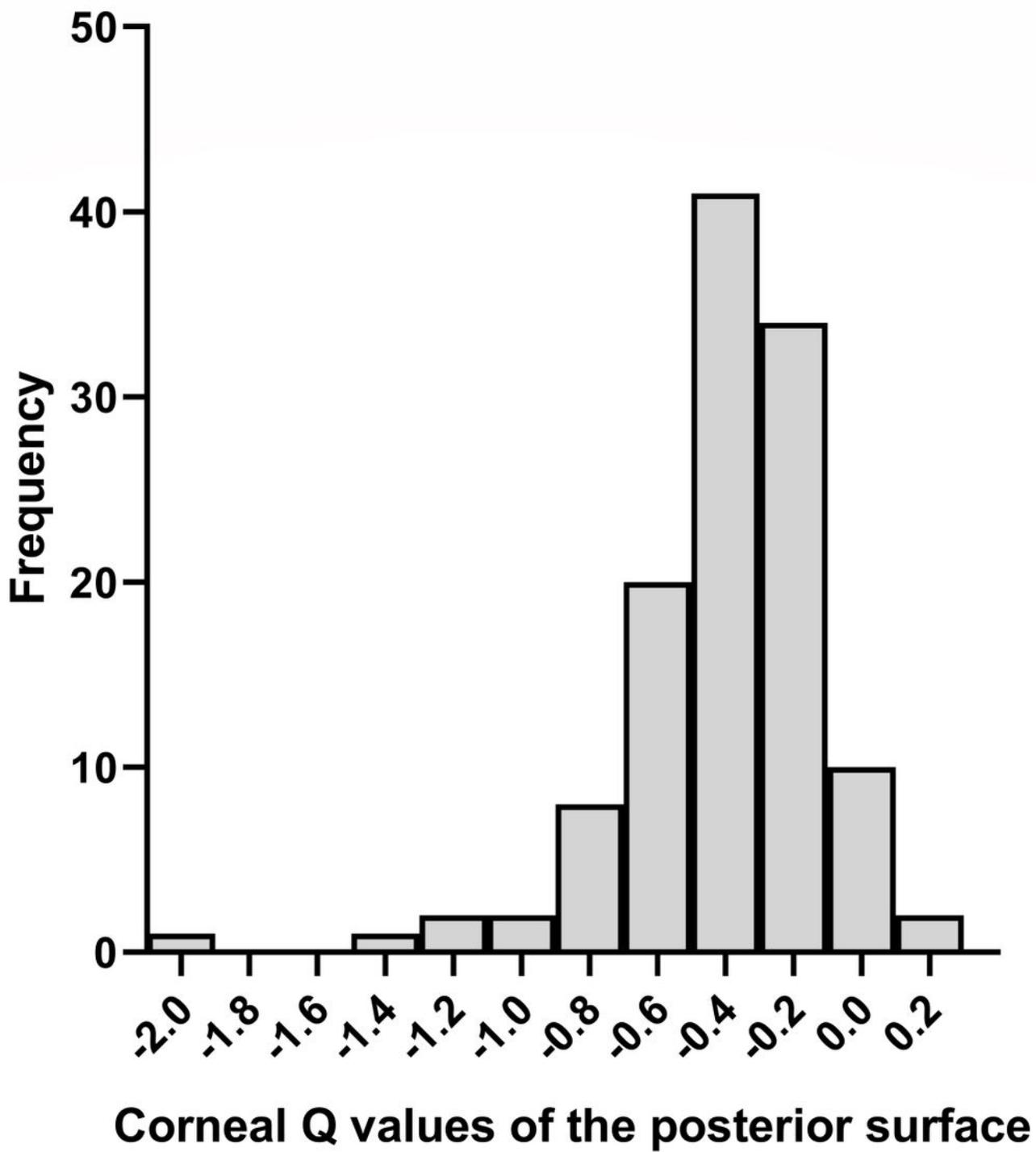


Figure 2

Corneal Q value distribution of the posterior surface.

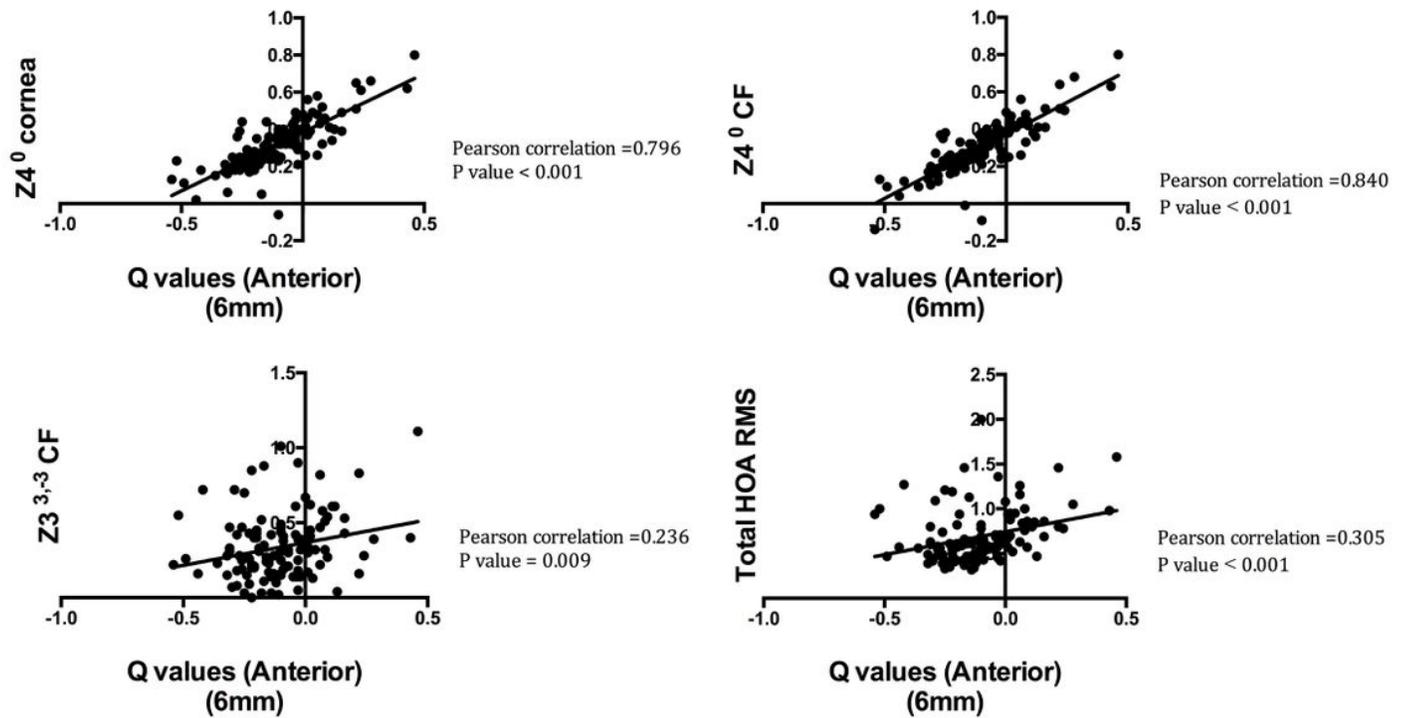


Figure 3

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

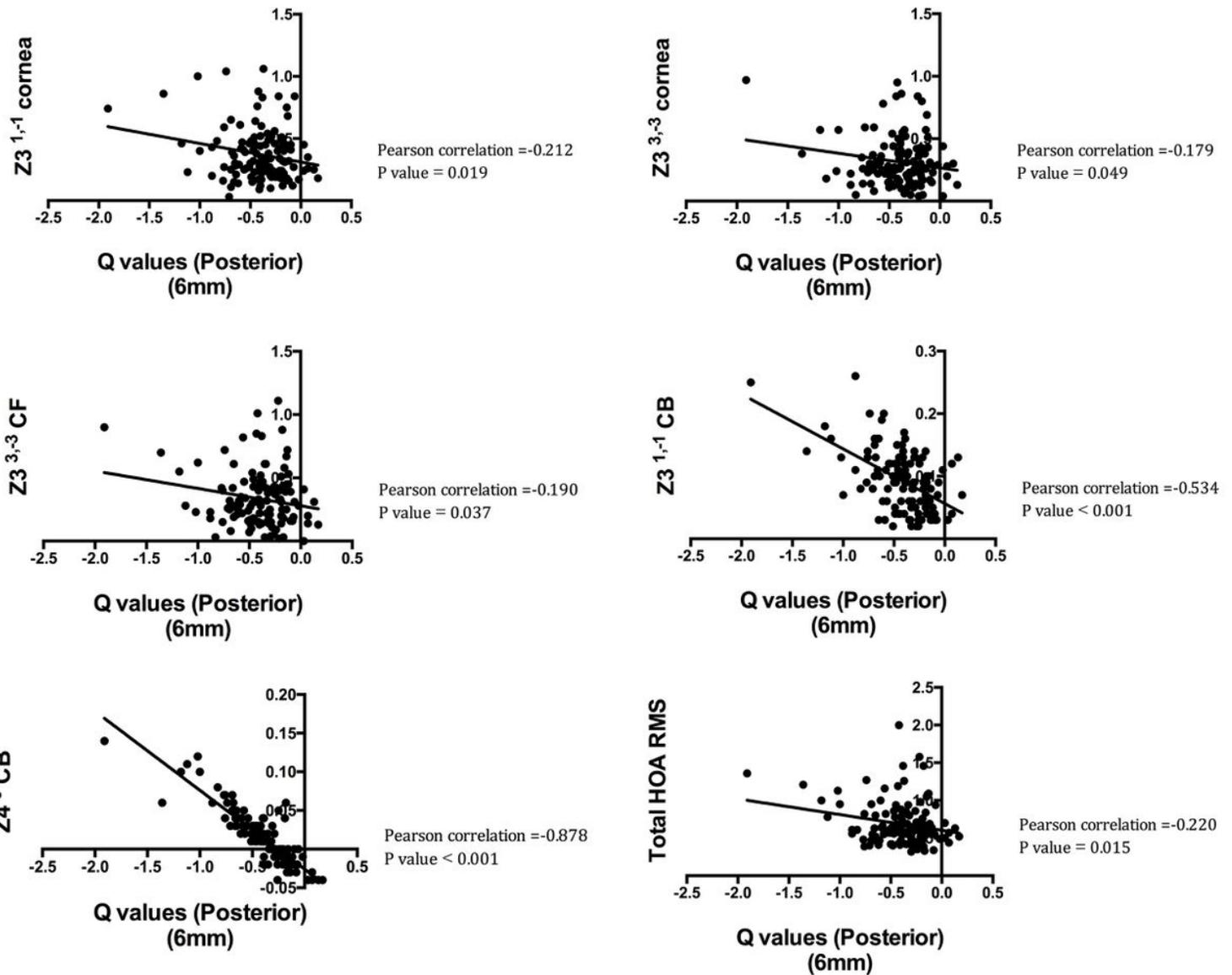


Figure 4

Correlations between Q values of posterior corneal surfaces 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)