

The Distribution of Keratometry in a Population Based Study

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Abstract

Purpose: To determine the distribution of keratometry values in a wide age range of 6-90 years.

Methods: In this cross-sectional study, samples were selected from two villages in Iran using multi-stage random cluster sampling. After completing optometry and ophthalmic examinations for all cases, corneal imaging was done using Pentacam, and keratometry values were determined.

Results: Of the 3851 selected people, 3314 people participated in the study, and after applying the exclusion criteria, analyses were done on data from 2672 people. Mean age of the participants was 36.30 ± 18.51 years (from 6 to 90 years). Mean keratometry (mean-K) in flat and steep meridians was 42.98 (42.9-43.06) diopters (D) and 43.98 (43.91-44.07) D, respectively. Average of mean-K was 43.48 (43.41-43.56) D. Mean-K increased linearly up to the age of 70 years, and the cornea became slightly flat afterwards (coefficient = 0.01; $P < 0.001$). Mean-K was significantly higher in females ($P < 0.001$). Myopic cases had the highest mean-K ($P < 0.001$). The correlation of mean-K with age, gender, central corneal thickness, anterior chamber depth, pupil diameter, and spherical equivalent was investigated in a multiple regression model. Only older age and female gender showed a statistically significant association with mean-K. Overall, 31.62% (29.14-34.09) of the sample in this study had at least 1.0 D of corneal astigmatism.

Conclusions: This is one of the few studies worldwide that demonstrates changes in keratometry in a wide age range from childhood to old age. Results indicated that age and gender are variables associated with keratometry.

Keywords: Age, Cornea, Gender, Keratometry, Refractive errors

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INTRODUCTION

Keratometry is the measurement of the corneal curvature which is considered one of the indicators of corneal health status. Knowledge of the values of the keratometry has many applications in screening before refractive surgery,¹ diagnosis and monitoring of corneal diseases such as keratoconus,² and successful contact lens fitting.³ The keratometry, next to other ocular parameters such as axial length, the curvature

and thickness of the crystalline lens, and the anterior chamber depth, can influence the type and degree of refractive error.⁴ Abnormal values of keratometry can lead to severe ametropia and, thus, amblyopia in early ages.⁵ Also, the difference between the keratometry in major meridians is a factor of corneal astigmatism. Therefore, knowledge of the keratometry is critical for understanding the status of refractive errors.⁶

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Measurement of the keratometry is done by keratometers and topography devices.⁷ In older devices, such as the Javal keratometer, this measure is limited to the central 3 mm of the anterior cornea.⁸ New corneal topographers were devised for a more accurate and wider assessment of the corneal surface.⁹ Among modern topographers, Pentacam has shown high accuracy.^{10,11} The device utilizes a rotating Scheimpflug camera and light source to capture images of the anterior and posterior surfaces of the cornea on different meridians around the optical axis. The output is a three-dimensional model calculated from 25000 points of the corneal surface (138000 points with the HR type). To date, there has been no study of the corneal power and keratometry from childhood to old age using Pentacam. Most previous studies have been done on adults over 40 years,^{12,13} and few studies have been done on children.¹⁴

The present study examines different age groups through a population-based approach. One of the most important aspects of this study is the possibility to compare and assess keratometry throughout the span of life. To the best of the authors' knowledge, this study is the first population-based study in the world to assess normal keratometry in all ages using Pentacam and build a database which should allow us to examine normal changes in keratometry that occur with aging.

METHODS

The present cross-sectional study was conducted in 2015. In this study, the target population was rural-dwellers of underprivileged areas of Iran. From these areas, two villages were selected from the north and southwest of the country.

Sampling

In this study, samples were selected using multi-stage cluster sampling. Two districts were randomly selected from the north and southwest of Iran using national data and information regarding underprivileged regions. In the southwest, Shahyoun district in Khuzestan Province, and in the north, Kajour in Mazandaran Province were selected.

After determining the target districts, a list of all the villages in these districts was provided, and a number of villages was randomly selected from the list for each district. The number of villages selected in each district was proportional to the population of each district: 15 villages from Shahyoun district and 5 from Kajour district. Villages in Shahyoun district were less populated.

After selecting the target villages, all necessary arrangements were made with the local health authorities and personnel, and all rural-dwellers over 1 year of age were invited to participate in the study using a consent form. For those under 18 years, consent was obtained from the head of the household. For those who consented to participate in the study, an appointment was scheduled for them to have their examinations.

Given the purpose of the original survey, the sample size was calculated based on the prevalence of visual impairment. For a rate

of 6.3% in a village in Iran, a precision level of 0.01, and a 95% confidence level, the sample size was calculated as 2267. Then a 1.5 design effect was applied on account of the sampling method, which corrected the sample size to 3400. A 10% non-response rate was also assumed, and the final sample size came to 3740.

In each village, a venue with standard illumination (1300 lux with room lights on) was selected for examinations. On the examination day, first demographic data were collected through an interview. Children's information was gathered from their parents. Ophthalmologic examinations were performed after the interview. Vision tests were conducted by two optometrists whose agreement was evaluated in 35 samples. According to intraclass correlation coefficients, the agreement between optometrists was 0.897 in testing manifest refraction and 0.923 for the measurement of uncorrected visual acuity (UCVA).

Examinations

Examinations for each participant began with testing the UCVA using the Snellen E chart at 6 m. Children ≤ 5 years who could not provide a response with this chart were trained for and tested with Lea symbols. In the next step, objective refraction was determined through auto-refraction with Nidek Ref/Keratometer ARK-510A for all participants. Then objective refraction was done with retinoscopy (Heine Beta 200 retinoscope, HEINE Optotechnik, Germany) to fine-tune auto-refraction results in all cases. If auto-refraction could not be completed for children, only objective refraction was performed. In the next step, subjective refraction was measured for those with UCVA worse than 20/20, and the best corrected visual acuity was determined. Then Pentacam HR (Oculus, Inc., Lynnwood, WA) was used to perform imaging in all subjects over 5 years of age. In case of any error message, artificial tears were instilled, and imaging was repeated in 10 min. Current contact lens users, participants with a history of ocular surgery, cases diagnosed with corneal opacities, pterygium, strabismus, keratoconus, corneal dystrophy, or ptosis, and those with erroneous Pentacam data were excluded from the study.

Definitions

In 5- to 15-year-old children, refractive errors were determined based on cycloplegic refraction. We used spherical equivalent cut-points of -0.50 diopter (D) for myopia and $+2.0$ D for hyperopia.¹⁵ We used the non-cycloplegic spherical equivalent to define refractive errors in subjects over 15 years old. Myopia and hyperopia were defined as a spherical equivalent < -0.5 D and > 0.5 D, respectively.¹⁵

The corneal astigmatism axis was classified as with-the-rule (WTR) if the axis was between 150° and 180° or between 0° and 30° , against-the-rule (ATR) if the axis was between 60° and 120° and oblique (OBL) if else.

Statistical analysis

Steep keratometry (steep-k), flat keratometry (flat-k), and mean keratometry (mean-K) values are summarized as their mean and 95% confidence intervals (CI). Mean-K was used to assess

the relationship between the studied indices and keratometry, and its relation to age, gender, refractive error, central corneal thickness, anterior chamber depth, and pupil diameter was evaluated using linear regression. Corneal astigmatism was calculated as the difference between flat-k and steep-k values.

Ethical issues

The Ethics Committee of Shahid Beheshti University of Medical Sciences approved the study protocol, which was conducted in accord with the tenets of the Declaration of Helsinki. All participants signed a written informed consent.

RESULTS

Of the 3851 selected people, 3314 people participated in the study. Of these, 2681 met the inclusion criteria, and 9 of them had missing keratometry data. Finally, analyses were done using data from 2672 subjects whose mean age was 36.30 ± 18.51 years (range, 6–90 years), and 1553 (58.1%) of them were female.

Table 1 presents the mean steep-k, flat-k, and mean-K values. Average mean-K in the present population was 43.48 (95% CI: 43.41–43.56) D. Figure 1 shows the keratometry distribution in this population, and Table 2 provides the percentiles for mean-K as well as kurtosis and skewness indices. Ninety-five and 99 percentiles of mean-K of the sample in this study was 45.82 D and 46.91 D, respectively.

As presented in Table 1, average mean-K was higher in females, and they had significantly steeper corneas ($P < 0.001$). Mean-K was lowest in the 6–20 age group, increased linearly up to the age of 70 years, and the cornea slightly flattened afterwards. As seen in Figure 2, corneal flattening occurred only in women after the age of 70.

Mean mean-K was 43.39 D in cases of emmetropia, 43.63 D in myopic individuals, and 43.58 D in hyperopics. Mean-K was higher in myopic individuals than hyperopic and emmetropic ones. The highest mean mean-K was observed in myopic people ($P < 0.001$).

The relationship of mean-K with age, gender, central corneal thickness, anterior chamber depth, pupil diameter, and spherical equivalent refraction was investigated in simple linear regression models. As presented in Table 3, all variables had statistically significant associations with mean-K except spherical equivalent. However, as shown in the Table 3, the multiple linear regression model indicated that only older age and female gender had a direct and statistically significant correlation with keratometry.

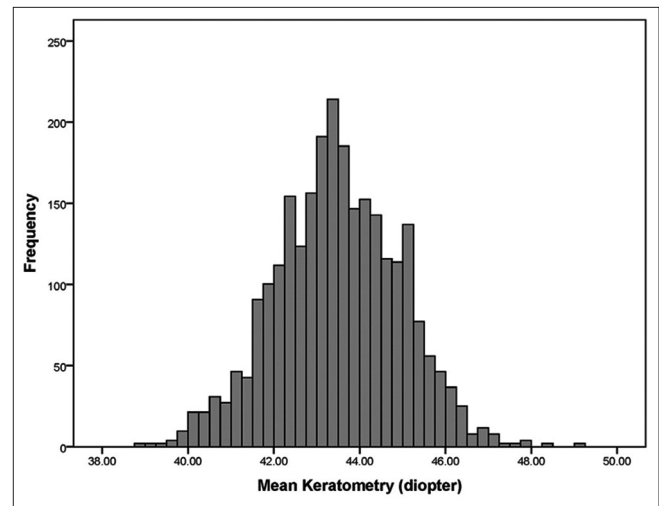


Figure 1: The distribution of mean keratometry (mean-K) in a wide age range of 6–90 years

Table 1: Mean and 95% confidence interval of keratometry and corneal astigmatism in rural population according age and gender and refractive errors

	n	Mean (95% CI)			
		Flat keratometry	Steep keratometry	Mean-K	Corneal astigmatism
Total	2672	42.98 (42.90-43.06)	43.99 (43.91-44.07)	43.48 (43.41-43.56)	1.01 (0.96-1.07)
Gender					
Female	1553	43.28 (43.18-43.38)	44.33 (44.22-44.43)	43.80 (43.70-43.90)	1.05 (0.97-1.12)
Male	1119	42.56 (42.44-42.69)	43.53 (43.41-43.65)	43.05 (42.93-43.16)	0.96 (0.88-1.05)
Age					
6-20	676	42.74 (42.61-42.88)	43.72 (43.58-43.87)	43.23 (43.1-43.370)	0.98 (0.90-1.06)
21-30	446	42.86 (42.67-43.06)	43.87 (43.67-44.08)	43.37 (43.18-43.56)	1.01 (0.87-1.14)
31-40	454	42.98 (42.78-43.18)	44.05 (43.86-44.24)	43.52 (43.33-43.70)	1.07 (0.95-1.19)
41-50	430	43.14 (42.91-43.37)	44.12 (43.91-44.34)	43.63 (43.43-43.84)	0.98 (0.83-1.13)
51-60	406	43.19 (42.97-43.41)	44.10 (43.88-44.32)	43.64 (43.44-43.85)	0.91 (0.75-1.08)
61-70	160	43.43 (43.07-43.79)	44.51 (44.11-44.92)	43.97 (43.62-44.33)	1.08 (0.82-1.35)
>70	99	43.10 (42.57-43.63)	44.56 (44.04-45.08)	43.83 (43.37-44.30)	1.46 (0.97-1.94)
Refractive errors					
Emmetropia	1331	42.95 (42.84-43.06)	43.83 (43.72-43.94)	43.39 (43.29-43.49)	0.88 (0.82-0.95)
Myopia	691	43.01 (42.86-43.17)	44.24 (44.07-44.41)	43.63 (43.47-43.78)	1.22 (1.12-1.33)
Hyperopia	581	43.05 (42.84-43.25)	44.11 (43.92-44.29)	43.58 (43.40-43.75)	1.06 (0.90-1.22)

Mean-K: Mean keratometry, CI: Confidence interval

Mean corneal astigmatism in this study was 1.01 D (95% CI: 0.96–1.07), and there was no significant inter-gender difference in terms of keratometry ($P = 0.138$). Changes in corneal astigmatism were also independent of age ($P = 0.194$). In this study, 31.62% (95% CI: 29.14–34.09) of participants had at least 1.0 D of corneal astigmatism.

Considering the subjects with at least 1 D corneal astigmatism, 27.1% of the participants of this study had WTR, 2.3% had ATR, and 1.5% had OBL corneal astigmatism. The prevalence of WTR, ATR, and OBL corneal astigmatism was

29.7%, 2.1%, and 1.7% in women and 23.2%, 2.6%, and 1.2% in men, respectively. The prevalence of WTR corneal astigmatism was significantly higher in women ($P = 0.002$). Table 3 presents the prevalence of different types of corneal astigmatism in different age groups. According to Table 3, the prevalence of WTR astigmatism decreased from 34.5% in the age group 6–20 years to 17.6% in subjects over 70 years. On the other hand, the prevalence of ATR astigmatism increased from 0.9% in the age group 6–20 years to 14.1% in subjects over 70 years [Figure 3].

Table 2: The percentiles, Skewness and Kurtosis of keratometry in this study.

	Percentiles					Normal distribution indices	
	25%	50%	75%	95%	99%	Skewness	Kurtosis
Total	42.47	43.47	44.50	45.82	46.91	0.004	0.049
Gender							
Female	42.91	43.78	44.82	46.08	47.00	-0.130	-0.054
Male	42.13	43.02	43.92	45.33	46.22	0.187	0.657
Age							
6-20	42.33	43.28	44.09	45.33	45.81	-0.038	-0.195
21-30	42.46	43.33	44.18	45.73	46.91	0.330	1.506
31-40	42.48	43.52	44.47	45.83	46.22	-0.305	-0.224
41-50	42.59	43.64	44.82	46.15	46.55	-0.218	-0.374
51-60	42.56	43.52	44.77	46.01	47.04	0.001	-0.338
61-70	42.98	44.11	45.08	46.69	47.98	-0.147	-0.266
>70	42.92	43.64	44.84	46.31	47.77	-0.017	0.159

Table 3: Simple and multiple linear regression analysis of the associations between mean keratometry and some variables studied.

	Simple linear regression		Multiple linear regression	
	Coefficient (95%CI)	P	Coefficient (95%CI)	P
Age (year)	0.010 (0.006-0.015)	<0.001	0.010 (0.006-0.014)	<0.001
Gender (male/female)	-0.758 (-0.909 to -0.607)	<0.001	-0.753 (-0.902 to -0.603)	<0.001
CCT (micron)	-0.003 (-0.005 to -0.001)	0.008		
ACD (mm)	-0.298 (-0.496 to -0.100)	0.003		
PD (mm)	-0.135 (-0.234 to -0.037)	0.007		
SE (D)	-0.043 (-0.094 to 0.008)	<0.001		

CCT: Central corneal thickness, ACD: Anterior chamber depth, PD: Pupil diameter, SE: Spherical equivalent, D: Diopter.

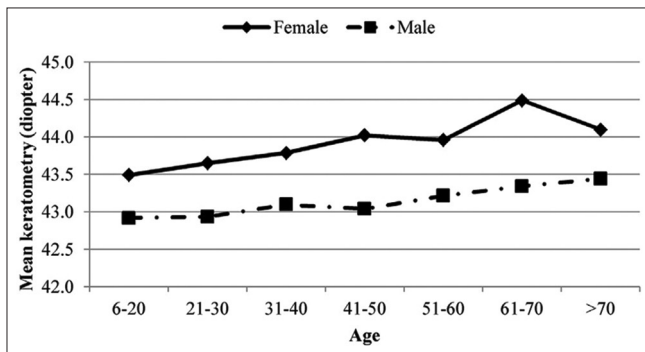


Figure 2: The distribution of mean keratometry (mean-K) by age according to gender

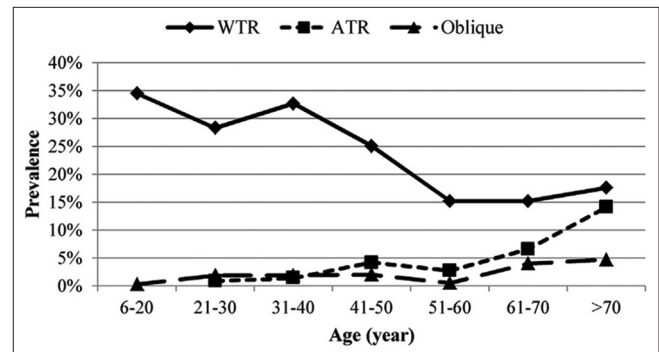


Figure 3: The prevalence of the different types of corneal astigmatism (with-the-rule [WTR]; against-the-rule [ATR]; Oblique [OBL]) by age

DISCUSSION

Knowledge of normal values and changes in the corneal curvature in all ages is not only helpful for the management of refractive errors but also the diagnosis of pathologic conditions such as keratoconus.² With aging, ocular structures such as the corneal curvature are affected, but given the overall changes in ocular components in different ages, it should be determined whether they can lead to abnormal eye conditions.

The mean-K in this study was 43.48 D. Table 1 shows keratometry values in each age group in our study. To compare keratometry values with other Iranian populations, we can refer to the Tehran Eye Study and the Shahroud Eye Cohort Study. In the Tehran Eye Study, mean-K in the 14- to 81-year-old population was 44.39 D in the right eye.¹⁶ This study did not include children. In the Shahroud Eye Cohort Study, the mean in the 40- to 64-year-old population was 43.73 D.¹² The Shahroud Study was limited to the adult age range, and in our study, mean-K was 43.60 D in the same age range, which is a similar result. In our study, this was 43.23 D in children and 43.66 D in adults which indicate similar results for corresponding age ranges. In a 19- to 84-year-old Canadian population, mean-K was 43.85 D.¹⁷ In our study, mean-K was 43.66 D in this age range.

Assessment of age-related changes of keratometry in our study showed that mean-K was lowest in the 6- to 20-year-age group and increased linearly up to the age of 70 years. The Tehran Eye and Shahroud studies reported a direct relationship between age and mean-K.^{12,16} These studies were conducted using Pentacam, and the results were in line with ours. Increased corneal curvature with age was also observed in Richdale's study in 2016. Their study was performed on the right eyes of 91 people between the ages of 30 and 50 years.¹⁸ An age-related increase in corneal curvature was also reported by Lee *et al.* in a study of 314 normal eyes in a 19- to 82-year-old sample.¹⁹ These results were in agreement with our study as well. The direct relation between age and keratometry are confirmed by other studies, too.^{18,19} Overall, there is strong evidence showing increased corneal power with age, which is more noticeable in this study due to the wide sample age range of 5–90 years. Age-related changes in the corneal surface are also related to genetic and environmental conditions such as association with free radicals and, thus, changes in the corneal structure. For example, aging is associated with decreased space between stromal collagen fibrils, while collagen bundles become thicker. These structural changes may affect the elasticity and rigidity of the cornea. The stroma becomes stiffer. These changes can have an impact on corneal curvature and astigmatism.^{20,21} According to Hayashi, increased corneal curvature with age is related to physiological changes in corneal biomechanics that occur with aging.²²

In this study, corneal astigmatism showed no significant change with age ($P = 0.194$). This was expected because both steep-k and flat-k directly increased with age. In a study of 3841 individuals between the ages of 5 and 90 years, corneal astigmatism was reported to be relatively constant

from childhood to the age of 80 years, and an increase was observed afterwards. Overall, corneal astigmatism and age had no significant relation, and they suggested that environment and genetics influenced changes in astigmatism.²³ In another study where corneal astigmatism was classified by type, they observed increased ATR astigmatism and reduced WTR astigmatism, and these changes were attributed to age-related anatomical changes in the eyelids and corneal structure.²²

Another finding of this study was the relation between gender and keratometry values. Females had significantly steeper corneas ($P < 0.001$). According to Table 1, mean-K was 43.80 D in females and 43.05 D in males. In terms of changes in the mean-K, as mentioned, there was a linear increase up to the age of 70 years, but the cornea flattened after that age only in women. Certain studies have mentioned the inter-gender differences in the anterior segment of the eye and the axial length. Currently available literature indicates that the cornea is steeper in women.^{13,24-26} The reason for such inter-gender keratometric and ocular structural differences is not well known. Part of these differences can be due to anatomical differences such as differences in eyelid structure and physiological differences in two genders, especially hormonal changes with age in women.²⁴

In the present study, we examined keratometry values by refractive errors. Some studies have reported that myopic cases have a smaller corneal radius of curvature and thus a higher corneal power, which is consistent with our study.^{18,27} It should be noted that some studies suggest corneal curvature has a poor role in the development of myopia and that axial length has a stronger influence. Therefore, higher amounts of myopia were not necessarily associated with increased curvature in all studies. Increased curvature is seen in curvatural myopia, while the cornea can remain unchanged in the axial type. During ocular development in childhood, these changes are in sync with the emmetropization process.^{28,29}

The findings of our study point to the need for more extensive studies to compare the results in wide age ranges. We also propose studies on differences and changes in corneal properties as an influence of age and gender, as well as hormonal and anatomical conditions. This study provides valuable information of keratometry values in a wide age range from childhood to old age and its relation to age, gender, and refractive errors. Keratometry values change with age. In the present study, higher values were observed in females and myopic individuals.

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Conflicts of interest

There are no conflicts of interest.

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