• Investigation •

Corneal diameter distribution and its determinant factors in elderly population: Tehran Geriatric Eye Study

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Received: 2025-12-03 Accepted: 2026-03-18

Abstract

● **AIM:** To determine the distribution and normative range of corneal diameter in individuals aged over 60, and its association with demographic variables, certain comorbidities, anthropometric measurements, additional ocular biometric indices, and refractive errors.

● **METHODS:** This population-based cross-sectional study involved participants aged over 60 residing in Tehran, selected by a multi-stage cluster random sampling. Following the acquisition of informed consent, comprehensive ophthalmological and optometric evaluations, including slit lamp examination, visual acuity assessment, and refraction, were conducted. Ocular biometric parameters, including corneal diameter, were assessed using the Pentacam AXL.

● **RESULTS:** A total of 4596 eyes (2292 right eyes and 2304 left eyes) from 2414 older individuals were examined. The mean age with 95% confidence interval (CI) of the study participants was 66.74y (66.51–66.97y), with 58.68% identifying as female. The corneal diameter in the older population had a normal distribution, with a mean of 11.82 mm (95%CI: 11.80–11.84), and a normal range of 11.02–12.62 mm. According to the results of multiple linear regression, a deeper anterior chamber (b=0.30, P<0.001), a university education level (b=0.08, P=0.001), and hyperopia (b=0.04, P=0.005) exhibited a positive correlation with corneal diameter, whereas female gender (b=-0.05, P<0.001), a thicker cornea (b=-0.01, P<0.001), a higher mean keratometry (b=-0.09, P<0.001), and astigmatism (b=-0.03, P=0.013) demonstrated an inverse correlation with corneal diameter. The corneal power was the most important factor that influencing corneal diameter. Nonetheless, the variables of myopia, axial length, diabetes, blood pressure, body mass index (BMI), economic situation, and age exhibited no significant association with corneal diameter.

● **CONCLUSION:** The corneal diameter range measured by Pentacam AXL in the elderly population is greater than certain prior studies and lesser than others. The findings serve as a reference for clinicians assessing corneal diameter in the elderly for clinical application.

● **KEYWORDS:** corneal diameter; white to white; elderly; Pentacam AXL

DOI:10.18240/ijo.2026.11.15

Citation: Lavaei N, Hashemi H, Ahmad MA, Yekta A, Pakzad R, Shiri Malekabadi E, Jamali A, Khabazkhoob M. Corneal diameter distribution and its determinant factors in elderly population: Tehran Geriatric Eye Study. *Int J Ophthalmol* 2026;19(11):2223-2233

INTRODUCTION

The cornea is responsible for over 70% of the eye's total refractive power; therefore, evaluating its dimensions, such as corneal diameter, is of great clinical and epidemiological importance[1]. Accurately determining corneal diameter in clinical settings is important for diagnosing specific conditions, such as microcornea[2], and megalocornea[3]. It is utilized to determine the appropriate size of intraocular lenses

(IOLs), including anterior chamber phakic lenses[4], and to anticipate the correct size of the capsular tension ring (CTR)[5]. Furthermore, corneal dimensions, including diameter, should be considered when assessing patients prior to cataract surgery, as recent advancements have introduced new formulas for calculating IOL power to enhance the precision of refraction prediction, some of which incorporate the corneal diameter parameter[6]. Consequently, attaining a satisfactory outcome and enhancing visual quality post-cataract surgery depends on this parameter[7].

A variety of instruments exist for measuring corneal diameter, including the IOL Master, Orbscan II, Pentacam, LenStar, and optical coherence tomography (OCT)[8]. Despite extensive research, a consensus on the precise normal values for corneal diameter remains, with studies indicating a broad spectrum of normal values[9-10]. This controversy arises from varying definitions of corneal diameter, as multiple reference points at the limbus are utilized to determine the horizontal diameter of the cornea. The disparity is also affected by the measuring instrument employed; within a constant population, the corneal diameter measured by Pentacam varies by over 0.2 mm from that obtained with the IOL Master[11], while the IOL Master shows a discrepancy over 0.6 mm when compared to the Orbscan II[12]. Furthermore, research indicates that ethnicity and race influence normative corneal diameter values[13-14]. For instance, the corneal diameter in Nigeria is estimated at 11.39±0.69 mm[15], while in Iranians aged 40 to 64, it is 11.80±0.50 mm[16], and in Chinese individuals aged 18 to 40, it is 12.00±0.38 mm[17]. Consequently, to identify anomalies within each population, the standard normal sizes of that population must be utilized; thus, comprehending the distribution of any ocular biometry parameter and recognizing its normative range in each population is critical[18].

Besides the measurement instrument and race, the age distribution of the study population is another factor contributing to variations in corneal diameter distribution[19]. The majority of studies have focused on corneal diameter in children, adolescents, or middle-aged adults[16-17,20-22], but few have examined the distribution and normative range of corneal diameter in the elderly population. Given that age is one of the important factors that affects the balance of ocular biometric parameters[23] and that the incidence of refractive errors, particularly myopia, is elevated in the elderly compared to other age groups[24], a precise understanding of corneal diameter distribution in this population and its association with refractive errors and other ocular biometrics is of great importance. However, despite its significance, this topic has been explored in only a limited number of studies, resulting in ongoing ambiguity[25].

This study aimed to assess the distribution and normal range of corneal diameter in individuals over 60 years of age, utilizing Pentacam AXL. It also sought to investigate the association between corneal diameter and refractive errors, alongside various ocular and non-ocular parameters, employing a population-based cross-sectional approach in Tehran's elderly population.

PARTICIPANTS AND METHODS

Ethical Approval Informed consent was obtained from all participants. The principles of the Declaration of Helsinki were followed at all stages of this study. The study protocol was approved by the Ethics Committee of the National Institute for Medical Research Development (NIMAD), under the auspices of the Iranian Ministry of Health (Ethics code: IR.NIMAD.REC.1397.292).

Study Design and Sampling This study was a part of the Tehran Geriatric Eye Study (TGES)[26-28]. The TGES is a population-based cross-sectional study conducted in 2019 with individuals aged 60 and above residing in Tehran. Sampling was performed *via* a multi-stage cluster random sampling technique. The 22 districts of Tehran municipality were designated as a single stratum. A blocked map of each district was subsequently prepared, with each block regarded as a distinct cluster. A total of 160 clusters were randomly chosen from 22 strata (distincts), ensuring that the number of clusters in each district was proportional to its population, with a sample size of 20 individuals per cluster. After identifying each cluster, a sampling team was dispatched to the corresponding address, and then located on the southwest side of the selected cluster. The initial house was designated as the cluster head. The sample moved subsequently proceeded counterclockwise, selecting further residences and invited all participants aged 60 and above to participate in the study after explaining the study aims and assuring confidentiality. The sampling process continued until the required sample size was reached in each cluster. The participants were thereafter transported to Noor Eye Hospital for evaluations on a scheduled day.

Eligibility Criteria The eligibility criteria for this study encompassed individuals aged over 60, who lived in Tehran, and consenting to participate. The exclusion criteria for this study were individuals with a history of eye surgeries for refractive errors, glaucoma, or cataracts; corneal abnormalities; any deviation or strabismus; the use of topical eye medications; and the use of contact lenses during the study period.

Variables Measurement

Demographic and other related variables Demographic data of the participants including the age, gender, and educational level were obtained through face-to-face interviews. Furthermore, to assess the economic status, data

on 15 household assets were gathered. Subsequently, principal component analysis (PCA) was employed to generate wealth index variable. Then, participants were categorized into three classifications: high, medium, and low economic status, based on the 33rd and 66th percentiles. Subsequently, height was measured with a stadiometer and weight was assessed with a digital scale, followed by the calculation of body mass index (BMI). Blood pressure was assessed using a digital sphygmomanometer, with systolic pressure ≥135 mm Hg or diastolic pressure ≥85 mm Hg classified as hypertension. Diabetes mellitus was characterized by a prior diagnosis or a hemoglobin A1c level of >6.5% in blood samples obtained.

Ocular variables Ophthalmological assessments comprised visual acuity evaluation with a light-emitting diode (LED) visual chart, Smart LC 13 (Medizs Inc. Korea) at a distance of 6 m, and refraction conducted with an Auto-refractometer/keratometer, ARK-510A (Nidek Co. LTD, Aichi, Japan). Comprehensive ophthalmological evaluations were conducted utilizing the Slit Lamp B900 (Haag-Streit AG, Bern, Switzerland). Ocular biometry and assessment of several eye parameters, including corneal diameter (mm), axial length (mm), anterior chamber depth (mm), central corneal thickness (μm), and flat (Kf) and steep (Ks) keratometry (D), were conducted using the Pentacam AXL (Oculus Optikgeräte GmbH, Wetzlar, Germany). The corneal diameter, or white-to-white (WTW) corneal diameter, refers to the distance from limbus to limbus along the horizontal axis. The mean corneal power (mean keratometry) was computed using the average of the Ks and Kf measurements. This study utilized spherical equivalent (SE) derived from auto refraction to define refractive errors. Myopia is characterized by an SE of less than -0.50 D, hyperopia by an SE more than +0.50 D, and emmetropia by a SE ranging from -0.50 to +0.50 D. Corneal astigmatism was determined by the disparity between Ks and Kf readings; a discrepancy beyond 0.50 D was classified as astigmatism. To avoid the potential impact of the tear film on Pentacam AXL imaging, participants were asked to blink fully once prior to imaging. Only measurements that indicated "OK" in the scan quality (QS) criteria box were considered valid.

Statistical Analysis The mean standard deviation (SD) and 95% confidence interval (CI) were employed to describe quantitative data, whereas the percentage and 95%CI were utilized to describe qualitative factors. The histogram, together with skewness and kurtosis indices, was employed to examine the distribution of corneal diameter. Simple and multiple linear regression analyses were employed to investigate the variables associated with corneal diameter. Initially, univariate linear regression was established for each variable under investigation, after which those variables with a *P*-value below 0.2 were incorporated into the multiple linear regression model. A reduced model was ultimately constructed using a backward method, incorporating only the significant variables. Standardized coefficients were used in the multiple linear regression model to determine the relative importance of significant variables. To describe the research variables, data from the right eye was utilized exclusively, while the regression model incorporated data from both eyes, corrected for intra-person correlation. The cluster sampling strategy was taken into account in the implementation of the regression model. All analyses were conducted by a single-blinded observer utilizing StataMP version 14, with a significance threshold set at 5%.

RESULTS

Out of 3791 persons invited to participate in the study, 3310 participated, resulting in a response rate of 87.3%. Following applying the exclusion criteria, 2414 participants were retained in the study, resulting in the analysis of 4596 eyes, comprising 2292 right eyes and 2304 left eyes. The mean age with 95%CI of the study participants was 66.74y (66.51 to 66.97), with 58.68% identifying as female. The mean of corneal diameter of the study participants was 11.82 mm (95%CI: 11.80 to 11.84), with a median of 11.80 mm. The mean of corneal diameter for women was 11.78 mm (95%CI: 11.75 to 11.80), whereas for men it was 11.89 mm (95%CI: 11.87 to 11.92). The mean axial length was 23.22 mm, the mean corneal power was 44.65 D, the anterior chamber depth was 3.00 mm, and the central corneal thickness was 525.10 μm. Myopia was identified in 20.83% of participants, hyperopia in 49.09%, while astigmatism was diagnosed in 62.62%. The mean of SE across all participants was +0.38 D (95%CI: +0.30 to +0.46), in myopic individuals -2.08 D (95%CI: -2.27 to -1.90), and in hyperopic individuals +1.08 D (95%CI: +1.04 to +1.12). Table 1 illustrates the distribution of additional demographic factors among the study participants.

Figure 1 illustrates the distribution of corneal diameter values, including the normal curve and range, in total, as well as categorized by gender. The normal corneal diameter range (mean±2SD) in the total population was 11.02–12.62 mm; thus, corneas beyond 12.62 mm are classified as macrocornea, while those below 11.02 mm are classified as microcornea for this population.

Table 2 shows the mean corneal diameter (95%CI) stratified by demographic variables. As shown in the table, there was a significant difference in the mean corneal diameter across different age groups (P=0.038), such that the mean corneal diameter in individuals aged 60–64y and those older than 80y was 11.85 mm (11.83–11.88) and 11.77 mm (11.69–11.84), respectively. In addition, the mean corneal diameter (95%CI) in males, 11.89 mm (11.87–11.92), was higher than that in females, 11.78 mm (11.75–11.80; P<0.001). Although the

Table 1 Distribution of demographic and eye-related variables in the participants

Variables	Effect size (95%CI)
Age (%), y	
60–64	42.71 (40.70 to 44.75)
65–69	30.93 (29.07 to 32.85)
70–74	16.57 (15.11 to 18.15)
75–79	6.54 (5.60 to 7.63)
≥80	3.22 (2.57 to 4.03)
Sex (%)	
Male	41.31 (39.31 to 43.34)
Female	58.68 (56.65 to 60.68)
Education (%)	
Illiterate	11.83 (10.57 to13.22)
Primary school	28.68 (26.87 to 30.57)
Guidance school	17.81 (16.30 to 19.43)
High school	27.81 (26.01 to 29.68)
College	13.84 (12.48 to 15.31)
Economic status (%)	
Low	30.54 (28.68 to 32.45)
Middle	32.67 (30.78 to 34.62)
High	36.78 (34.82 to 38.77)
Diabetes (%)	
Yes	26.57 (24.80 to 28.41)
No	73.42 (71.58 to 75.19)
Hypertension (%)	
Yes	76.52 (74.74 to 78.21)
No	23.47 (21.78 to 25.25)
Refractive errors[a] (%)	
Emmetropia	30.07 (28.21 to 31.99)
Myopia	20.83 (19.20 to 22.55)
Hyperopia	49.09 (47.03 to 51.15)
Astigmatism	
Yes	62.62 (60.61 to 64.59)
No	37.37 (35.40 to 39.38)
WTW corneal diameter (mm), mean	11.82 (11.80 to 11.84)
AL (mm), mean	23.22 (23.18 to 23.26)
Mean-K (D), mean	44.65 (44.58 to 44.72)
ACD (mm), mean	3.00 (2.98 to 3.01)
CCT (μm), mean	525.10 (523.67 to 526.53)
BMI (kg/m^2), mean	28.79 (28.60 to 28.98)
Corneal volume (mm^3), mean	58.13 (57.98 to 58.29)
Pupil diameter (mm), mean	
Overall	3.63 (3.57 to 3.69)
Myopia	3.68 (3.55 to 3.81)
Hyperopia	3.65 (3.56 to 3.74)

[a]Refractive errors are only myopia and hyperopia. CI: Confidence interval; WTW: White to white; AL: Axial length; Mean-K: Mean keratometry; ACD: Anterior chamber depth; CCT: Central corneal thickness; BMI: Body mass index.

Table 2 Distribution of corneal diameter based on study variables in the participants

Variables	Mean (95%CI)	*P*
Age, y		0.038
60–64	11.85 (11.83 to 11.88)	
65–69	11.82 (11.79 to 11.85)	
70–74	11.80 (11.76 to 11.84)	
75–79	11.77 (11.71 to 11.83)	
≥80	11.77 (11.69 to 11.84)	
Sex		<0.001
Male	11.89 (11.87 to 11.92)	
Female	11.78 (11.75 to 11.80)	
Education		<0.001
Illiterate	11.72 (11.67 to 11.77)	
Primary school	11.78 (11.74 to 11.81)	
Guidance school	11.86 (11.82 to 11.90)	
High school	11.86 (11.83 to 11.89)	
College	11.88 (11.84 to 11.92)	
Diabetes		0.316
No	11.83 (11.81 to 11.85)	
Yes	11.81 (11.78 to 11.84)	
Hypertension		0.003
No	11.87 (11.84 to 11.90)	
Yes	11.81 (11.79 to 11.83)	
Economic status		<0.001
Low	11.76 (11.73 to 11.79)	
Middle	11.84 (11.81 to 11.87)	
High	11.86 (11.84 to 11.89)	
Refractive errors[a]		0.019
Emmetropia	11.80 (11.77 to 11.83)	
Myopia	11.79 (11.76 to 11.83)	
Hyperopia	11.84 (11.82 to 11.87)	
Astigmatism		<0.001
No	11.86 (11.84 to 11.89)	
Yes	11.79 (11.77 to 11.82)	

[a]Refractive errors are only myopia and hyperopia. CI: Confidence interval.

mean corneal diameter did not differ between individuals with and without diabetes (P=0.316), the corneal diameter in the hypertension group was lower than that in individuals without hypertension (P=0.003). There were significant differences in the mean corneal diameter according to education level (P<0.001), economic status (P<0.001), and astigmatism (P<0.001). Further details are presented in Table 2.

Table 3 indicates that, with the exception of the diabetes variable, which lacked significance at the 0.2 level in the univariate linear regression, all other variables (age, gender, education level, economic status, blood pressure, BMI, axial length, mean corneal power, anterior chamber depth, central corneal thickness, refractive errors, and astigmatism)

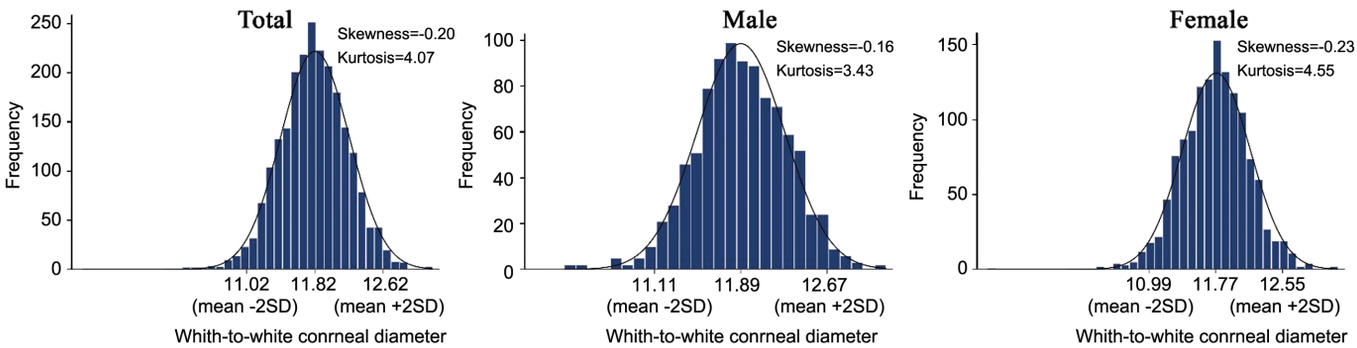


Figure 1 Corneal diameter distribution in the total study population and separated by gender in Tehran Geriatric Eye Study (TGES) SD: Standard deviation.

were included in the full multiple linear regression model. However, in the reduced model, only significant variables were incorporated into the multiple linear regression model. Therefore, the outcomes of both the full and reduced multiple models are explained herein. The R^2 values for the full and reduced multiple models were 29.6% and 29.4%, respectively, signifying that 29% of the variance in corneal diameter can be elucidated by the model variables.

The findings indicated that whereas older people had smaller corneal diameters in the simple model, this correlation was not statistically significant in the full model (P>0.05). Women had smaller ocular diameters compared to men (coefficient in full model=-0.05, P<0.001). Moreover, when educational attainment rises, the average corneal diameter expands. The average ocular diameter of those with a university degree was 0.08 mm greater than that of illiterate individuals (coefficient in full model=0.08, P=0.001). A direct and substantial correlation was identified between corneal diameter with anterior chamber depth (coefficient in full model=0.30, P<0.001); and pupil diameter (coefficient in full model=0.02, P<0.001); conversely, corneal power (coefficient in full model=-0.09, P<0.001), central corneal thickness (coefficient in full model=-0.01, P<0.001) and corneal volume (coefficient in full model=-0.01, P<0.001) exhibited an inverse correlation with corneal diameter.

Myopic people exhibited a smaller corneal diameter compared to emmetropic individuals; nevertheless, this difference lacked statistical significance (coefficient in full model=-0.01, P=0.799). Furthermore, hyperopic individuals had a greater corneal diameter than emmetropic persons, a finding that was statistically significant (coefficient in full model=0.04, P=0.005). Astigmatic people had a smaller corneal diameter compared to non-astigmatic individuals, a finding that was statistically significant (coefficient in full model=-0.03, P=0.013). No substantial correlation was seen among the variables of economic status, blood pressure, BMI, and axial length of the eye with corneal diameter in the multiple model (P>0.05). Corneal power emerged as the most significant predictor of corneal diameter (standardized beta: -0.41).

DISCUSSION

Using a revolving Scheimpflug camera, the Pentacam AXL is a new generation technology that measures the axial length of the eye and offers detailed images and numerous parameters of the anterior segment of the eye[29-30]. This device has great consistency and accuracy in monitoring ocular biometric parameters[31-32].

The clinical relevance of accurate corneal diameter measurement has gained renewed importance with the advent of fourth- and fifth-generation IOL power calculation formulas that incorporate anterior segment biometry to refine effective lens position (ELP) estimation[33]. For example, the Olsen formula, which employs optical ray tracing, explicitly incorporates WTW corneal diameter, along with anterior chamber depth and lens thickness, to personalize ELP prediction[34]. Beyond formula inputs, precise WTW measurements remain indispensable for selecting appropriate sizes of CTR in zonular instability and for sizing phakic IOLs in pseudophakic patients requiring secondary lens implantation[35]. Establishing population-specific normative WTW values, therefore, supports not only formula optimization but also surgical planning precision, ultimately contributing to reduced refractive surprises and enhanced visual outcomes in elderly cataract surgery candidates.

Before interpreting the results, it should be noted that due to the cross-sectional study design, the observed associations cannot be interpreted causally; therefore, the results should be interpreted with caution. However, based on the study's findings, the corneal diameter had a mean of 11.82 mm and a normal range of 11.02 mm to 12.62 mm, indicating a normal distribution. According to previous research, the average corneal diameter was found to be 12.00 mm in Chinese childern by IOL Master[17], 11.65 mm in young Chinese adults by Pentacam[22], 11.68 mm in middle-aged Iranians by Orbscan II[21], and 11.39 mm in middle-aged Nigerians by millimeter ruler[15]. Since certain research have found that ocular parameters, such as corneal diameter, differ by race and ethnicity, the first explanation for these differences

Table 3 Univariate and multiple linear regression analyses of associations between corneal diameter and study variables

Variables	Univariate linear regression model			Multiple linear regression model			
				Full model		Reduced model	
	Coefficient (95%CI)	*P*	R^2	Coefficient (95%CI)	*P*	Coefficient (95%CI)	*P*
Age (y)							
60–64	Reference	–	0.01	Reference	–	–	–
65–69	-0.04 (-0.09 to -0.01)	0.032		-0.02 (-0.05 to 0.01)	0.087		
70–74	-0.06 (-0.12 to -0.02)	0.008		-0.02 (-0.05 to 0.01)	0.232		
75–79	-0.11 (-0.18 to -0.04)	0.002		-0.02 (-0.07 to 0.02)	0.300		
≥80	-0.12 (-0.21 to -0.04)	0.003		-0.08 (-0.15 to 0.01)	0.122		
Sex							
Male	Reference	–	0.02	Reference	–	Reference	–
Female	-0.13 (-0.16 to -0.10)	<0.001		-0.05 (-0.07 to -0.03)	<0.001	-0.05 (-0.07 to -0.03)	<0.001
Education							
Illiterate	Reference	–	0.02	Reference	–	Reference	–
Primary school	0.06 (0.01 to 0.12)	0.038[a]		0.05 (0.01 to 0.08)	0.025	0.05 (0.01 to 0.09)	0.012
Guidance school	0.15 (0.09 to 0.22)	<0.001		0.08 (0.04 to 0.13)	<0.001	0.09 (0.05 to 0.14)	<0.001
High school	0.15 (0.09 to 0.21)	<0.001		0.05 (0.01 to 0.10)	0.016	0.06 (0.02 to 0.10)	0.004
College	0.16 (0.09 to 0.23)	<0.001		0.08 (0.03 to 0.14)	0.001	0.08 (0.04 to 0.13)	<0.001
Economic status							
Low	Reference	–	0.01	Reference	–	–	–
Middle	0.07 (0.03 to 0.12)	0.001		0.01 (-0.02 to 0.04)	0.447		
High	0.09 (0.05 to 0.14)	<0.001		-0.01 (-0.04 to 0.02)	0.466		
Diabetes							
No	Reference	–	0.001	–	–	–	–
Yes	-0.01 (-0.05 to 0.03)	0.507					
Hypertension							
No	Reference	–	0.004	Reference	–	–	–
Yes	-0.05 (-0.10 to -0.02)	0.004		-0.01 (-0.03 to 0.02)	0.464		
BMI (kg/m^2)	-0.01 (-0.01 to 0.01)	0.197	0.001	0.01 (-0.01 to 0.01)	0.801		
AL (mm)	0.13 (0.09 to 0.17)	<0.001	0.12	0.01 (-0.01 to 0.02)	0.613		
Mean-K (D)	-0.10 (-0.11 to -0.09)	<0.001	0.18	-0.09 (-0.10 to -0.08)	<0.001	-0.09 (-0.10 to -0.08)	<0.001
ACD (mm)	0.35 (0.30 to 0.41)	<0.001	0.09	0.30 (0.24 to 0.36)	<0.001	0.31 (0.26 to 0.36)	<0.001
CCT (μm)	-0.01 (-0.01 to -0.01)	0.027	0.003	-0.01 (-0.01 to -0.01)	<0.001	-0.01 (-0.01 to -0.01)	<0.001
Refractive errors[a]							
Emmetropia	Reference	–	0.004	Reference	–	Reference	–
Myopia	-0.02 (-0.07 to 0.03)	0.547		-0.01 (-0.04 to 0.03)	0.799	-0.01 (-0.04 to 0.03)	0.736
Hyperopia	0.04 (0.01 to 0.08)	0.035		0.04 (0.01 to 0.06)	0.005	0.03 (0.01 to 0.06)	0.009
Astigmatism							
No	Reference	–	0.008	Reference	–	Reference	–
Yes	-0.07 (-0.11 to -0.04)	<0.001		-0.03 (-0.05 to -0.01)	0.013	-0.03 (-0.06 to -0.01)	0.004
Pupil diameter (mm)	0.03 (0.02 to 0.04)	<0.001	0.010	0.02 (0.01 to 0.03)	<0.001	0.02 (0.01 to 0.03)	<0.001
Corneal volume (mm^3)	-0.02 (-0.03 to -0.01)	<0.001	0.037	-0.01 (-0.02 to -0.01)	<0.001	-0.01 (-0.06 to -0.01)	0.004

Variables with *P*<0.05 in the univariate linear regression model were included in the multiple linear regression model. R^2=0.296 in full model of multiple linear regression; R^2=0.294 in Reduced model of multiple linear regression. The reduced model was developed by the backward approach on the full model. [a]Refractive errors are only myopia and hyperopia. BMI: Body mass index; AL: Axial length; Mean-K: Mean keratometry; ACD: Anterior chamber depth; CCT: Central corneal thickness; CI: Confidence interval.

can be attributed to ethnic-racial variances[13-14]. Second, the current study examined corneal diameter in individuals over 60 years of age, and differences between the aforementioned studies and the present study may be due to age differences. The third reason was differences in refractive error status across the cited studies; therefore, the prevalence of refractive

Table 4 Mean corneal diameter reported in other studies and their race/ethnicity, age and measurement device

Author	Year[a]	Sample size	Subjects	Race/ethnicity	Age (y)	Measurement device	Gender	Mean±SD	Normal range
Xu *et al*[22]	2021	7893 right eyes	Only myopic eyes	Chinese	18–40	Pentacam	M&F	11.65±0.38	10.91–12.39
Jiang *et al*[17]	2017	5970 right eyes	Overall	Chinese	4–18	IOL Master	M&F	12.00±0.38	11.25–12.75
Liao *et al*[37]	2020	103 right eyes	Overall	Chinese	15–35	IOL Master 700	M&F	12.01±0.40	NR
						OA-2000	M&F	11.87±0.53	NR
Iyamu and Osuobeni[15]	2012	130 right eyes	Overall	Africans (Nigerians)	20–79	Millimeter ruler	M	11.49±0.60	NR
							F	11.23±0.80	NR
							M&F	11.39±0.69	NR
Calvo-Sanz *et al*[11]	2022	42 right eyes	Only myopic eyes	Spanish	23–51	Pentacam	M&F	11.84±0.31	NR
						IOL Master	M&F	12.05±0.30	NR
						Cirrus OCT	M&F	11.88±0.65	NR
Buckenham Boyle *et al*[12]	2021	35 right eyes	Overall	New Zealander	18–25	Orbscan II	M&F	11.77±0.40	NR
						IOL Master 700	M&F	12.40±0.43	NR
						Galilei G2	M&F	12.25±0.42	NR
						DRI OCT Triton	M&F	12.42±0.47	NR
Gharaee *et al*[20]	2014	1001 right eyes	Overall	Iranians	18–45	Orbscan II	M	11.61±0.36	NR
							F	11.73±0.38	NR
							M&F	11.66±0.37	NR
Hashemi *et al*[21]	2010	399 right eyes	Overall	Iranians	14–81	Orbscan II	M	11.76±0.48	NR
							F	11.63±0.45	NR
							M&F	11.68±0.46	10.76–12.60
Hashemi *et al*[16]	2015	4787 right eyes	Overall	Iranians	40–64	LENSTAR/BioGraph	M	11.87	NR
							F	11.75	NR
							M&F	11.80±0.50	10.80–12.80
Jamali *et al*[19]	2021	818 eyes (right/left)	Candidates for cataract surgery	Iranians	>30	OA-2000	M	11.85±0.46	NR
							F	11.79±0.44	NR
							M&F	11.81±0.45	NR
Present study	2026	2292 right eyes	Overall	Iranians	>60	Pentacam AXL	M	11.89±0.39	11.11–12.67
							F	11.77±0.39	10.99–12.55
							M&F	11.82±0.40	11.02–12.62

[a]Year of publication. Overall include myopia, hyperopia, emmetropia, and astigmatism. M: Male; F: Female; NR: Not reported; SD: Standard deviation.

error in the present study differed from that reported in other studies[15,17,21-22]. But the fourth main cause of this disparity is the different instruments that were used[9]. As a result, a variety of normal ranges have been found in various studies.

Beyond instrumental differences, methodological heterogeneity in the anatomical definition of corneal diameter further contributes to discrepancies in reported normative values across studies. The term "corneal diameter" encompasses distinct measurement concepts that are often used interchangeably despite representing different anatomical landmarks. The true anatomical limbus, the transitional zone between corneal and scleral tissue, can be defined histologically by the termination of Bowman's layer or Descemet's membrane, but clinically, measurements typically rely on visible landmarks[36]. WTW diameter, the parameter assessed in the present study using the Pentacam AXL, represents the horizontal distance between the external scleral margins of the limbus. In contrast, some devices report values based on the anterior chamber angle or scleral spur visualization, which yields systematically smaller values[12]. Furthermore, slit-lamp-based manual measurements often approximate the corneal diameter by aligning calipers with the iris root or the inner limbal margin, introducing additional inter-observer variability[15]. These definitional inconsistencies can account for some differences in reported values even when the same population is examined.

The mean corneal diameter in some of similar studies is displayed in Table 4, along with the participants' age group, race/ethnicity, and measurement instrument[11-12,15-17,19-22,37]. Nevertheless, there are differences among the literature that demonstrate the influence of various factors on corneal diameter. The literature on the connection between age and corneal diameter is therefore seriously contradictory. In our study, the age and corneal diameter have an inverse association according to the simple linear regression model, but not according to the multiple linear regression model. This demonstrates that various confounding factors affect corneal diameter and that age alone cannot significantly affect it. The association between age and corneal diameter is also debatable in many literatures because Hashemi *et al*[21], who studied persons aged 14–81 and Jiang *et al*[17], who studied people aged 4–18, did not find a relationship between the two. Conversely, studies by Xu *et al*[22], Hashemi *et al*[16], Iyamu and

Osuobeni[15], and Jamali *et al*[19], who examined participants aged 18–40y, 40–64y, and 30y and older, respectively, demonstrated that the mean corneal diameter was lower in the elderly. Although the cause of this disparity is unclear, Iyamu and Osuobeni[15] suggested that the smaller corneal diameter in older subjects was due to their shorter height. This finding has also been linked by some research to a decline in corneal thickness with aging[38].

However, because the aforementioned studies are cross-sectional and, in contrast to longitudinal research, it was not feasible to investigate the link between corneal diameter and age over time, the findings should be interpreted cautiously. Therefore, rather of being directly related to age, the smaller corneal diameter in older participants might be the result of a cohort effect. In other words, certain situations may affect age groups differently. Therefore, some age groups may experience age-specific conditions or exhibit differing susceptibility to particular events or exposures. These effects can influence health outcomes among individuals within the affected cohort[39]. To elaborate, younger and older individuals in recent generations tend to have greater height compared with previous generations due to improvements in lifestyle and nutrition. This suggests that many factors influenced by age, such as corneal diameter, may change over time, and their effects may not be attributable solely to age but rather to differences in underlying variables that affect the outcomes. Although revealing cohort effects requires longitudinal data, however, based on the findings of these studies and the current study, it can be concluded that adults over the age of 18 have smaller corneal diameters than younger adults. However, because our study only included elderly individuals over 60 and the average difference in this age group was small, it is not statistically significant.

Men's corneal diameters were greater than women's in this study, which is in line with the findings of the majority of investigations[15,17,21-22]. It is reasonable to assume that men's corneal diameter is larger than women's since prior research has demonstrated that other ocular biometry values, such as axial length and anterior chamber depth, are similarly greater in men than in women[40-41], which is attributable to men's higher height.

According to this study, there was a statistically significant correlation between hyperopia and corneal diameter, with hyperopic people having larger corneas than emmetropic people. While some investigations found no difference in the corneal diameter of hyperopic people[21], the Hashemi *et al*[16] study found that hyperopic people also had greater corneal diameters. Nonetheless, research has indicated that corneas with greater diameters are flatter[16-17]. Conversely, a flatter cornea and lower corneal power can result in hyperopia[42]. The regression coefficient between hyperopia and corneal diameter, however, was only 0.04—possibly not clinically significant.

In the current study, there was no statistically difference in corneal diameter between myopic and emmetropic eyes. The corneal diameter of eyes with myopia less than -3.00 D did not differ significantly from that of emmetropic eyes in the study by Zha *et al*[43]; however, the corneal diameter of eyes with myopia greater than -3.00 D was lower than that of emmetropic eyes. Our study's findings are in line with this one because the mean SE among myopic people was less than -3.00 D (-2.08 D) in our investigation. The findings of the aforementioned study and the current study suggest that myopic eyes generally have smaller corneal diameters; however, because the difference between emmetropic and mildly myopic eyes is less pronounced, it is not statistically significant.

According to the current study, astigmatic eyes had a smaller corneal diameter than non-astigmatic eyes. But in a study of people between the ages of 14 and 81, Khabazkhoob *et al*[44] found no association between astigmatism and corneal diameter. This finding was similarly presented in the study by Jamali *et al*[19]. Although part of this discrepancy can be attributed to differences in age distribution, the measurement device may also have contributed. In our study, we used the Pentacam AXL, whereas the Khabazkhoob *et al*'s[44] study used the Orbscan II system. Refractive error status further complicates comparisons, as it may independently influence both corneal geometry and astigmatism classification[45]. Moreover, advancing age is associated with increased corneal irregularity[46], which could differentially affect diameter measurements depending on the instrument's algorithmic approach. Ultimately, these methodological and demographic heterogeneities underscore the need for standardized protocols when investigating corneal biometric relationships.

The results of the study showed that higher mean corneal diameters were correlated to higher levels of education. Although previous research has suggested a correlation between corneal diameter and other ocular biometrics such axial length and anterior chamber depth, no study has examined the correlation between education level and corneal diameter[40,47]. Higher levels of education are known to be correlated to myopia[48]; but it has shown that eyes with higher levels of myopia have lower corneal diameters[43]. Near work also can induce change in corneal morphology and astigmatism, but our study showed that astigmatic eyes had smaller corneal diameters. Further research is necessary to ascertain the link between corneal width and educational attainment, as this result runs counter to our findings and cannot be interpreted[17].

The study's multiple linear regression results showed that there was no correlation between corneal diameter and axial

length. In contrast, the majority of earlier research[16-17,19] has shown a clear association between them. It's interesting to note that in this study, a direct relationship between these two parameters was first observed in the simple model. However, the relationship between axial length and corneal diameter was not significant after the two variables, anterior chamber depth and corneal power, were simultaneously entered into the model (full model). This finding can be interpreted in two ways. From a methodological point of view, a closer examination of the previously listed studies reveals that the confounding effects of these two variables were not controlled in any of them; therefore, it can be suggested that confounding variables influenced the reported correlation between corneal diameter and axial length. From a physiological point of view, the positive association between anterior chamber depth and corneal diameter may be explained by the emmetropization process. In long eyes, which tend to be myopic, the cornea may elongate to increase the radius of curvature and shift toward hyperopia as a compensatory mechanism[16]. In other words, cases with larger corneal diameters tend to have flatter corneas. Previous studies have shown that a larger corneal radius of curvature is observed not only in hyperopic cases but is also associated with flatter corneas[19]. The larger corneal diameter observed in the hyperopic group in the present study may support this explanation.

In this study, corneal diameters had a positive correlation thinner central thickness, which was consistent with the findings of other studies conducted on infants[49] and middle-aged adults[16]. This suggests that rather than corneal expansion, the mechanical stretching of the stromal layer may be the cause of the increase in corneal diameter[49]. Consistent with previous research[19], the results of the present study also demonstrated that corneas with larger diameters had lower mean-K, or refractive power. The lower refractive power of corneas with larger widths makes sense because prior research has shown that these corneas are flatter and have less curvature[16-17]. The results also demonstrated that eyes with larger corneal diameters have deeper anterior chambers under the assumption of a constant refractive condition. Our findings are also supported by the findings of earlier research[19,22]. It is clear that the anterior chamber's depth rises as a result of the thinner corneal thickness, since corneas with greater diameters have thinner thicknesses[16].

Only 29% of the variance in the corneal diameter was explained by the variables in the multiple linear regression model, according to the study's R^2 value of 29.4%. Although, from a statistical point of view, this value is low and warrants cautious interpretation of the results, such low values are common for biological parameters. The low model fit can be explained in two ways. First, because a linear model was used, we were only able to assess linear associations between variables, whereas some of these variables may have nonlinear relationships with corneal diameter that the model could not detect[50]. Second, additional factors likely influence the model fit. For example, the corneal radius of curvature is an important and deterministic factor that was not evaluated in the present study. Other variables, such as lens thickness, ethnicity, and corneal imaging type are also determinants of corneal diameter values. Although the effects of these variables have been confirmed in previous studies[16,21,51], it was not feasible to collect data on these factors due to implementation constraints during the study.

To better interpret and comprehend the findings, it is important to take into account the strengths and limitations of the current study. This study's merits include its large sample size and its use of a reliable sampling technique, which reduces selection bias and sampling variability. However, information bias was reduced when data was gathered by qualified and experienced personnel. All of these factors increased the accuracy of the study results and led to a more accurate and closer estimate of the corneal diameter parameter to its true value in the population. One of the limitations of this study is that, like other cross-sectional studies, it is not possible to distinguish cause from effect; rather, it is only possible to determine the presence or absence of a relationship between the parameters. As a result, the results should be interpreted with more caution.

In conclusion, according to the findings, corneal diameter was negatively associated with astigmatism, corneal power, corneal volume, and central corneal thickness, and positively associated with male gender, higher education, anterior chamber depth, pupil diameter, and hyperopia. Multiple linear regression analysis revealed no association between corneal diameter and the following variables: age, myopia, axial length, economic status, diabetes, blood pressure, and BMI. Mean-K showed the strongest association with corneal diameter among the factors under investigation. Twenty-nine percent of the variance in corneal diameter changes could be explained by the established model.

ACKNOWLEDGEMENTS

Authors' Contributions: Design and conduct of the study (Pakzad R, Khabazkhoob M, Lavaei N, Hashemi H); collection, management of the data (Pakzad R, Khabazkhoob M, Jamali A); analysis, and interpretation of the data (Khabazkhoob M, Pakzad R, Lavaei N, Jamali A, Hashemi H, Yekta A); and preparation, review, and approval of the manuscript (Hashemi H, Pakzad R, Khabazkhoob M, Yekta A, Jamali A, Lavaei N, Ahmad MA, Shiri Malekabadi E).

Data Availability Statement: The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

AI-Generated Content Disclosure: Artificial intelligence (AI) was used solely to cross-check numerical values between the manuscript text and tables for consistency. No AI was used for data analysis, interpretation, scientific reasoning, or generation of the manuscript content.

Foundation: Supported by National Institute for Medical Research Development (NIMAD) affiliated with the Iranian Ministry of Health and Medical Education (Ethics code: IR.NIMAD.REC.1397.292).

Conflicts of Interest: Lavaei N, None; **Hashemi H,** None; **Ahmad MA,** None; **Yekta A,** None; **Pakzad R,** None; **Shiri Malekabadi E,** None; **Jamali A,** None; **Khabazkhoob M,** None.

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