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# The normal distribution of corneal eccentricity and its determinants in two rural areas of north and south of Iran

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## Abstract

***Purpose***: The aim of this study was to determine the distribution of corneal eccentricity (E-value) in a normal population and to examine related factors.

***Methods***: In this cross-sectional study, two villages were selected in Iran using multistage cluster sampling. Selected persons were invited to have a comprehensive eye examination. Examinations in each village were performed at a specific location under standard conditions. After testing for vision and refraction and conducting the slit-lamp exam, E-value was measured with Pentacam.

***Results***: Of the 3851 selected individuals, 3314 participated in the study. After applying the exclusion criteria, data from 2610 subjects was used in the analysis for this report. Mean E-value was 0.53 [95% confidence interval (CI): 0.52 to 0.54]. E-value was not significantly different between males and females. Mean E-value reduced with age from 0.60 in subjects aged 6–20 years to 0.47 in subjects older than 70 years. The hyperopic group of participants had significantly lower E-value than myopic and emmetropic ones ($P < 0.001$). The relationship of E-value with age, gender, and other anterior segment variables and spherical equivalent was examined in a multiple linear regression model. In multiple linear regression model, age (coef = −0.003), spherical equivalent refraction (coef = −0.005), pupil diameter (coef = 0.018), anterior chamber volume (coef = −0.001), and anterior chamber angle (coef = 0.003) significantly correlated with E-value.

***Conclusions***: The results of this study showed that the cornea in normal populations is prolate, and the degree of prolateness varies by age, such that older age is associated with a less prolate cornea. This study showed that factors such as age and refractive errors and anterior chamber indices influence the E-value.

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*Keywords:* Corneal eccentricity; Distribution; Cross sectional study; Determinants

## Introduction

The cornea, which is the most important refractive surface, does not conform to a spherical shape, and the corneal radius of curvature varies from the center to the periphery. In other words, the corneal surface is an aspheric surface.[1] Notably, corneal eccentricity (E-value) is one of the important parameters in determining the shape of the corneal surface. In fact,

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eccentricity describes the rate of corneal flattening from the center to the periphery. Due to differences in peripheral and central corneal curvature and corneal shape, eccentricity values can vary. The eccentricity value is between zero and one in prolate corneas, and it is less than zero in oblate corneas.[2]

Knowledge of normal eccentricity values at different ages has implications for identifying corneal abnormalities such as keratoconus, contact lens fitting, refractive surgery, cataract surgery, and IOL power calculation.[2–4] In contact lens fitting, the corneal shape determines the relationship between the cornea and the lens. Corneas with the same keratometry readings may be different in terms of eccentricity. Therefore, when the contact lens base curve is based only on keratometry values, the selected lens can have a wrong fit.[2] The eccentricity parameter also has importance in describing changes in corneal shape when studying the results of orthokeratology.[5] According to previous studies, eccentricity can be a diagnostic factor for the early diagnosis of keratoconus in its primary stages, and it has been suggested that eccentricity increases before slit-lamp signs appear.[3] Some studies suggest that the eccentricity value in normal adult population is from 0.4 to 0.6,[6–9] but it can be greater than 0.8 in keratoconus patients.[3] According to the available literature, this index also has significant implications for refractive surgery.[10] Induced astigmatism as a result of cataract surgery is related to several factors; however, the highest amount of induced astigmatism is seen in corneas with high anterior eccentricity.[4] Given the extensive applications for eccentricity, it seems necessary to perform more studies regarding this parameter in wide age ranges.

There are few studies concerning E-value and its relationship with age, gender, refractive errors, central corneal thickness, and anterior chamber depth (ACD), and as mentioned, all studies have been restricted to a limited age range.[7–9,11,12] This study was conducted to determine the normal range of eccentricity in a wide age range and examine its relationship with demographic variables, refractive errors, and a number of anterior segment parameters.

## Methods

In the present cross-sectional study, the target sample was the rural Iranian population. Details of the methodology of this study have been presented in previous reports[13,14]; however, a brief summary is presented here for review.

Sampling in this study was conducted using a multistage cluster sampling approach. Two rural regions were selected randomly from the north and southwest of Iran. After selecting these two regions, the rosters of all villages in these two regions were prepared, and a number of villages in proportion to the total number of villages in each region were selected: 5 villages from the northern region and 15 from the southwest. All people over the age of 1 were invited to participate in this study, and those who were willing to participate signed a written consent. In the case of children, the parents signed the consent forms. Two optometrists conducted the vision tests, and one ophthalmologist performed the ophthalmic examinations under standard conditions.

Vision tests included measurement of uncorrected vision, corrected vision with current glasses, and corrected vision with the Snellen E chart from a distance of 6 m. First, refraction was tested with an auto-refractometer (NIDEK ARK-510A Auto Refractor/Keratometer, Japan) for each individual, and then the results were checked through retinoscopy (Heine Beta 200 retinoscope, HEINE Optotechnik, Germany). After these examinations, a slit-lamp (BM 900, Haag Streit, USA) examination was done, and finally, Pentacam HR (Oculus, Inc., Lynnwood, WA) imaging was performed for all subjects over 5 years of age. If the machine reported an error in imaging, artificial tears were instilled, and images were retaken after 10 min. The latest version of the device (6.03r11) and Pentacam software (1.17r72) were used. To minimize bias as a result of diurnal variations, imaging sessions were held between 9 a.m. and 2 p.m., allowing for at least 3 h of awake time by the time of the examinations. Subjects with a history of intraocular surgery, history of any corneal surgery, use of contact lenses at the time of the study, corneal opacities, pterygium, strabismus, keratoconus, scissoring reflex on retinoscopy, Fleischer rings on slit-lamp examination, corneal dystrophy, and ptosis were excluded. Also, Pentacam images displaying an error status were excluded from the study.

### *Ethical issues*

The Ethics Committee of Mashhad University of Medical Sciences approved the study protocol, which was conducted in accord with the tenets of the Declaration of Helsinki. The consent forms were signed by the parents or guardians of children below 18 years.

### *Statistical analysis*

In this study, mean E-value and its 95% confidence interval (CI) was determined. Since cluster sampling was applied, the design effect was considered in the data analysis. Simple and multiple linear regression was used to explore relationships.

A backward linear regression model was employed to determine the final model of the variables affecting E-value. One-way analysis of variance was used to investigate the variation of E-value among the categories of refractive error. Then the post-hoc Scheffe test was applied to determine the means differences.

## Results

Of the 3851 selected individuals for this study, 3314 subjects participated in the study. A total of 2681 subjects were examined with the Pentacam examinations and were eligible for enrollment in this study. Of these subjects, 71 were excluded from the analysis because of the missing E-value, and 2610 subjects were eligible for inclusion in this report. After excluding outliers, the final analysis was done on data

Table 1
The mean and 95% confidence interval (CI) of corneal eccentricity (E-value) in two rural areas of north and southwest of Iran.

| Age | Total | Female | Male |
|---|---|---|---|
| | Mean (95% CI) | Mean (95% CI) | Mean (95% CI) |
| 6–20 | 0.60 (0.58–0.61) | 0.59 (0.58–0.61) | 0.60 (0.58–0.62) |
| 21–30 | 0.57 (0.55–0.59) | 0.56 (0.54–0.58) | 0.59 (0.57–0.61) |
| 31–40 | 0.54 (0.52–0.56) | 0.54 (0.52–0.57) | 0.54 (0.50–0.57) |
| 41–50 | 0.51 (0.48–0.53) | 0.52 (0.50–0.55) | 0.48 (0.44–0.52) |
| 51–60 | 0.44 (0.41–0.47) | 0.44 (0.41–0.48) | 0.43 (0.38–0.48) |
| 61–70 | 0.48 (0.43–0.52) | 0.48 (0.42–0.54) | 0.47 (0.41–0.54) |
| >70 | 0.47 (0.40–0.53) | 0.46 (0.39–0.54) | 0.47 (0.35–0.59) |
| Total | 0.53 (0.50–0.54) | 0.53 (0.52–0.54) | 0.53 (0.51–0.55) |

CI: Confidence interval.

from 2533 subjects. The mean age of the included subjects was 36.23 ± 18.46 years (from 6 to 90 years), and 1478 (58.3%) of them were female.

Table 1 shows the mean E-value with 95% CI in this sample by age and gender. The overall mean E-value was 0.53 (95% CI: 0.52 to 0.54). Fig. 1 illustrates the distribution of E-value in this population. Mean E-value was not statistically significantly different between two genders ($P = 0.738$). The results of this study indicated that E-value significantly decreases with age. The distribution of E-value based on refractive errors is shown in Fig. 2. The post-hoc Scheffe test demonstrated, E-value was significantly lower among hyperopic cases compared to myopic ($P < 0.001$; Mean difference: −0.069) and emmetropic ones ($P < 0.001$; Mean difference: −0.070).

The relationship of E-value with age, gender, spherical equivalent refraction, and anterior segment variables was investigated in simple and multiple linear regression model. Table 2 summarizes the relationship between E-value and studied variable.

According to Table 2, in the simple linear model, E-value had a significant correlation with younger age, increased ACD, increased anterior chamber volume, increased anterior chamber angle, and increased pupil diameter.

In the final model of linear regression, age (coef = −0.003), spherical equivalent refraction (−0.005), pupil diameter (coef = 0.018), anterior chamber volume (coef = −0.001), and anterior chamber angle (coef = 0.003) significantly correlated with E-value.

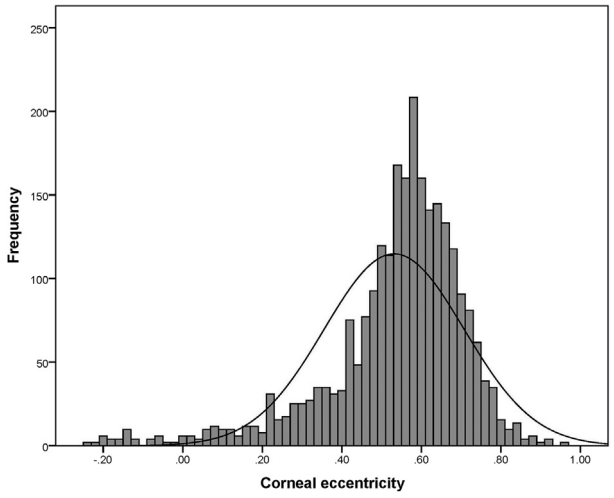


Fig. 1. The distribution of corneal eccentricity (E-value) in two rural areas of north and southwest of Iran.

## Discussion

The aim of this study was to investigate E-value in a normal population with a large sample size. The information derived from this study can firstly play an important role in increasing our knowledge of the corneal anatomy and optics. The results of this study can also be used in clinical decision-making, including diagnosis of abnormal corneas such as keratoconus. Similarly, they can be useful in refractive correction with surgical methods and in contact lens fitting.

The mean value of E-value was 0.53 in the total population of this study. As demonstrated in the results, the value was between zero and one in all age groups, indicating a prolate shape for the cornea.[2] The results of similar studies are presented in Table 3.

As the table demonstrates, the mean E-value reported from different regions of the world varies between 0.27 and 0.66, and this inter-study variation can be due to differences in measurement devices or differences in the characteristics of the studied populations. In a 2013 study in the United States, the authors reported corneas to be significantly more prolate among their African-American population compared to white individuals, providing evidence on the role of race on corneal shape.[16] Therefore, it seems that factors such as race and age of the studied populations, as well as variations in study methods and measuring devices, are important factors affecting results regarding the E-value.

According to the results of the present study, a significant inverse relationship was found between the E-value and age. As such, the cornea was in its most prolate form in the 6–20 year age group, and eccentricity decreased linearly (towards decreased prolateness) up to the age of 70 years, and all the while it remained in the prolate range. Similar to our results, previous studies reported an inverse relation (reduced prolateness of the corneal shape) with aging.[7,8,11,12,17,18]

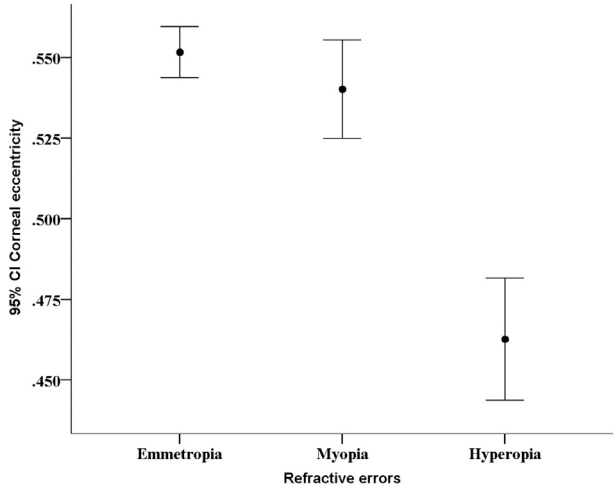


Fig. 2. The distribution of corneal eccentricity (E-value) by refractive errors.

Table 2
Simple and multiple associations between the corneal eccentricity (E-value) and investigated variables by linear regression.

| | Simple linear regression | Multiple linear regression |
|---|---|---|
| | Coefficient (95% CI); *P*-value | Coefficient (95% CI); *P*-value |
| Age (year) | −0.003 (−0.003 to −0.002); <0.001 | −0.003 (−0.004 to −0.003); <0.001 |
| Gender (male = 1; female = 1) | −0.003 (−0.017 to 0.011); 0.636 | |
| Spherical equivalent (diopter) | −0.001 (−0.005 to 0.002); 0.468 | −0.005 (−0.009 to −0.002); <0.001 |
| Mean-Keratometry (diopter) | 0.004 (0–0.009); 0.076 | |
| Anterior chamber depth (mm) | 0.040 (0.023–0.056); <0.001 | |
| Anterior chamber angle (degree) | 0.004 (0.003–0.005); <0.001 | 0.003 (0.002–0.004); <0.001 |
| Anterior chamber volume (microL) | 0 (0.001–0.001); <0.001 | −0.001 (−0.001 to −0.001); <0.001 |
| Central corneal thickness (micron) | 0 (0–0); 0.297 | |
| Pupil diameter (mm) | 0.037 (0.028–0.047); <0.001 | 0.018 (0.008–0.029); <0.001 |

CI: Confidence interval.

In a study on corneal shape by Hashemi et al., the authors reported greater changes in corneal peripheral regions compared to the central cornea, and according to the same study, age-related changes were more pronounced in the anterior cornea than the posterior surface, while the cornea maintained its prolate shape.[19] Not many studies have exclusively examined the relation between E-value and age. In a study, age-related changes in corneal prolateness have been attributed to age-related changes in the corneal periphery. These include steepening of the peripheral curvature and the reduced peripheral corneal thickness with age.[17] It should be noted that aging is associated with changes in the corneal tissue, the structure of its layers, reduced corneal elasticity, the topographic profile, and the curvature in the peripheral and central zones.[20] Therefore, the shape of the cornea can also be affected by these changes. Contrary to the mentioned studies, some studies suggest that there is no significant correlation between age and corneal shape factors.[21,22] These studies have differences with the present study which include the number of samples, inclusion of patients with a history of corneal surgery in the sample, the exclusive inclusion of adults, and use of different measurement devices. Knowledge of age-related changes in corneal shape can give us a better understanding of normal and abnormal corneal conditions in different age groups and improve outcomes of refractive correction using contact lenses or corneal surgical techniques.

In our study, eccentricity did not significantly correlate with gender, keratometry values, or central corneal thickness as separate variables. Some previous studies have investigated the relationship between gender and parameters affecting the corneal shape.[19,23,24] In studies by Goto et al., Asgari et al., and Patel et al. there was no significant inter-gender difference in eccentricity values.[8,11,12] These results were in line with the findings of our study. No report contradicting our results was found; nonetheless, given hormonal influences and differences between genders, further studies are needed.

Lack of a significant correlation between eccentricity and mean keratometry was another observation in the present study. Not many studies are available on this topic to draw comparisons. In the study by Benes et al., there was no relation between the values of eccentricity and radius of curvature.[2] In the study by Klein, the instantaneous power of the cornea was found to be independent of changes in the E-value.[25] However, in a study by Asgari et al., a significant direct relation was found between mean keratometry and eccentricity, such that a higher eccentricity value was associated with increased corneal prolateness, steeper corneal curvature, and increased corneal power.[12] It should be noted that the age range of the subjects in the latter study was 40–64 years,[12] and Benes et al.'s study included 3- to 87-year-old participants.[2] Measurement devices were also different. Valid comparisons require applying similar methods in future studies.

According to the results of this study, the correlation between eccentricity and central corneal thickness was not statistically significant. This suggests that the central corneal thickness and the corneal shape have no relation, and their changes occur independently of each other. No study was found on the relationship between eccentricity and the central corneal thickness. Thus, comparison of results and further discussion is not possible. In this study, the relationship between corneal shape and thickness may have lacked significance on account of excluding cases with keratoconus and

Table 3
Summary of other studies.

| Study | Year | Sample size | Age | Place | Device | Eccentricity value |
|---|---|---|---|---|---|---|
| Goto et al.[11] | 2001 | 132 | 23–83 | USA | TMS-2 (Computed Anatomy, New York, NY) | 0.29–0.40 |
| Chui et al.[15] | 2005 | 22 | 11.2 ± 2.2 | China | 1-Medmont E300<br>2-Keratron Scout<br>3-Humphrey Atlas 991 | 0.66 |
| Patel et al.[8] | 2009 | 62 | 21–30 | New Zealand | Orbscan II | 0.52 |
| Benes et al.[1] | 2013 | 1408 | 3–95 | Czech Republic | Autorefractokeratometer with Placido disc | 0.30 |
| Pinero et al.[9] | 2017 | 107 | 23–65 | Spain | VX120 | 0.43 |
| **Iran** | | | | | | |
| Asgari et al.[12] | 2012 | 8532 | 40–64 | Shahroud | Pentacam HR | 0.27 ± 0.63 |
| Current study | 2017 | 2533 | 6–90 | Tehran | Pentacam HR | 0.53 |

abnormal corneas. In other words, contrary to keratoconus corneas, where there is steeping and increased eccentricity as the cornea becomes thinner,[3] no relation exists between thickness and eccentricity in normal corneas. In fact, these parameters may be related in cases when the cornea changes, but they are independent from each other in the normal cornea.

Another observation of the present study was the inverse relation between eccentricity and spherical equivalent refraction. As such, eccentricity increased as the spherical equivalent decreased towards myopia. In the study by Asgari et al., similar to our results, an inverse relation was reported, and it was stated that as spherical equivalent trends towards myopia the cornea becomes more prolate, and the central cornea shows increased power, thus eccentricity increases.[12] In another study in 2013, it was pointed out that myopic individuals have a steeper and more prolate cornea.[2] Therefore, in general, the eccentricity value is higher in myopic subjects and lower in hyperopic cases.

The present study has some strengths and weaknesses. One of the strengths of our study was that it was done on a large sample size and in a very wide age range. In this study, we tried to examine the relationship between E-value and many effective demographic variables. The limitation of our study was that we did not study the relationship between anthropometric indices and E-value. There is mixed evidence in the literature that there can be a relationship between body mass index (BMI), weight and height, and corneal surface. This uncertainty of the relationship warrants further exploration of such relationship. Also, we did not evaluate biometric indices especially axial length and their relationship with E-value which can add very valuable information to our results. Another limitation of our study is that we cannot generalize our results to the entire rural areas of the country.

In conclusion, the results of this study showed that the cornea in normal populations is prolate, and the degree of prolateness varies by age, such that older age is associated with a less prolate cornea. This study showed that factors such as age and type of spherical ametropia influence the E-value, but factors such as keratometry, gender, and corneal thickness are not related to the E-value. The results of this study can be used to better understand the trend of changes in corneal shape from childhood to old age and can also be used to distinguish healthy corneas from keratoconus, refine the approaches used for the correction of refractive errors by refractive surgery, as well as the design and fitting of contact lenses.

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