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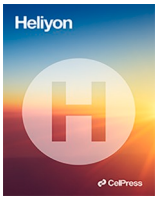

Review article

Influence of different parameters on the corneal asphericity (Q value) assessed with progress in biomedical optics and imaging – A review

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ABSTRACT

The corneal eye diseases such as Keratoconus cause weakening of the cornea, with this disease the cornea can change in shape. This condition affects between 1 in 3,000 to 1 in 10,000 people. The main reason for the development of such conditions is unknown and can have significant impacts. Over the last decade, with advancements in computerized corneal topography assessments, researchers have increasingly expressed interest in corneal topography for research as well as clinical activities. Up till now, several aspheric numerical models have been developed as well as proposed to define the complex shape of the cornea. A commonly used term for characterizing the asphericity in an eye is the Q value, a common indicator of the aspherical degree of the cornea. It is one of the critical parameters in the mathematical description model of the cornea as it represents the cornea's shape and the eye's characteristics. Due to the utmost importance of this Q value of the cornea, a couple of studies have attempted to explore this parameter and its distribution, merely in terms of its influence on the human eye's optical properties. The corneal Q value is an important factor that needs to be determined to treat for any refractive errors as corneal degeneration are disease that can lead to potential problems with the structure of the cornea. This study aims to highlight the need to understand Q value of the cornea as this can essentially assist with personalising corneal refractive surgeries and implantation of intraocular lenses. Therefore, the relevance of corneal Q value must be studied in association with different patients, especially ones who have been diagnosed with cataracts, brain tumours, or even COVID-19. To address this issue, this paper first carries out a literature review on the optics of the cornea, the relevance of corneal Q value in ophthalmic practice and studies corneal degenerations and its causes. Thereafter, a detailed review of several noteworthy relevant research studies examining the Q value of the cornea is performed. To do so, an elaborate database is created, which presents a list of different research works examined in this study and provides key evidence derived from these studies. This includes listing details on the age, gender, ethnicity of the eyes assessed, the

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control variables, the technology used in the study, and even more. The database also delivers important findings and conclusions noted in each study assessed. Next, this paper analyses and discusses the magnitude of corneal Q value in various scenarios and the influence of different parameters on corneal Q value. To design visual optical products as well as to enhance the understanding of the optical properties of an eye, future studies could consider the database and work presented in this study as useful references. In addition, the work can be used to make informed decisions in clinical practice for designing visual optical products as well as to enhance the understanding of the optical properties of an Eye.

1. Introduction

In terms of an eye of a mammal, the cornea and sclera form together in the outer eye tunic. This structure tackles any internal pressure and offers protection to the insides of the eye from any injuries. Regarding the eye's optical system, the cornea is the main module [1] and the major refractive component [2–4]. The cornea in an eye tackles any internal pressures and offers protection to the insides of the eye from any injuries. It is the main module of an eye's optical system and is the major refractive component. Corneal topography with the aid of computerization can offer complete information on the characteristics of the cornea. Achieving such information can be significant in clinical practice, which includes procedures such as corneal refractive surgery and contact lens fitting and management. The cornea-air interface contributes about 75 % of the total dioptric power of the human eyeball [1] whereas the cornea is known to contribute around 70 % of the entire refractive power [2–4]. In terms of the shape of the cornea and its structure, it is transparent and curved, and the external surfaces are smooth-to-good in terms of optical standards. Normally, the mammalian eye globe approximately represents a sphere, at times slightly levelled in the direction of anteroposterior. This happens due to the curvature of the cornea and sclera being comparable. For humans and several other species, the cornea is overall highly curved as compared to the eyeball [1]. The cornea is horizontally oval, measuring 11–12 mm horizontally and 9–11 mm vertically. The corneal horizontal diameter (white to white) using the ORBSCAN II system has revealed average corneal diameter as 11.71 $\pm$ 0.42 mm. The average corneal diameter was 11.77 $\pm$ 0.37 in males compared to 11.64 $\pm$ 0.47 in females. The corneal diameter ranged from 11.04 to 12.50 in males and 10.7–12.58 in females [5,6]. The sight happens, when a beam of light falls on the corneal surface, refracted by the eye lens, the combination of light beams generates a focus of beams. Light is focused on a specific region inside the vitreous humour, inverted on the retina to form the images, then transformed by the optic nerve to the processing centre in the brain. The quality of the generated image affected by Q-value, by how is the cornea is spherical. The curvature of the cornea shapes, the surface that refracts the light beams, and that curvature determines the quality of the generated image. Also, the curvature is the main factor for myopia and hyperopia due to the affection of corneal surface curvature, which will decide for which the path for beam lights to take. The curvature intensity determines the clarity of the generated picture, and it is the main reason for myopia and hyperopia because of the cornea surface curvature, which decides the path for the light beam to be focused on a single point.

1.1. Optics of the cornea

The optics of the eye and the physiology of light transduction within the retina are perhaps essential aspects of vision. To elaborate, some researchers investigating the cornea have defined it as a quadric surface with aspheric surface [2–4]. The term aspheric surface or surface asphericity refers to a non-spherical surface. With respect to an eye, cornea sphericity is generally described by the determination of the conicoid asphericity which fits best the cornea portion to be defined [7]. In this context, a commonly used term for characterizing the asphericity in an eye is the Q value, a common indicator of the aspherical degree. In terms of the quadric surface, the Q value refers to the change in the radius from the centre to the peripheral. It is one of the critical parameters in the mathematical description model of the cornea as it represents the cornea's shape and the eye's characteristics. These include aberration distribution, spherical aberration as well as the refractive power [8,9]. Due to the utmost importance of this Q value of the cornea, a couple of studies have attempted to explore this parameter and its distribution, merely in terms of its influence on the human eye's optical properties [10–12]. Corneal Placido topographers measure geometrical corneal slope values. These values are converted into curvature values e.g., axial (sagittal) curvature or instantaneous (tangential) curvature, which are initially given in mm. The Pentacam measures geometrical height (elevation) values, which are likewise converted into values of axial (sagittal) or instantaneous (tangential) curvature and given in mm. These geometrical radius (mm) values are commonly converted it into refractive power values, which are given in dioptre's (D). This is normally done according to the simple formula of

$$D = (1.3375–1)*(1000)/Rmm.$$

1.2. Relevance of corneal Q value in ophthalmic practice

Some studies have stated that the corneal Q value is an important factor that needs to be determined in senior people to treat for any refractive errors; however, not much studies are present in the literature which cover elderly populations of several countries [13–15]. Further, as mentioned by some researchers [7], the main dioptric element of the overall ocular optical complex is the cornea. This is

because the cornea provides the maximum single dioptric contribution to the total structure. A significant dioptric change can be obtained due to slight changes in the shape of the cornea. As a result, refractive surgeries attempt to mainly chose the anterior surface of the cornea. This is also beneficial due to the reduced intrusiveness of the procedure [7]. The optical zone is the part of the cornea that significantly contributes to foveal image formation and encompasses the entrance pupil. The width of the practical optical zone is determined through the pupil diameter, where the latter can vary as a function of the pupillary dynamics [16,17]. To attain a high-quality retinal image, there must be no aberrations in the pupil entrance. Optically, an ideal cornea should consist of an optical zone that comprises of an adequately shaped factor (i.e., the asphericity) of an elliptical surface [7].

In ophthalmology, together with the propagation and use of the aberration theory, the impact of corneal Q values on spherical aberrations after a surgery (such as corneal refractive and intraocular ones), is attracting a lot of popularity. Essentially, a Q value provides an idea on the curvature changes of the cornea away from the periphery centre. This is linked directly to the spherical aberration, a crucial Higher Order Aberration (HOA). Typically, the cornea is prolate, which means that it is steeper in the centre and flatter in the periphery. On average, based on the research studies conducted in the past, the Q value of a typical cornea is around −0.26. This is a representation of a prolate cornea which contributes slightly but significantly to the spherical aberration of nearly +0.27. Ideally, a person with a Q value of −0.50 would have no spherical aberrations in their eye. Nevertheless, such a perfectly shaped parabola cornea is found in a very few people. Usually, the majority of corneas have a Q value between −0.2 and −0.4. A more oblate shaped cornea is one where its Q value progresses from a negative number to 0, followed by a positive magnitude. With an oblate shaped cornea, the cornea is expected to be steeper in the periphery and flatter in the centre, thus resulting in increased positive spherical aberration [7,18,19].

The cornea offers protection against things that can cause damage, germs and dirt. In fact, it is also known that some sun's ultraviolet light can be filtered by the cornea. Therefore, it has a major part in terms of providing vision. Light either gets refracted or bent when it enters one's eyes due to the curved edges of the cornea. This assists in determining the performance of an eye with regards to focusing on close by and far-away objects. However, if due to an injury, an infection or a disease the cornea is damaged, then the potential vision can be affected, mainly due to the resulting scars. Consequently, in such a case, light entering the eye may be blocked or distorted. While the cornea is expected to heal naturally after most infections or injuries, special treatment might be required for more serious issues [5,19–64].

1.3. Corneal a sphericity and spherical aberration

The radial variation from the centre to the periphery of the quadric surface is what the Q-value, also known as the "aspherical degree," measures. The primary parameter for the mathematical model of the cornea is the Q-value, which defines the cornea's shape and the human eye's optical characteristics [6,65–68]. A topographical system is employed for estimating the "Q-value(s)" from measurements of topographical maps. Clinically, the (Q) value impacts several significant characteristics, including aberrations, total lens power, and refractive errors. Regarding surgery, the Q-value is regarded considered a key factor in determining the treatment mode in laser eye surgery [68–70]. It is shown in the topograph and is closely related to the thickness map. The average value of the anterior corneal surface's spherical aberrations was determined to be 0.27 mm, with a significant standard deviation of 0.10 mm. Because of this volatility, the value must be calculated for every single patient. The clearest picture is produced when the overall spherical aberration value for the eye is 0.00. Targeting this number has the most impact under low-light circumstances. Q-value and corneal spherical aberration are not the same. A wavefront's deviation from the ideal after passing through a refracting surface is referred to as spherical aberration. It is a measurement of a surface's impact on light that is done in microns. The Q value, which has no units but characterizes the refracting surface and measures surface form. Spherical aberration is affected by a surface's form. The Q-value of a perfect spherical surface is 0.00. A halo (or blur) surrounds the paraxial picture when spherical aberration is present in the image. An optical system with multiple surfaces, like the human eye, which has four refracting surfaces (the anterior/posterior crystalline lens and the anterior/posterior cornea), uses the same nomenclature. Positive spherical aberration occurs when the system has higher optical power away from the optical axis, or toward the periphery. It is negative if the reverse is true [66–70].

1.4. Corneal degenerations and its causes

Researchers have stated that conditions that can cause some damage to the cornea include [20–22]:

- Keratitis
- Ocular Herpes
- Herpes Zoster

These conditions sometimes involve the inflammation of the eye, occurring after the contact of fungi, bacteria, or viruses with the cornea. This might lead to infections and ulcers but can be treated by antifungal or antibiotic eyedrops. Keratoconus is a non-inflammatory disorder marked by gradual corneal thinning, scarring, and deformation into a conical shape [71], When patient's eye is affected by keratoconus, the eye may suffer from "Forme fruste keratoconus (FFKC)" or subclinical keratoconus. This term describes a cornea with no clinical findings but only topographic signs of the disease and/or suspicious topographic appearing on normal slit lamp examination [72,73]. Patients with subclinical or forme fruste keratoconus are now in danger of ectasia following Kerat refractive surgery. However, this risk can be reduced by appropriate screening, even in myopia eyes with a high refractive error [74]. Q-value describes the unusual shape of the cornea or the corneal constitute factor. The optimum number is −0.26. Positive

readings may indicate myopia correction whereas more positive values may indicate keratoconus or hyperopia correction. Keratoconus, suspected keratoconus, Formed fruste keratoconus, and ectasia are the most corneal illnesses that are related to the q-value [6,65–70,75,76].

Corneal degeneration are disease which can lead to potential problems with the structure of the cornea. One of the commonly known types of corneal degenerations is Keratoconus. In this disease, the cornea tends to become thin along with facing a change in its shape. Steepening of the cornea results in it becoming a cone-shaped in the lower area. Such a problem means that during teenage years, one may start to have a blurring vision and by early adulthood, the problem tends to worsen. A mild to severe distortion may be created due to the change in the curvature of the cornea. These problems are commonly known as near-sightedness and astigmatism. While soft contacts or glasses solve the problem for most people, some other routes may be needed for other people. Cornea transplant is usually performed for some people with keratoconus. In this procedure, a donated cornea is used to replace the damaged one. Corneal topography is a valuable tool for confirming the keratoconus diagnosis, Several indices, algorithms, and even neural network approaches to the geometry and optical properties of the anterior corneal surface have been developed for keratoconus diagnosis and detection [20,23–25,77,78] (see Fig. 1).

Fig. 2 illustrates the visible differences in a healthy cornea and a keratoconus one. As observed from the figure, an eye with keratoconus has a cornea which thins and slowly starts to bulge towards the outer side and develops into cone shaped. Due to these changes, significant distorted vision as well as blurriness may occur in one's eyes [27].

Furthermore, structural problems may also be caused within the cornea due to several other diseases, characterised by corneal dystrophies. Some of the commonly known types are [26]:

- Map-dot-fingerprint dystrophy
- Fuchs' dystrophy
- Lattice dystrophy

These dystrophies may result in some irregularities in the cornea. Depending on the intensity of the dystrophy, some may be painless, but some may cause severe pain and an individual's vision may get worse. While some can be treated with minor procedures, a corneal transplant may be required for some overtime. Nevertheless, an eye doctor can thoroughly examine an eye to diagnose such problems accurately [20].

As mentioned earlier, a patient with keratoconus may have a very steep cornea at the centre. The shape of the cornea will be hyper prolate and with regards to the Q value of such a patient, the value may be more than the extreme negative value (perhaps higher than −0.9). It must be noted that a Q value of 0 means that the cornea is perfectly spherical, where the cornea has a uniform shape throughout [7,18,19].

The natural lens in an internal eye is mildly prolate with a somewhat negative spherical aberration in youngsters. The slightly positive spherical cornea aberration is neutralised in such a case. However, with age, the natural lens' spherical cornea aberration increases. As a result, along with the positive spherical aberration in adults, gradual worsening of the vision quality takes place. In today's ophthalmic practice, an intraocular lens (IOL) replaces the cataractous lens in a typical cataract surgery. Overall, the IOL along with the collective influences of the spherical aberrations, tend to have a critical part in the vision quality of the whole ophthalmic structure [18,19,28,29].

1.5. Need for further understanding on corneal Q value

Based on a detailed review of the literature and assessment of earlier studies, it appears that while the Q value of the cornea plays a key role in the elderly population in order to design suitable intraocular lenses, although being able for treating any refractive errors, only a few studies consider most elderly population [31]. Understanding of Q values of the cornea can essentially assist with personalising corneal refractive surgeries and implantation of IOLs. Therefore, it is necessary that the relevance of corneal Q values is studied in association with different patients, especially ones who have been diagnosed with cataract, brain tumours, or even COVID-19. Different corneal surfaces are distinct in terms of their respective Q values. As a result, specifying a single Q value to a

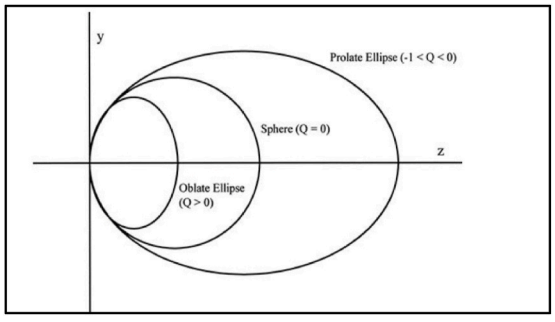

Fig. 1. Shows the link between the asphericity and the profile of the cornea in an illustrative manner [79].

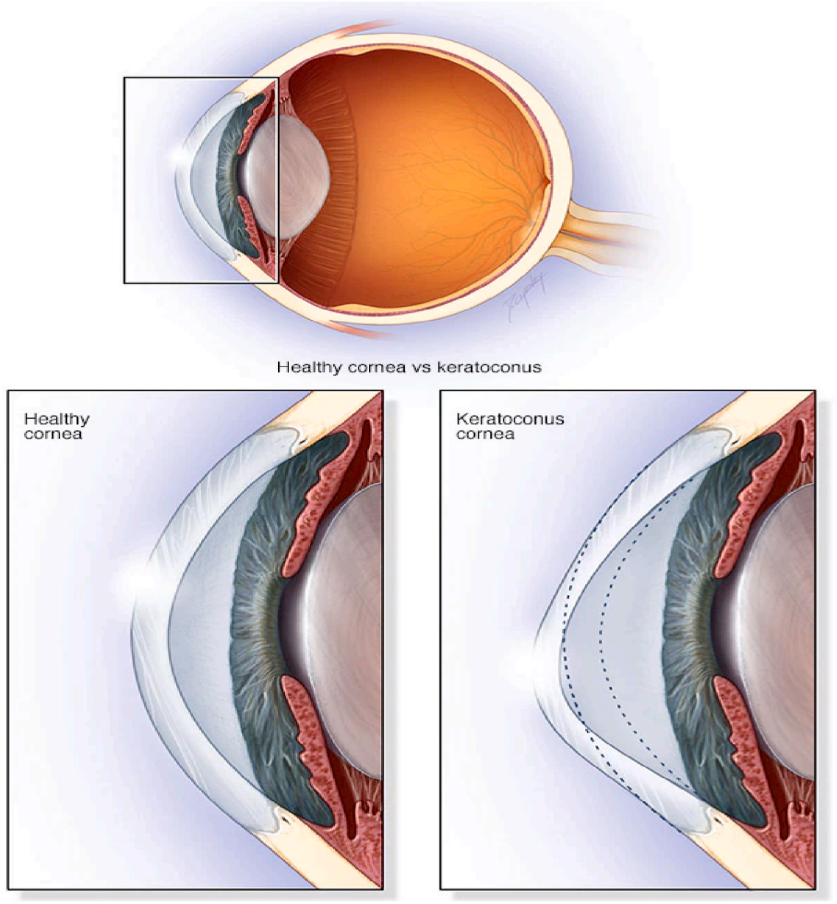

Fig. 2. Comparison between a healthy cornea and a keratoconus cornea [27].

cornea would not precisely reflect the cornea shape [14]. To enhance the vision of patients with potential eye diseases such as cataracts, it is recommended to evaluate different ranges of Q values, even after the implantations of IOLs. This is also based on the fact that a number of parameters can influence the Q values of the cornea. Review of studies present in literature demonstrates that the focus of most of these has been the relationship between the corneal Q values with spherical aberrations, refractive statuses, refractive errors and ages [32–35]. Limited research work has been carried out on the other high-order aberrations (HOAs) and corneal Q values. Assessment of these can assist in providing the association of the Q values with corneal HOAS in patients with cataracts and other eye diseases, thus allowing for the treatment and corrections of refraction and designing IOLs errors. Conic sections relate to some of the most basic aspheric surfaces since they may be made by cutting a cone into sections. The surfaces that arise if we let these surfaces to have a toric apex (astigmatism) are hyperboloids, paraboloid, prolate ellipsoids, spheroids, and oblate ellipsoids. Three factors may be used to identify each of these surfaces: Apical radii in the horizontal, vertical, and asphericity quotient [75,76,80–86].

Therefore, based on an increasing interest in determining Q values of the cornea for different subjects, **this current study *aims*** to provide a detailed review by analysing several noteworthy relevant research studies. To do so, an elaborate table is created as part of this research which presents a list of different research works examined in this study along with providing the relevant details, which include the important findings and conclusions.

2. Comparison of investigative studies examining the properties of a cornea

Table 1 presents a list of noteworthy publications and the aims of these studies along with providing a review of the important findings of these works. These studies were selected based on their relevance to the current study.

3. Analysis of obtained corneal Q values for different scenarios

As mentioned in earlier studies [31], the Q value of the cornea is an important factor in designing intraocular lenses as well as for treating refractive errors. Accurate corneal measurements and imagery are essential for selecting the best corneal refractive strategies for long-term, safe visual outcomes [13,97]. Based on a review of latest works, it seems that the Q values range from −0.03 to −0.33.

Table 1
Comparison of different investigative studies examining the various properties of corneas in different subjects.

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
Elsayed et al. (2020) [31]	To analyze corneal Q values along with its linked factors in Egyptian adults while being able to compare the Q values to other ethnicities	130 females and 120 males	Egypt	500	20–60 years; average age = 29.96 years	The data was classified by the spherical equivalent (SE) or the refractive error, the sex and the age.	The depth of the anterior chamber, the thinnest distance at the corneal location, the max keratometry reading of the anterior corneal surface (K-max) and the mean or average curvature radius (Rm) was measured.	The Pentacam HR (Oculus, Wetzlar, Germany) was used to obtain the corneal topography, which combines a rotating Scheimpflu camera with an illuminated thin slit. The data obtained was further analysed using SPSS (SPSS 25 Software; IBM Corporation, Armonk, New York, USA)	SSPS was used for analysing the results. Mean ± standard deviation (SD) expressions were used for expressing normally distributed continuous data while median and range was used for the other data. Percentage and numbers were employed for expressing the categorical data. For comparing the two groups, *t*-test was used and for comparing more than two groups, one-way analysis of variance along with its post-hoc analysis was applied. The Mann-Whitney *U* test was used for analysing variables that were not distributed normally. Any qualitative data was compared with the $\chi 2$ tests. In order to evaluate the connection between the continuous variables, the Spearman's rank correlation coefficient was employed. Finally, at $P < 0.05$, statistically significant results were established.	The mean Q values of the cornea were measured at diameters of 6 mm and 8 mm for each quadrant and two meridians at diameters of 8 mm.	• At diameters of 6 mm and 8 mm, the mean anterior surface Q values were −0.27 and −0.37, respectively. •For each quadrant's superior, inferior, temporal and nasal, the mean Q values were recorded as −0.35, −0.33, −0.244 and −0.55, respectively, at a diameter of 8 mm. •The vertical and horizontal meridians were recorded as −0.34 and −0.40, respectively, at a diameter of 8 mm. •Significant correlations of the mean Q values were found with anterior chamber depth, mean curvature radius (front), maximum keratometry reading (K-max), SE refractive errors, sex and age. •Between the corneal thickness at the thinnest location and the mean Q values, no significant correlation was determined.	The results obtained can be useful to design innovative or futuristic optical properties, or further enhance the equipment used to measure optical properties of the eye.

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Table 1 (*continued*)

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
											•Overall, the obtained Q values were closer to African Americans in comparisons to other ethnicities, where significant differences were noticed.	
Zhang et al. (2019) [37]	Comparison of differences in the anterior corneal properties of anterior corneal surface aberration following small-incision lenticule extraction (SMILE) and Q value-guided femtosecond laser-assisted in situ keratomileusis (Q-FS-LASIK)	124	China	240	N/A	Patients enrolled either had myopia or myopia astigmatism. The study excluded patients with contraindications to corneal refractive surgery, noticeably irregular astigmatism of the cornea, any corneal opacities, leukoma, macula, nebula or with histories of corneal refractive surgery	Anterior corneal surface aberration properties	Tomography instrument (Sirius; CSO, Florence, Italy)	Mean ± standard deviation (SD) expressions were used to specify continuous variables while frequency (%) was used to express categorical variables. Student *t*-test was also utilised for comparing baseline characteristics between the two categories analysed.	51 patients in the SMILE group and 73 in the Q-FS-LASIK group	•Both, the SMILE and Q-FS-LASIK methods demonstrated an aberration of high order along with primary spherical and coma aberrations. •However, in addition to increased stability as well as maintaining enhanced visual quality, the Q-FS-LASIK showed a lower high order aberration.	To understand long-term changes in aberration, future studies are required
Amorim-de-Sousa et al. (2019) [33]	This study evaluates the asphericity of the cornea in relation to the refractive error, sex and age.	40 females and 69 males	Portugal	109	20–62 years	Subjects who underwent corrective interventions to address corneal conditions who were registered as patients at an optometry office were included in this study. This excluded people with cataracts or other refractive issues.	To further analyze the refractive error and the corneal asphericity.	Autorefractometer/ autokeratometer NIDEK ARK-700A and videokeratoscope MODI 2.0; SPSS software package v.22 (SPSS Inc., Chicago, IL)	SPSS statistics was utilised with a consideration of $P < 0.05$. Analysis of variance (ANOVA) along with Kruskal–Wallis exams were conducted for evaluating the variations between variable groups assessed in the study. Bonferroni post hoc tests were used for the adjusting the statistical significance values. Based on the distribution	N/A	•For a 7 mm diameter chord, the MODI 2.0 and NIDEK ARK-700A demonstrated a good agreement in terms of the corneal asphericity. •For 1,484 right hand side eyes investigated, the mean Q value was −0.24. This was for a mean age of 40.2 years with 58.6 % females. •Between refractive error groups, ages and	Improvements to the study can be made by further evaluation of the corneal parameters by means of tomography over a longer period of time. This can bring into the light the differences across cross sectional studies between various age groups and the changes between each subject.

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Table 1 (*continued*)

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
									normalitiy of the data, Wilcoxon as well as paired-samples t tests were conducted for comparing parameters in the longitudinal study. Pearson and Spearman correlation tests were also carried out.		genders, no variations were seen in the Q values obtained. •Also, no significant differences were seen in the Q values for 190 eyes tested in the longitudinal analysis over time. •Within a 5–10 year period, a majority of the population demonstrated little or no significant change. •Nevertheless, there existed some considerable differences for a smaller portion. •Overall, the mean Q values were found comparable to those of the whites, leading to the slightly reduced positive eye aberrations.	
Xiong et al. (2017) [30]	Analysing Q values and its related factors	955 females and 728 males	Chinese	1683	>30 years (Average age = 53.64 years)	Did not include any participants with corneal diseases or pathology. Neither patients wore contact lenses or had the LASIK surgery. Also, excluded individuals with eyes that demonstrated increased deviation from the reference surface,	Age, gender and refractive power.	Bausch & Lomb Orbscan IIz (software version 3.12); Pachymetry Stats program; SPSS software (version 18.0.0).	Mean Fit Method; SPSS was used for descriptive statistics to calculate the average Q values.	Q values at aperture diameters of 3.0, 5.0- and 7.0-mm were calculated. A p-value of $\leq$0.05 was considered to be statistically significant.	•Mean Q values at aperture diameters of 3.0, 5.0- and 7.0-mm were −0.28, −0.28, and −0.29, correspondingly. •A negative correlation between the refractive power and age with the mean Q value was obtained at the anterior surface of	Could use the results of this study for providing a valuable reference in designing optical products for enhanced vision. Also, the results could be incorporated for studying the human eye and its optical properties.

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Table 1 (*continued*)

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
						incomplete topographic map, or poor measurement repeatability.					the 5.0 mm aperture diameter. •At 3.0, 5.0, and 7.0 mm, the mean Q values of the posterior surface were −0.26, −0.26, and −0.26, correspondingly. •A positive correlation between refractive power and age with the mean Q value was obtained for the posterior surface at the 5.0 mm aperture diameter. •For the first time, this study looked at Chinese subjects. As compared to earlier studied American and European ethnicities, it appears that the Chinese subjects have different corneal Q values. A correlation between the age and refractive power with the Q values was found.	
Juan et al. (2017) [38]	The study correlates and further investigates the connection between orthokeratology lens decentration and the pre-treatment parameters of the cornea.	N/A	Chinese	108	N/A	Patients who underwent orthokeratology were included in this study. Approximately half the population included in the control group returned to normal after the procedure,	This study compares several pre-treatment parameters for the cornea	Pentagram topographer (Oculus; Wetzlar, Germany). IBM SPSS Statistics for Windows (version 20.0, IBM Corp.; Armonk, NY) and MEDCALC (version 12.0; Medcalc, Mariakerke, Belgium).	SPSS Statistics was used. For comparing variables of the two groups, a *t*-test and/or a chi-square test was implemented. For predicting the value for lens decentration, a receiver operating	The formula for Q Value, $Q = -E^2$ (E-value = eccentricity) is used by the Pentacam software and is calculated automatically, and it can be inferred that a value above 0 is	•For lens decentration, the preferential sides are the inferior and the temporal quadrants. This was linked to the complexities occurring (i.e. corneal epithelial	Future work can include applying the findings across other ethnicities and requires in dept research.

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Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
						whereas the other half were included in the lens-decentration group. The two groups had similar factors such as area of residence, sex and age groups.			characteristic curvature (ROC curvature) analysis was used. Finally, at $P < 0.05$, statistically significant results were established.	oblate and a value below 0 is prolate. All data points included all 4 quadrants.	staining and ghosting). •In-depth work showed that there were much higher differences in Q values of the cornea while there were lower differences in the corneal horizontal curvature between the superior-inferior and nasal-temporal quadrants in the lens decentration group as compared to the control group. •Overall, between these mentioned quadrants, the sum of differences of the pre-treatment Q values of the cornea is a useful and trustworthy predictor for lens decentration in orthokeratology.	
Yazdani et al. (2017) [39]	Evaluating corneal asphericity at three diameters and assessing the influence of gender, refractive errors and ages	332 females and 168 males	Iran	500	15–70 years (Average age = 29.51 years)	Subjects with best corrected visual acuity higher than 20/25 were included. Excluded subjects included patients with histories of use of any ocular medication, contact lens, refractive and ocular surgeries.	corneal asphericity (Q value)	Keratograph 4 (OCULUS, Wetzlar, Germany). SPSS software version 11.5.	SPSS statistics was adopted. Pearson correlation coefficient was used to study the correlations between different parameters. To determine variations in parameters between groups, one-way analysis of variance and student *t*-test was adopted. Significance level	Patients' right eyes were investigated.	•For diameters of 5 mm, 6 mm and 7 mm, the mean ± standard deviation values for the corneal asphericity were −0.21, −0.24 and −0.27, respectively. •No correlations were found between refractive errors, gender or age with the	The study provides recommendations for further research works, stating cases that can be assessed such as, corneal astigmatism, corneal power and the link between base curve and asphericity. Evaluation of corneal asphericity with regards to various refractive error serverities

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Table 1 (*continued*)

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
									was set at 0.05. Kolmogorov-Smirnov test was used to check the quantitative variables' normal distribution.		corneal asphericity. •An increase in the corneal asphericity was demonstrated with an increase in the diameter.	could also be useful.
Torquetti et al. (2016) [35]	Evaluating cornea and its anterior and posterior surfaces in keratoconus patients implanted with intrastromal corneal ring segments	20 females and 22 males	Brazil	50	16–53 years; average age = 30.2 years	Patients had manual implantation of Ferrara intrastromal corneal ring segments (ICRS). Eyes with advanced keratoconus and apical scarring were excluded.	Uncorrected visual acuity (UCVA), best corrected visual acuity (BCVA), refraction, keratometry, asphericity, elevation, pachymetry, root mean square (RMS), spherical aberration and coma	Slit-lamp and fundus evaluations, spherical equivalent (SE), manifest refraction, logMAR UCVA and logMAR BCVA. A dual Scheimpflug imaging system (Galilei 2, SW version 6.1.3, Ziemer Ophthalmic Systems AG, Port, Switzerland) was utilised for corneal evaluation.	For descriptive statistics, the Graph Pad Prism (GraphPad2014, Chicago, IL, USA) was used, including mean ±standard deviations. Student's *t*-test for paired data was used to compare preoperative and postoperative data. A two-tailed probability of 5 % or less was considered statistically significant.	N/A	•For a period of about 12 months, the patients were followed up. Improvements were noted in the mean best corrected visual acuity (BCVA) as well as the mean Uncorrected visual acuity (UCVA). •The mean spherical refraction showed some changes while the mean refraction astigmatism reduced significantly. •Statistically significant changes were noted from preoperative to postoperative, in the anterior and posterior surface cornea parameters. •The only exception included the elevation posterior at the cornea apex and posterior asphericity. •Variations in both anterior and	Future studies could use the presented data in order to develop further reliable ICRS nomograms.

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Table 1 (*continued*)

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
											posterior cornea surfaces were noted with implantation of Ferrara ICRS.	
Fuller and Alperin (2013) [10]	This study investigates the dissimilarities in asphericity of the cornea between white and African-American ethinic groups.	N/A	African-American and White	160	The mean age group was 40.4 and 41.3 for the white and African-American groups, respectively.	The subjects were categorized into various classifications such as age, SE and their ethnicity. The test and analysis was conducted on the right eyes of the subjects.	corneal asphericity (Q value)	Pentacam HR (Oculus, Wetzlar, Germany)	N/A	The Q-values are attained from the vertical and the horizontal meridians and the nasal, inferior, temporal and the superior quadrants.	•For the white population and the African-Americans, the mean Q values obtained were −0.20 and −0.26, respectively. This indicated that the white population had less prolate eyes as compared to the African-Americans. •In the age range of 30–39 years, the mean Q values demonstrated significant differences with a lack of correlation with ages in both ethnicities investigated. •In terms of gender, only males demonstrated contrasts in the Q values. •Between Q values and standard error for both ethnicities, a lack of correlation was shown. •Significant comparisons between mean Q values in opposing meridians were found across and within the two ethnicities while	N/A

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Table 1 (*continued*)

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											no significant variations between the vertical and horizontal meridians were seen in any ethnicity. •Overall, the mean Q values, demonstrating the corneal asphericity, varied considerably between the white and African-American pop-ulations. Highest variations were seen in opposing quadrants while factors such as gender or age seem to have little or no effect on the corneal Q values.	
González-Méijome, Villa-Collar, Montés-Micó and Gomes (2007) [36]	Measuring the Q values (anterior corneal asphericity) with varying diameters of the cornea	26 females and 10 males	Portugal	36	19–27 years; average age = 21 years	Patients with corneal surgeries, contact lens wear, corneal scarring or corneal pathology were excluded	Q values of anterior cornea	Medmont E300 videokeratoscope (Medmont Pty. Ltd.); Topographic data was analysed with the use of Vol-CT 6.89 software (Sarver & Associates, Inc). SPSS software (version 14.0, SPSS Inc) was used to analyze the data	Bonferroni post hoc correction is used to perform the analysis of variance. The Kolmogorov Smirnov normality test was used to assess the normal distribution with a significance level of alpha set at 0.05. Pearson correlation analysis was used to determine the correlation between the Vol-CT Q and videokeratoscope.	Q-values at 3.0 mm, 4.0 mm, 5.0 mm, 6.0 mm, and 7.0 mm of corneal diameters were obtained. Mean corneal astigmatism was -1.06 ± 0.64D	•As the corneal astigmatism increases, so does the peripheral rate of growth in corneal Q with distinctive corneal diameters. The Vol-CT software produces Q values ($P = 0.026$) and the Medmont pro-duces values ($P = 0.04$) and shows a significance difference.	Implementing the results obtained for customised procedures of refractive surgery. Improving vision quality beyond the simple correction of refractive error without altering the eye's aberration structure
Mori, Y., Shimizu,K., Minami,K., Kamiya,K., Shoji,	To examine whether corneal asphericity affects underestimation	NA	Japan.	Fifty-four eyes of 37 patients	range (2–14) years	Eyes that had intraoperative and postoperative complications	the Q value and refractive errors	Multiple regression analysis using 22 eyes of 22 patients resulted in a significant factor,	Stepwise multiple regression analysis was performed with the	The multiple regression analysis showed a significant	•he corneal asphericity after myopic LASIK	NA

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Table 1 (*continued*)

Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
N. and Miyata, K., 2016 [87].	in the SRK/T intraocular lens (IOL) power calculation after myopic laser in situ keratomileusis (LASIK) and to evaluate the predictability of IOL power underestimation using the asphericity					from previous cataract surgery or other ocular pathology influencing the CDVA were excluded.		which was the Q value ($P < 0.001$, $R2 = 0.80$). The refractive errors in 53 eyes were predicted with tolerances of 64.5 % and 87.0 % within ±0.5 diopter (D) and within ±1.0 D, respectively. Bland-Altman analysis showed that 95 % of the limitation range was 2.59 D.	descriptive factors. With the sample size ($n = 22$) and a significance level of 0.05, the detection power in multiple regression analysis of a factor was anticipated as 0.89 when R2 was 0.36.	correlation between IOL power underestimation and the Q value only ($P < 0.001$, $R2 = 0.80$). The slope and constant of the regression equation were 6.01 (95 % confidence interval [CI], 4.60 to 7.43) and −1.17 (95 % CI, −1.98 to −0.36), respectively	significantly correlated with the IOL power underestimation with use of the SRK/T formula. •The refractive error could also be predicted well with the use of asphericity.	
Savini, G., Hoffer, K.J. and Barboni, P., 2015 [88].	To evaluate the possible influence of anterior corneal surface asphericity on the refractive outcomes in eyes having intraocular lens (IOL) implantation after cataract surgery.	NA	Italy.	115 eyes of 115 consecutive patients.	NA	those after corneal refractive surgery or very short and very long eyes are excluded	anterior corneal surface asphericity	Preoperative anterior corneal surface asphericity Q-values were obtained using the Keratron Placido-disk corneal topographer, a rotating Scheimpflug camera (Pentacam, Oculus Optikgeräte GmbH), and a rotating Scheimpflug camera combined with a Placido-disk corneal topographer (Scheimpflug–Placido corneal topographer) (Sirius, Costruzione Strumenti Oftalmici).	Statistical analysis was performed using Excel software (Microsoft Corp.) and Medcalc for Windows (version 12.7, Medcalc Software bvba). Regression analysis was performed to determine whether a relationship existed between the arithmetic error in refraction prediction and the Q-value. The coefficient of determination R2 was used to express the proportion of the variation in the dependent variable (ie, the refraction prediction error) explained by the regression model	The highest coefficient of determination was detected between the Hoffer Q formula and the Placido-disk corneal topographer ($R2 = 0.2630$), for which the error in refraction prediction (y) was related to the Q-value (x) according to the formula $y = -0.2641 + 1.4589 \times x$.	•Corneal asphericity influences the refractive outcomes of IOL implantation and should be taken into consideration when using third generation IOL power formulas. •this study is limited by the fact that data were retrieved from a single database with a relatively small sample. Thus, our findings have to be confirmed by other studies performed on larger samples and with different IOL models. •The data suggest that anterior corneal surface asphericity influences the	NA

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Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
											refractive outcome of IOL power calculations obtained using the Haigis, Hoffer Q, Holladay 1, and SRK/T formulas. If not taken into account, a prolate shape can lead to a myopic surprise, whereas an oblate shape can lead to a hyperopic surprise. •Preliminary results suggest that part of the refraction prediction error can be ascribed to corneal asphericity, which influences the refractive outcomes of the Haigis, Hoffer Q, Holladay 1, and SRK/T formulas. •Prolate corneas tend to end up with a myopic refraction and oblate corneas with a hyperopic outcome	
Berty, M.M., Eliwa, T. F., Gaafar, A.A.M. and Mousa, A.S., 2022 [89].	To analyze the changes in the anterior and posterior corneal surfaces measured with a Scheimpflug imaging device in keratoconus patients implanted with intracorneal ring segments (ICRS)	NA	Egypt	92 eyes of 60 patients with keratoconus	The mean age was 21.20 years (range: 14–34 years)	Patients with advanced keratoconus (grade 4 according to Amsler Krumeich classification), 10 central corneal opacity, previous corneal surgery such as corneal laser refractive surgery or corneal collagen cross	corneal asphericity (Q value) and elevations of both anterior and posterior corneal surfaces	Corneal imaging was performed with a Scheimpflug imaging device (Sirius; CSO, Firenze, Italy), with recording of corneal thickness at the thinnest location, curvature data (flat K, steep K, average K and topographic cylinder) of both anterior and posterior surfaces,	Statistical analysis was performed with the Statistical Product and Service Solutions (SPSS) version 18 software (SPSS Inc., Chicago, IL). The paired *t*-test was used to evaluate the changes of each parameter	The aim of this study is to evaluate the effect of ICRS implantation on the posterior corneal surface and to correlate this effect with the visual outcome.	•ICRS implantation has a flattening effect on both anterior and posterior corneal surfaces, with reduction in elevations and improvement of corneal asphericity.	Further studies are required to establish these findings and understand further correlations between corneal parameters and visual outcome

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Source (Year)	Purpose of the study	Participants (Gender)	Ethnicity/ Country	Number of cases or eyes	Age	Control variables	Parameters studied	Equipment and software used	Statistical analysis methods	Notes	Important findings, novelties and conclusions	Future work
	and to correlate those changes with the visual outcomes.					linking, history of herpetic keratitis, history of acute hydrops, ocular comorbidities that may affect visual acuity such as cataract, glaucoma or retinal disease, and systemic diseases affecting healing process such as autoimmune or connective tissue disease were excluded from the study.		anterior and posterior asphericity (Q) values, and maximum anterior and posterior elevations.	preoperatively and postoperatively, while analysis of variance (ANOVA) was used to evaluate the statistical significance in the difference of three or more values. Differences were considered statistically significant when the p value was less than 0.05. All results are expressed as mean and standard deviation (SD)		•Change in asphericity is significantly correlated to improvement of visual acuity. •Better baseline BCVA, flatter baseline anterior and posterior corneal surfaces, less prolate anterior Q value and lower magnitude of anterior elevations preoperatively are good predictive factors of the expected visual outcome.	
Safarzadeh, M. and Nasiri, N., 2016 [90]	To assess the anterior segment parameters of keratoconus (KC) eyes at different stages of the disease by a new Scheimpflug camera combined with Placido disk corneal topography (Sirius, CSO, Italy) in a sample of the Iranian population.	NA	Iranian population.	225 eyes	NA	previous ocular surgery, corneal scarring, trauma, pregnancy or lactation, glaucoma, and causes of ocular astigmatism other than corneal i.e. lenticular astigmatism such as early cataract, lens subluxation, or lenticonus. Individuals with connective tissue disease, such as Marfan or Stickler syndrome, were also excluded from the study.	corneal thickness at the apex (CTA), thinnest corneal thickness (TCT), anterior chamber depth (ACD), corneal volume (CV), corneal keratometry (K), corneal asphericity (Q), and corneal elevation in the anterior and posterior surface. Also, the Zernike coefficients for the corneal aberrations including total root mean square (RMS), RMS Coma, RMS spherical aberration (SA), RMS	Placido disk corneal topography (Sirius, CSO, Italy)	a comprehensive ocular examination including Scheimpflug-Placido topography (Sirius, CSO, Italy) using software version 1.0.5.72 was performed on all eyes. The Sirius is a new topography device that combines a monochromatic rotating Scheimpflug camera and a Placido disk. The scanning process acquires a series of 25 Scheimpflug images (meridians) and 1 Placido top-view image to analyze the anterior segment by obtaining 25	NA	•the anterior segment measurements provided by the Sirius Scheimpflug camera–Placido corneal topography system were highly repeatable and can be used in clinical routine and for research purposes as a valuable tool in diagnosing KC, especially KC suspect and early KC.	NA

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							Astigmatism, Baiocchi Calossi Versaci front index (BCVf), and BCV back index (BCVb) were noted for all eyes.		radial sections of the cornea and anterior chamber.			
Scholz, K., Messner, A., Eppig, T., Bruenner, H. and Langenbucher, A., 2009 [91].	To assess corneal asphericity (Q) and evaluate potential factors influencing the shape of the anterior corneal surface.	205 men, 288 women	Germany	487 eyes	age 17–81 years	To be included, subjects had to be healthy and have no pathology of the eye, fixation problems, or previous eye surgery. Those wearing contact lenses or having an SE greater than −8.00 D or +6.50 D were excluded.	The study was performed to determine what factors might have an influence on corneal asphericity.	The topographic measurements were taken with a Placido-based videokeratoscope (Tracey iTrace Visual Function Analyzer with integrated EyeSys Vista Corneal Topography, Tracey Technologies Corp.)	Statistical evaluations were performed using the SPSS statistical software package (version 15.0.0, SPSS, Inc.). The nonparametric Mann-Whitney *U* test was used to determine the differences between the groups of test objects and groups of subjects and the Spearman rank correlation coefficient ρ, to calculate the correlation between variables. A P value less than 0.05 was considered statistically significant and a value of 0.01, highly statistically significant.	NA	•Although the study found some significant differences between isolated age groups, between hyperopes and emmetropes/ myopes, and between men and women, categorization of corneal asphericity, or even an adjustment to a model eye, is not sufficient because of the large interindividual variation in corneal shape. Therefore, individualized IOLs are necessary to provide satisfactory retinal image quality in all patients after cataract surgery. Such individualization relies on accurate measurements of topographic and biometric parameters. •There were high interindividual variations in the Q	NA

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											value. Thus, proper correction of spherical aberration with intraocular lenses (IOLs) requires sophisticated selection of the asphericity of IOL surfaces based on biometric data and individual corneal Q values.	
Chen, C.C., Izadshenas, A., Rana, A.M.A. and Azar, D.T., 2002 [92]	To analyze corneal asphericity after hyperopic laser in situ keratomileusis (LASIK) and its relationship to the clinical outcomes.	NA	USA	23 patients (33 eyes)	Group A (31–71) Group B (36–66)	this study, analysed the outcomes and topographic changes in hyperopic and hyperopic astigmatic patients after LASIK using a quantitative descriptor of Q. It also investigated the relationship of postoperative Q to preoperative Q, corneal curvature, and clinical outcomes including mean keratometric power, best spectacle-corrected visual acuity (BSCVA), and achieved and attempted correction.	analyze corneal asphericity (Q) before and after LASIK. Corneal asphericity was evaluated to determine the association with the postoperative refractive error, best spectacle-corrected visual acuity (BSCVA), uncorrected visual acuity (UCVA), achieved refractive correction, mean corneal power (K), refractive yield (achieved/ attempted correction), and keratometric yield (change in keratometry/ attempted correction).	hyperopic LASIK using the VISX laser.	Statistical analyses were performed using the Mann-Whitney *U* test for analyses of age, sex, mean follow-up, preoperative Q, K, R, SE, and preoperative logMAR of UCVA and BSCVA between the 2 groups. The postoperative data obtained at the 1-month (n = 33 eyes), 3-month (n = 22 eyes), and 6-month (n = 15 eyes) examinations were compared with the preoperative data	NA	•Prolate corneas show increased prolateness after hyperopic LASIK. •The increase was highly correlated with the attempted and achieved corrections. •The increased prolateness did not correlate with visual or refractive outcomes. It did not treat oblate corneas, so the conclusions may be valid for hyperopic treatment of prolate corneas only. •Asphericity may be a useful quantitative descriptor of the corneal optical contour after hyperopic LASIK. Negative central Q increased after hyperopic LASIK, especially when greater degrees of	

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											refractive correction were attempted.	
González-Méijome, J. M., Villa-Collar, C., Montés-Micó, R. and Gomes, A., 2007 [93].	To measure the anterior corneal asphericity (Q) with different corneal diameters.	10 men and 26 women	Portugal.	Thirty-six eyes of 36 patients	(range 19–27 years)	Exclusion criteria were corneal pathology or corneal scarring, contact lens wear, and corneal surgery.	Q-values were analysed in eyes with different degrees of corneal astigmatism (low, moderate, and high).	topographic data were also analysed using Vol-CT 6.89 software (Sarver & Associates, Inc) to obtain the Q-values with different corneal diameters. Variable Q models of corneal sagittal height were compared against models assuming constant Q-values obtained with the Medmont E300 videokeratoscope (Medmont Pty. Ltd.) and a standard Q model of −0.26.	Data were analysed using the SPSS statistical package (version 14.0, SPSS, Inc.).	NA	•There were differences in sagittal corneal height calculations considering constant or variable models of Q. Concern arises when surgical interventions depend on corneal Q-values to predict the outcomes. •Surgeons should be aware which procedure is behind Q computing by different corneal topographers and that a constant Q-value cannot reflect the actual shape of the cornea as significant departures from the actual sagittal height can arise depending on which Q-value is assumed.	NA
Zhang, J., Zheng, L., Zhao, X., Xu, Y. and Chen, S., 2016 [94]	to compare the changes in corneal biomechanical properties following small-incision lenticule extraction (SMILE) versus Q-value–guided femtosecond laser-assisted in	NA	China	160 patients	NA	Patient inclusion criteria included a sphere plus cylinder measurement of less than −10.00 D and a cylinder measurement of less than −5.00 D.	Corneal hysteresis (CH) and the corneal resistance factor (CRF) were quantitatively assessed	Ocular Response Analyzer (ORA Depew, NY, USA)	All statistical analyses were performed using SPSS 19.0 (SPSS Inc., Chicago, USA).	NA	•Both SMILE and Q-FS-LASIK resulted in a decrease in CH and the CRF at postoperative 1 day, with the decreases stabilizing after this point. There were no	NA

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	situ keratomileusis (Q-FS-LASIK).										significant differences between the short-term effects of SMILE and Q-FS-LASIK on corneal biomechanical properties.	
Smadja, D., Santhiago, M.R., Mello, G.R., Krueger, R.R., Colin, J. and Touboul, D., 2013 [95].	To compare the discriminating ability of corneal elevation generated by a dual Scheimpflug analyzer calculated with different reference surfaces for distinguishing normal corneas from those with keratoconus and subclinical keratoconus	NA	NA	391 eyes of 208 patients	NA	NA	orneal elevation measurements obtained by best-fit toric and aspheric (BFTA) and best-fit sphere (BFS) reference surfaces were compared by receiver operator characteristic (ROC) curves.	dual Scheimpflug analyzer (GALILEI Analyzer; Ziemer Ophthalmic Systems AG, Port, Switzerland).	ROC curve analysis and corneal elevation measured by BFTA	Maximum elevation values were recorded within the central 5-mm diameter in both anterior and posterior elevation maps. Discriminating ability of corneal elevation measurements obtained by best-fit toric and aspheric (BFTA) and best-fit sphere (BFS) reference surfaces were compared by receiver operator characteristic (ROC) curves.	•The ability to discriminate between normal cornea and forme fruste keratoconus with elevation parameters was significantly improved by using BFTA instead of BFS reference surface.	NA
Zhang, Z., Wang, J., Niu, W., Ma, M., Jiang, K., Zhu, P. and Ke, B., 2011 [96]	To observe and analyze corneal asphericity and its related factors in Chinese subjects.	NA	China	1052 right eyes	All cases were grouped by age in years (A: ≤9; B: 10 to 19; C: 20 to 29; D: 30 to 39; E: 40 to 49; F: ≥50)	NA	Q value	Wavelight-ALLEGRO Topographer	statistical correlation	NA	•Corneal asphericity in this population is related more to corneal quadrant location than to age. •The results from this study suggest that degree of myopia and central corneal radius both have a significant though weak association with corneal asphericity in Chinese eyes.	NA

Table 2
Comparison of different investigative studies examining the various properties of corneas in different subjects.

Corneal Q value	Ethnic group	Source
−0.33	Australian	[41]
−0.33	Chinese	[42]
−0.22	Chinese	[43]
−0.22	German	[44]
−0.24	Dutch	[45]
−0.08	Indian	[46]
−0.20	American Caucasian	[10]
−0.26	African-American	[10]
−0.346	American	[47]
−0.30	Chinese	[48]
−0.29	Chinese	[30]

However, it must be noted that the variation in the obtained values is due to a number of factors. These include equation choice for attaining a best fit curve, dimensions restricted to the horizontal meridian, restrictions in the accuracy of the technique employed, selection bias, and sampling sizes [31,40].

Based on the findings of Table 1, it appears that while studies have been carried out on a number of different ethnic groups, most studies analysed the eyes of adults. Determining the Q values of the cornea was one of the main aims of most of these works. Several different software were used by researchers across the globe but in terms of statistical analysis, determining the mean ± standard deviation was the most common expression.

Table 2 lists the reported corneal Q values obtained by different researchers for different ethnicities. The minimum value was reported as −0.346 while the maximum was −0.08, based on these studies. Researchers obtaining a difference in the corneal Q values have stated that these differences mostly arise due to variations in a subject's race and age, the sampling sizes, and the discrepancies in testing equipment.

The following sections provide an elaborate discussion on the differences in the different parameters that possibly lead to variations in the obtained Q values with other works.

3.1. Influence of different parameters on corneal Q values

For the purpose of determining the corneal Q values, a number of different ethnic groups have been analysed. These included Caucasians [41,45,47], American Caucasians [10], African Americans [10], Indians [46] and Chinese [12,30,43]. Based on Xiong et al. (2017) study [15], it was shown that the anterior and posterior surface mean Q values do not change with a change in the diameter. This suggests that the cornea is a true quadratic asphere. Also, it appears that a single Q value can be used to describe corneal asphericity. However, with an increase in age, it was revealed that the anterior surface's corneal Q value tends to shift towards a more negative magnitude. On the other hand, with an increase in age, the posterior surface's corneal Q value shifted towards a lesser negative magnitude. While the Q values obtained in Zhang's [48] study showed no significant difference, statistical significance was seen in Ref. [15]. Since the latter incorporated a larger sampling size, and consisted of a wide-ranging age data, it could be relied upon in further works as a dependable reference. Moreover, as discussed earlier, there was a wide range of ages assessed in different studies. This can also introduce some sort of variability in the results obtained.

Furthermore, the relationship between gender and the corneal Q values was also noticed by some researchers [12,15,31,45]. To be specific, it was noticed that females tend to have a much negative Q value as compared to males for the anterior surface. This suggests that an anterior surface with higher asphericity can be found in females. Conversely, with regard to the posterior surface, the opposite was true. It must be noted that while this was determined by one study [15], some studies [10,33,39,43], concluded that gender did not influence the corneal Q values. It seems that these studies concluded such a finding due to smaller sampling sizes and therefore being unable to identify minute differences.

Sampling size can also have a major influence on the results obtained as a larger sampling size could allow for the determination of a more accurate value. Analysing previous works, it can be concluded that larger sampling sizes (perhaps greater than 1,000 subjects) could be more representative of the investigated population [44–52].

Many biomedical engineering researchers are interested in topography, ultrasonic tomography, X-ray CT, MRI, impedance computer tomography (ICT), diffuse tomography, PET, and other techniques [5,6,53–64]. After the COVID-19 pandemic, medical scientific research expanded dramatically. Despite the economic problems worldwide due to COVID-19 pandemic, doctors discovered that the coronavirus affects people and the cause's severe acute respiratory syndrome, the eye cornea, and human mussels [5,62–64]. According to Shah et al., 2022, people used mRNA vaccination to compete with COVID-19, which caused acute corneal transplant rejection in four out of eight patients. Acute corneal endothelial rejection may occur following any dosage of COVID-19 mRNA vaccination. Acute topical steroid treatment may result in full clinical symptom resolution, so more research is needed in this area [53].

The cornea is the eye's surface that is the most connected to nerves. Sensory axons from the trigeminal nerve's ophthalmic branch are essential to maintain the cornea's homeostasis. As a result, ocular nerves are a prime target for Sars-CoV-2 infection. In diabetics with chronic COVID-19 infection and hypoxemia, systemic neuropathic symptoms and severe sensory impairment have been

connected. In addition, changes in sensitivity, pain, and the onset of dry eye disease have all been associated with subbasal axonal neuropathy (DED). Barros et al., 2022, studied the corneal nerves of COVID-19 individuals with ocular surface syndrome. Corneal confocal imaging has shown that COVID 19 infection and small fiber neuropathy may be connected in practice. In this observational retrospective study, 23 patients who have overcome COVID-19 were included. A control group of 46 people who were not affected was also recruited. In vivo confocal microscopy was utilised to look for neuroma-like forms, axonal beadings, and dendritic cells in ocular subbasal nerve fibers. DED and ocular surface disease were assessed using the OSDI questionnaire and the Schirmer tear test. According to the researchers, COVID-19 infection induces ocular surface small fiber neuropathy, which has symptoms and morphological characteristics with DED and diabetic neuropathy. A chronic sensory fiber axonopathy is caused by viral infection. The corneas of COVID-19 patients reveal morphological abnormalities similar to diabetic and DED corneas and functional loss and sensitivity changes. COVID-19 patients experience pain and suffering similar to those who suffer from DED [5,62–64].

Finally, to measure the anterior and posterior corneal surfaces, different testing methods and equipment have been used by various researchers. Some researchers employed a diagnostic system that maps the entire corneal surface [15,42], while some used a visual function analyser with integrated corneal topography systems [44] that makes use of a video keratoscope. The method used in the latter involves combining the anterior and posterior surfaces as a whole. A topographic modelling system for collecting data has also been utilised by some researchers [41,43,47]. Other studies included making use of a camera system for measuring the focus depth of the axis movement [45], the Pentacam HR system and a different topographer [10,46,48].

Overall, a mixed response is obtained in terms of the link between the different parameters and the corneal asphericity. It appears that further studies are still needed in this research area, specially those which evaluate other morphological corneal parameters as well by different techniques over a longer period of time. These studies would then be able to ascertain the observed differences in various cross-sectional studies between different groups. In an interesting study [49], which aimed to clarify the origin of changes in corneal asphericity and induced spherical aberration after a laser refractive surgery, the authors concluded that increases in corneal asphericity, as well as the induction of spherical aberration, arise due to the effects of corneal remodelling that occurs because of healing and due to the reduction in ablation efficiency based on the angle of incidence of the laser. These results were also reported in several other research studies [50–52].

4. Conclusions

The cornea is a significant refractive component of an individual's eye, which contributes majorly to the eye's refractive power. Corneal Q value is a commonly used term to characterise the asphericity of the cornea and is a critical parameter in describing the eye model. Researchers in the past have attempted to study the corneal Q values with respect to a number of different parameters such as age, gender and ethnicity. Determining the corneal Q value is crucial as it can assist in treating refractive errors as well as with the implantation of intraocular lenses. This study provides a detailed review of several noteworthy relevant research studies examining the Q values of the cornea. Based on the review, it appears that parameters such as age, gender and ethnicity may influence the resulting Q values of subjects analysed. Therefore, to design visual optical products and enhance the understanding of the optical properties of an eye, future studies could consider the works of previous researchers as valuable references. Furthermore, the Q value which is to be considered as a description of the corneal curvature associates with the corneal parameters mathematically and physically to provide a conceived relationship between the entangled parameters, also each parameter effect on the Q valve taken into consideration through the various theoretical and practical considerations to shape a clear image on that effect and how these parameters can describe the corneal asphericity and its effect on sight process.

Data availability

No data was used for the research described in the article.

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CRediT authorship contribution statement

Noor T. Al-Sharify: Investigation, Conceptualization. **Husam Yahya Nser:** Investigation. **Nebras H. Ghaeb:** Validation. **Zainab T. Al-Sharify:** Supervision. **Ong Hang See:** Supervision. **Leong Yeng Weng:** Writing – review & editing. **Sura M. Ahmed:** Software, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] D.M. Maurice, Chapter 6 - the cornea and sclera. Vegetative Physiology and Biochemistry, Academic Press, 1962, pp. 289–368, https://doi.org/10.1016/B978-1-4832-3090-0.50013-7. ISBN 9781483230900.
[2] S. Zheng, J. Ying, B. Wang, Z. Xie, X. Huang, M. Shi, Three-dimensional model for human anterior corneal surface, J. Biomed. Opt. 18 (6) (2013 Jun) 065002, https://doi.org/10.1117/1.JBO.18.6.065002.
[3] W.A. Douthwaite, A. Parkinson, Precision of orbscan II assessment of anterior corneal curvature and asphericity, J. Refract. Surg. 25 (5) (2009 May) 435–443.
[4] F. Manns, V. Fernandez, S. Zipper, S. Sandadi, M. Hamaoui, A. Ho, et al., Radius of curvature and asphericity of the anterior and posterior surface of human cadaver crystalline lenses, Exp. Eye Res. 78 (1) (2004 Jan) 39–51.
[5] S.M. Ahmed, O.H. See, L.Y. Weng, N.T. Al-Sharify, H.Y. Nser, Z.T. Al-Sharify, N.H. Ghaeb, Corneal elevation topographic maps assessing different diseases detection: a review, Ain Shams Eng. J. (2023) 102292. .
[6] A. Barros, J. Queiruga-Piñeiro, J. Lozano-Sanroma, I. Alcalde, J. Gallar, L.F.V. Cueto, J.F. Alfonso, J. Quirós & Merayo-Lloves, Small fiber neuropathy in the cornea of Covid-19 patients associated with the generation of ocular surface disease, Ocul. Surf. 23 (2022) 40–48, https://doi.org/10.1016/j.jtos.2021.10.010. .
[7] A. Calossi, Corneal asphericity and spherical aberration, J. Refract. Surg. 23 (5) (2007) 505–514.
[8] A. Queiros, C. Villa-Collar, J. Jorge, R. GutieÂrrezAÂ, J.M. GonzaÂlez-MeÂijome, Multi-aspheric description of the myopic cornea after different refractive treatments and its correlation with corneal higher order aberrations, Optometry 5 (4) (2012 Oct) 171–181.
[9] D. Gatinel, M. Haouat, T. Hoang-Xuan, A review of mathematical descriptors of corneal asphericity, J. Fr. Ophtalmol. 25 (1) (2002 Jan) 81–90.
[10] D.G. Fuller, D. Alperin, Variations in corneal asphericity (Q value) between African-Americans and whites, Optom. Vis. Sci. 90 (7) (2013 Jul) 667–673, https://doi.org/10.1097/OPX.0b013e318296befe.
[11] H. Huang, J. Yang, H. Bao, S. Chen, B. Xia, J. Zou, Retrospective analysis of changes in the anterior corneal surface after Q value guided LASIK and LASEK in high myopic astigmatism for 3 years, BMC Ophthalmol. 12 (2012 Jun 18) 15, https://doi.org/10.1186/1471-2415-12-15.
[12] K.Y. Chan, S.W. Cheung, P. Cho, Corneal parameters of six- to 12-year-old Chinese children, Clin. Exp. Optom. 95 (2) (2012 Mar) 160–165, https://doi.org/10.1111/j.1444-0938.2011.00682.x.
[13] A. Queiros, C. Villa-Collar, R. GutieÂrrezAÂ, J. Jorge, M.S. Ribeiro-QueiroÂs, S.C. Peixoto-de-Matos, et al., Anterior and posterior corneal elevation after orthokeratology and standard and customized LASIK surgery, Eye Contact Lens 37 (6) (2011 Nov) 354–358, https://doi.org/10.1097/ICL.0b013e318232e32d.
[14] A. Queiros, C. Villa-Collar, R. GutieÂrrezAÂ, J. Jorge, M.S. Ribeiro-QueiroÂs, S.C. Peixoto-de-Matos, et al., Local steepening in peripheral corneal curvature after corneal refractive therapy with contact lenses, standard LASIK and custom LASIK, Optom. Vis. Sci. 87 (6) (2010 Jun) 432–439, https://doi.org/10.1097/OPX.0b013e3181da8628.
[15] Y. Xiong, J. Li, N. Wang, X. Liu, Z. Wang, F. Tsai, X. Wan, The analysis of corneal asphericity (Q value) and its related factors of 1,683 Chinese eyes older than 30 years, PLoS One 12 (5) (2017) e0176913.
[16] Y. Yang, K. Thompson, S.A. Burns, Pupil location under mesopic, photopic, and pharmacologically dilated conditions, Invest. Ophthalmol. Vis. Sci. 43 (2002) 2508–2512.
[17] M. Camellin, F. Gambino, S. Casaro, Measurement of the spatial shift of the pupil center, J. Cataract Refract. Surg. 31 (2005) 1719–1721.
[18] R. Edward, What is the relevance of asphericity in today's ophthalmic practice? Philippine J. Ophthalmol. 36 (1) (2011) 5–6.
[19] J. Holladay, Spherical aberration: the next Frontier. Cataract & Refractive Surgery Today, 2006, pp. 95–102.
[20] WebMD, Your eyes and cornea problems [online] Available at: https://www.webmd.com/eye-health/cornea-conditions-symptoms-treatments, 2021. (Accessed 14 May 2021).
[21] T.N. Azher, X.T. Yin, D. Tajfirouz, A.J. Huang, P.M. Stuart, Herpes simplex keratitis: challenges in diagnosis and clinical management, Clin. Ophthalmol. 11 (2017) 185–191, https://doi.org/10.2147/OPTH.S80475.
[22] D.W. Kimberlin, C.Y. Lin, R.F. Jacobs, et al., Natural history of neonatal herpes simplex virus infections in the acyclovir era, Pediatrics 108 (2) (2001) 223–229.
[23] Y. Rabinowitz, Keratoconus, Surv. Ophthalmol. 42 (4) (1998) 297–319.
[24] M.H. Friedlaender, G. Smolin, Corneal degenerations, Ann. Ophthalmol. 11 (10) (1979 Oct) 1485–1495.
[25] A.M. Roszkowska, E. Wylegala, Corneal degenerations, in: M. Babizhayev, D.C. Li, A. Kasus-Jacobi, L. Žorić, J. Alió (Eds.), Studies on the Cornea and Lens. Oxidative Stress in Applied Basic Research and Clinical Practice, Humana Press, New York, NY, 2015, https://doi.org/10.1007/978-1-4939-1935-2_2.
[26] G. Waring, M. Rodrigues, P. Laibson, Corneal dystrophies. I. Dystrophies of the epithelium, Bowman's layer and stroma, Surv. Ophthalmol. 23 (2) (1978) 71–122.
[27] Mayo Clinic, Keratoconus - symptoms and causes [online] Available at: https://www.mayoclinic.org/diseases-conditions/keratoconus/symptoms-causes/syc-20351352, 2021. (Accessed 23 May 2021).
[28] R. Bellucci, A. Scialdone, L. Buratto, et al., Visual acuity and contrast sensitivity comparison between Tecnis and AcrySof SA60AT intraocular lenses: a multicenter study, J. Cataract Refract. Surg. 31 (2005) 712–717.
[29] M. Packer, I.H. Fine, R.S. Hoffman, P.A. Piers, Improved functional vision with a modified prolate intraocular lens, J. Cataract Refract. Surg. 30 (2004) 986–992.
[30] Y. Xiong, J. Li, N. Wang, X. Liu, Z. Wang, F. Tsai, X. Wan, The analysis of corneal asphericity (Q value) and its related factors of 1,683 Chinese eyes older than 30 years, PLoS One 12 (5) (2017) e0176913.
[31] M.R. Elsayed, I. Saeed, A.M. Hamed, H.M. Fayk, T.N. Attia, Analysis of corneal asphericity (Q value) and its related factors in adult Egyptians: a cross-sectional study, Delta J Ophthalmol [serial online] 21 (2020) 236–241 [cited 2021 May 15], http://www.djo.eg.net/text.asp?2020/21/4/236/304943.
[32] Z. Xia, C. Lin, X. Huang, J. Ying, M. Shi, S. Zheng, Group analysis of Q values calculated with tangential radius of curvature from human anterior corneal surface, Journal of Ophthalmology 2018 (2018) 1–5.
[33] A. Amorim-de-Sousa, A. Vieira, J. González-Méijome, A. Queirós, Age-related variations in corneal asphericity and long-term changes, Eye Contact Lens 45 (2) (2019) 99–104.
[34] M. Yu, M. Chen, W. Liu, J. Dai, Comparative study of wave-front aberration and corneal Asphericity after SMILE and LASEK for myopia: a short and long term study, BMC Ophthalmol. 19 (1) (2019).
[35] L. Torquetti, C. Arce, J. Merayo-Lloves, G. Ferrara, P. Ferrara, B. Signorelli, A. Signorelli, Evaluation of anterior and posterior surfaces of the cornea using a dual Scheimpflug analyzer in keratoconus patients implanted with intrastromal corneal ring segments, Int. J. Ophthalmol. 9 (9) (2016 Sep 18) 1283–1288, https://doi.org/10.18240/ijo.2016.09.08. PMID: 27672592; PMCID: PMC5028662.
[36] J.M. González-Méijome, C. Villa-Collar, R. Montés-Micó, A. Gomes, Asphericity of the anterior human cornea with different corneal diameters, J. Cataract Refract. Surg. 33 (3) (2007 Mar) 465–473, https://doi.org/10.1016/j.jcrs.2006.11.004.
[37] J. Zhang, L. Zheng, X. Zhao, Y. Sun, W. Feng, M. Yuan, Corneal aberrations after small-incision lenticule extraction versus Q value-guided laser-assisted in situ keratomileusis, Medicine (Baltim.) 98 (5) (2019 Feb) e14210, https://doi.org/10.1097/MD.0000000000014210.
[38] J. Li, C. Yang, W. Xie, G. Zhang, X. Li, S. Wang, X. Yang, J. Zeng, Predictive role of corneal Q-value differences between nasal-temporal and superior-inferior quadrants in orthokeratology lens decentration, Medicine (Baltim.) 96 (2) (2017 Jan) e5837, https://doi.org/10.1097/MD.0000000000005837.

[39] N. Yazdani, L. Shahkarami, H. OstadiMoghaddam, A. Ehsaei, Topographic determination of corneal asphericity as a function of age, gender, and refractive error, Int. Ophthalmol. 37 (2017) 807–812.
[40] J.J. Rozema, D.A. Atchison, M.J. Tassignon, Statistical eye model for normal eyes, Invest. Ophthalmol. Vis. Sci. 52 (2011) 4525–4533.
[41] L.G. Carney, J.C. Mainstone, B.A. Henderson, Corneal topography and myopia, Invest. Ophthalmol. Vis. Sci. 38 (2) (1997) 311–319.
[42] J. Ying, B. Wang, M. Shi, Anterior corneal asphericity calculated by the tangential radius of curvature, J. Biomed. Opt. 17 (7) (2012) 075005, https://doi.org/10.1117/1.JBO.17.7.075005.
[43] S.W. Cheung, P. Cho, W. Douthwaite, Corneal shape of Hong Kong-Chinese, Ophthalmic Physiol. Opt. 20 (2) (2000) 119–125.
[44] K. Scholz, A. Messner, T. Eppig, H. Bruenner, A. Langenbucher, Topography-based assessment of anterior corneal curvature and asphericity as a function of age, sex, and refractive status, J. Cataract Refract. Surg. 35 (6) (2009) 1046–1054, https://doi.org/10.1016/j.jcrs.2009.01.019.
[45] M. Dubbelman, V.A. Sicam, G.L. Van der Heijde, The shape of the anterior and posterior surface of the aging human cornea, Vis. Res. 46 (6–7) (2006) 993–1001, https://doi.org/10.1016/j.visres.2005.09.021.
[46] D.G. Horner, P.S. Soni, N. Vyas, N.L. Himebaugh, Longitudinal changes in corneal asphericity in myopia, Optom. Vis. Sci. 77 (4) (2000 Apr) 198–203.
[47] W.R. Davis, T.W. Raasch, G.L. Mitchell, D.O. Mutti, K. Zadnik, Corneal asphericity and apical curvature in children: a cross-sectional and longitudinal evaluation, Invest. Ophthalmol. Vis. Sci. 46 (6) (2005) 1899–1906, https://doi.org/10.1167/iovs.04-0558.
[48] Z. Zhang, J. Wang, W. Niu, M. Ma, K. Jiang, P. Zhu, et al., Corneal asphericity and its related factors in 1052 Chinese subjects, Optom. Vis. Sci. 88 (10) (2011 Oct) 1232–1239, https://doi.org/10.1097/OPX.0b013e31822717ca.
[49] Y. Kwon, S. Bott, Postsurgery corneal asphericity and spherical aberration due to ablation efficiency reduction and corneal remodelling in refractive surgeries, Eye 23 (2009) 1845–1850, https://doi.org/10.1038/eye.2008.356.
[50] G. Yoon, S. MacRae, D.R. Williams, I.G. Cox, Causes of spherical aberration induced by laser refractive surgery, J. Cataract Refract. Surg. 31 (2005) 127–135.
[51] J.T. Holladay, J.A. Janes, Topographic changes in corneal asphericity and effective optical zone after laser in situ keratomileusis, J. Cataract Refract. Surg. 28 (2002) 942–947.
[52] R.G. Anera, J.R. Jiménez, L.J.D. Barco, E. Hita, Changes in corneal asphericity after laser refractive surgery, including reflection losses and nonnormal incidence upon the anterior cornea, Opt Lett. 28 (2003) 417–419.
[53] A.P. Shah, D. Dzhaber, K.R. Kenyon, K.M. Riaz, D.P. Ouano, E.H. Koo, Acute corneal transplant rejection after COVID-19 vaccination, Cornea 41 (1) (2022) 121–124, https://doi.org/10.1097/ICO.0000000000002878. .
[54] H. Onyeaka, C.K. Anumudu, Z.T. Al-Sharify, E. Egele-Godswill, P. Mbaegbu, COVID-19 pandemic: a review of the global lockdown and its far-reaching effects, Sci. Prog. 104 (2) (2021) 368504211019854, https://doi.org/10.1177/00368504211019854.
[55] K.I. Rallis, R. Fausto, D.S. Ting, M.A. Al-Aqaba, D.G. Said, H.S. Dua, Manifestation of herpetic eye disease after COVID-19 vaccine: a UK case series, Ocul. Immunol. Inflamm. (2022) 1–6, https://doi.org/10.1080/09273948.2022.2046795.
[56] H. Onyeaka, Z.T. Al-Sharify, M.Y. Ghadhban, S.Z. Al-Najjar, A review on the advancements in the development of vaccines to combat coronavirus disease 2019, Clin Exp Vaccine Res 10 (1) (2021 Jan) 6–12, https://doi.org/10.7774/cevr.2021.10.1.6.
[57] D.S. Cha, M. Moshirfar, M.S. Herron, J.M. Santos, P.C. Hoopes, Prediction of posterior-to-anterior corneal curvature radii ratio in myopic patients after LASIK, SMILE, and PRK using multivariate regression analysis, J. Clin. Med. 12 (13) (2023) 4536. .
[58] W. Al-dolat, L. Abu-Ismail, A. Khamees, N. Alqudah, M.M. Abukawan, H.M. Alrawashdeh, W. Al Momani, K.A. Kheirallah, Is wearing a face mask associated with symptomatic dry eye disease among medical students during the COVID-19 era? An online survey, BMC Ophthalmol. 22 (2022) 159, https://doi.org/10.1186/s12886-022-02377-z.
[59] U. Camellin, I. Ninotta, G. Latino, A. Alibrandi, P. Aragona, A.M. Roszkowska, Prediction of total corneal power in keratoconus using anterior surface data, Clin. Exp. Optom. (2023) 1–7. .
[60] C. Tangmonkongvoragul, S. Chokesuwattanaskul, C. Khankaeo, R. Punyasevee, L. Nakkara, S. Moolsan, O. Unruan, Prevalence of symptomatic dry eye disease with associated risk factors among medical students at Chiang Mai University due to increased screen time and stress during COVID-19 pandemic, PLoS One 17 (3) (2022) e0265733, https://doi.org/10.1371/journal.pone.0265733. .
[61] F.L. Sáez-Gutiérrez, J.S. Velázquez, J.L. Alió del Barrio, J.L. Alio, F. Cavas, Novel multivariable evolutionary algorithm-based method for modal reconstruction of the corneal surface from sparse and incomplete point clouds, Bioengineering 10 (8) (2023) 989. .
[62] N.T. Al-Sharify, Z.T. Al-Sharify, T.A. Al-Sharify, M.T. Al-Sharify, A.T. Al-Sharify, A technical overview and comparison between PET and M RI scanning, Sys. Rev. Pharm. 11 (1) (2020) 35–41, 10.5530/srp.2020.1.06.
[63] N.T. Al-Sharify, D.R. Rzaij, Z.M. Nahi, Z.T. Al-Sharify, An experimental investigation to redesign a pacemaker training board for educational purposes, IOP Conf. Ser. Mater. Sci. Eng. 870 (1) (2020) 012020, 10.1088/1757-899X/870/1/012020.
[64] Z. Majid, N.T. Al-Sharify, Z.T. Al-Sharify, Measurement of muscle activity using arduino advanced software for sustainable aid, Journal of Green Engineering 10 (9) (2020) 4965–4976. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85093968330&partnerID=40&md5=32993d9278eb4e68e089e985633cf848.
[65] F. Rüfer, A. Schröder, C. Erb, White-to-white corneal diameter: normal values in healthy humans obtained with the Orbscan II topography system, Cornea 24 (3) (2005) 259–261, https://doi.org/10.1097/01.ico.0000148312.01805.53. .
[66] A. Queirós, C. Villa-Collar, J. Jorge, Á.R. Gutiérrez, J.M. González-Méijome, Multi-aspheric description of the myopic cornea after different refractive treatments and its correlation with corneal higher order aberrations, Journal of Optometry 5 (2012) 171–181.
[67] P. Perez-Merino, S. Marcos, Effect of intraocular lens decentration on image quality tested in a custom model eye, J. Cataract Refract. Surg. 44 (2018) 889–896.
[68] P. Beneš, S. Synek, S. Petrová, Corneal shape and eccentricity in population, Coll. Antropol. 37 (2013) 117–120.
[69] A. Gokul, D.V. Patel, C.N. McGhee, Dr John Nottingham's 1854 landmark treatise on conical cornea considered in the context of the current knowledge of keratoconus, Cornea 35 (2016) 673–678.
[70] C. Fowler, T. Dave, Review of past and present techniques of measuring corneal topography, Ophthalmic Physiol. Opt. 14 (1994) 49–58.
[71] A. Lavric, P. Valentin, KeratoDetect: keratoconus detection algorithm using convolutional neural networks, Comput. Intell. Neurosci. 2019 (2019) 1–9, https://doi.org/10.1155/2019/8162567.
[72] X. Zhang, S.Z. Munir, S.A. Sami Karim, W.M. Munir, A review of imaging modalities for detecting early keratoconus, Eye 35 (2021) 173–187, https://doi.org/10.1038/s41433-020-1039-1.
[73] M.A. Henriquez, M. Hadid, L. Izquierdo, A systematic review of subclinical keratoconus and forme fruste keratoconus, J. Refract. Surg. Thorofare NJ 1995 36 (2020) 270–279, https://doi.org/10.3928/1081597X-20200212-03.
[74] D. Gatinel, J. Malet, T. Hoang-Xuan, D.T. Azar, Corneal elevation topography: best fit sphere, elevation distance, asphericity, toricity and clinical implications, Cornea 30 (2011) 508, https://doi.org/10.1097/ICO.0b013e3181fb4fa7.
[75] J.R. Viñuela, D.P. Piñero, M.B. Martínez, Comparing sagittal heights calculated using corneal parameters and those measured with profilometry, Contact Lens Anterior Eye 46 (2) (2023) 101747. .
[76] L. Spadea, L. Di Genova, E. Trovato Battagliola, M.P. Paroli, Topography-Guided transepithelial photorefractive keratectomy for the treatment of persistent and visually-significant adenoviral corneal infiltrates, Therapeut. Clin. Risk Manag. (2023) 341–349.
[77] D.P. Piñero, J.L. Alió, A. Alesón, M.E. Vergara, M. Miranda, Corneal volume, pachymetry, and correlation of anterior and posterior corneal shape in subclinical and different stages of clinical keratoconus, J. Cataract Refract. Surg. 36 (5) (2010) 814–825.
[78] D.P. Piñero, J.C. Nieto, A. Lopez-Miguel, Characterization of corneal structure in keratoconus, J. Cataract Refract. Surg. 38 (12) (2012) 2167–2183.
[79] W.R. Davis, T.W. Raasch, G.L. Mitchell, D.O. Mutti, K. Zadnik, Corneal asphericity and apical curvature in children: a cross-sectional and longitudinal evaluation, Invest. Ophthalmol. Vis. Sci. 46 (6) (2005) 1899–1906.
[80] N.T. Al-Sharify, S.M. Ahmed, H.Y. Nser, O.H. See, Z.T. Al-Sharify, N.H. Ghaeb, L.Y. Weng, Corneal topography, an overview of its devices and systems–A review, in: AIP Conference Proceedings, vol. 2787, AIP Publishing, 2023 ,, July, 1.
[81] Z.T. Al-Sharify, T.A. Al-Sharify, N.T. Al-Sharify, H.Y. Naser, A critical review on medical imaging techniques (CT and PET scans) in the medical field, IOP Conf. Ser. Mater. Sci. Eng. 870 (1) (2020) 012043, 10.1088/1757-899X/870/1/012043.

[82] H.Y. Nser, N.T. Al-Sharify, S.M. Ahmed, L.Y. Weng, O.H. See, Z.T. Al-Sharify, N.H. Ghaeb, Review study of refraction error measurement methods of human cornea, in: AIP Conference Proceedings, vol. 2787, AIP Publishing, 2023 ,, July, 1.
[83] A.H. Al-Timemy, L. Alzubaidi, Z.M. Mosa, H. Abdelmotaal, N.H. Ghaeb, A. Lavric, S. Yousefi, A deep feature fusion of improved suspected keratoconus detection with deep learning, Diagnostics 13 (10) (2023) 1689. .
[84] X. Wang, L. Xia, Evaluation of the effects of myopic astigmatism correction and anterior corneal curvature on functional optical zone after SMILE, J. Refract. Surg. 39 (2) (2023) 135–141. .
[85] X. Lv, F. Zhang, Y. Song, C. Zhai, N. Guo, L. Lai, Y. Xu, Corneal biomechanical characteristics following small incision lenticule extraction for myopia and astigmatism with 3 different cap thicknesses, BMC Ophthalmol. 23 (1) (2023) 42. .
[86] L. Spadea, L. Di Genova, E. Trovato Battagliola, M.P. Paroli, Topography-Guided transepithelial photorefractive keratectomy for the treatment of persistent and visually-significant adenoviral corneal infiltrates, Therapeut. Clin. Risk Manag. (2023) 341–349.
[87] Y. Mori, K. Shimizu, K. Minami, K. Kamiya, N. Shoji, K. Miyata, Relationship of corneal asphericity to intraocular lens power calculations after myopic laser in situ keratomileusis, J. Cataract Refract. Surg. 42 (5) (2016) 703–709.
[88] G. Savini, K.J. Hoffer, P. Barboni, Influence of corneal asphericity on the refractive outcome of intraocular lens implantation in cataract surgery, J. Cataract Refract. Surg. 41 (4) (2015) 785–789.
[89] M.M. Berty, T.F. Eliwa, A.A.M. Gaafar, A.S. Mousa, Effect of intracorneal ring segments on posterior corneal topography in eyes with keratoconus, Arch. Soc. Esp. Oftalmol. 97 (8) (2022) 424–431.
[90] M. Safarzadeh, N. Nasiri, Anterior segment characteristics in normal and keratoconus eyes evaluated with a combined Scheimpflug/Placido corneal imaging device, Journal of Current Ophthalmology 28 (3) (2016) 106–111.
[91] K. Scholz, A. Messner, T. Eppig, H. Bruenner, A. Langenbucher, Topography-based assessment of anterior corneal curvature and asphericity as a function of age, sex, and refractive status, J. Cataract Refract. Surg. 35 (6) (2009) 1046–1054.
[92] C.C. Chen, A. Izadshenas, A.M.A. Rana, D.T. Azar, Corneal asphericity after hyperopic laser in situ keratomileusis, J. Cataract Refract. Surg. 28 (9) (2002) 1539–1545.
[93] J.M. González-Méijome, C. Villa-Collar, R. Montés-Micó, A. Gomes, Asphericity of the anterior human cornea with different corneal diameters, J. Cataract Refract. Surg. 33 (3) (2007) 465–473.
[94] J. Zhang, L. Zheng, X. Zhao, Y. Xu, S. Chen, Corneal biomechanics after small-incision lenticule extraction versus Q-value–guided femtosecond laser-assisted in situ keratomileusis, Journal of Current Ophthalmology 28 (4) (2016) 181–187.
[95] D. Smadja, M.R. Santhiago, G.R. Mello, R.R. Krueger, J. Colin, D. Touboul, Influence of the reference surface shape for discriminating between normal corneas, subclinical keratoconus, and keratoconus, J. Refract. Surg. 29 (4) (2013) 274–281.
[96] Z. Zhang, J. Wang, W. Niu, M. Ma, K. Jiang, P. Zhu, B. Ke, Corneal asphericity and its related factors in 1052 Chinese subjects, Optom. Vis. Sci. 88 (10) (2011) 1232–1239.
[97] Z. Schlegel, T. Hoang-Xuan, D. Gatinel, Comparison of and correlation between anterior and posterior corneal elevation maps in normal eyes and keratoconus-suspect eyes, J. Cataract Refract. Surg. 34 (5) (2008) 789–795.