Analysis of Age, Gender, and Refractive Error-Related Changes of the Anterior Corneal Surface Parameters Using Oculus Keratograph Topography

Nasrin Moghadas Sharif1,2, Negareh Yazdani1,2, Leila Shahkarami6, Hadi Ostadi Moghaddam3,4, Asieh Ehsaei2,3
1Student Research Committee, Mashhad University of Medical Sciences, Mashhad, Iran, 2Department of Optometry, Mashhad University of Medical Sciences, Mashhad, Iran, 3Refractive Errors Research Center, Mashhad University of Medical Sciences, Mashhad, Iran

Abstract

Purpose: To assess refractive error, gender, and age-related differences in corneal topography of a normal population with Oculus Keratograph 4.

Methods: This cross-sectional study included a total of 500 normal eyes of 500 individuals with ages ranging from 10 to 70 years. All participants underwent detailed ocular examinations, including visual acuity measurement, slit-lamp examination, and refractive error evaluation. Slit-lamp examination was performed for all individuals to rule out apparent corneal diseases. Corneal topography parameters were assessed using Oculus Keratograph. The data were analyzed based on gender, refractive error, and age groups using independent sample t-test and one-way analysis of variance.

Results: Of a total of 500 participants (age: 29.51 ± 11.53 years) recruited for the present study, 66.4% were female, and 33.6% were male. The mean spherical equivalent of refraction was −0.98 ± 1.65 diopters. Significant differences were noted in steep keratometry (P = 0.035) and corneal astigmatism (P = 0.014) between genders. Assessment of the data based on refractive error revealed significant differences in an index of vertical asymmetry (P < 0.001), index of height asymmetry (P = 0.003), and index of height decentration (P = 0.011). Considering age groups, significant differences were observed in flat keratometry readings (P < 0.001), mean corneal astigmatism (P = 0.02), minimum radius of curvature (P = 0.037), and apex power (P < 0.001).

Conclusions: There was a prominent variation in some topographic parameters based on gender, age, and refractive error. The information on corneal parameters obtained with Oculus Keratograph from normal eyes provides a reference for comparison with diseased corneas.

Keywords: Age, Cornea, Gender, Keratograph, Refractive error, Topography

INTRODUCTION

Cornea, the most important refractive structure, accounts for two-thirds of the total optical power of the eye.1 Any alteration in corneal curvature directly influences the type and degree of refractive error. Accurate assessment of its optical properties is crucial for both diagnostic and therapeutic purposes such as the diagnosis and management of Keratoconus,2,3 contact lens fitting,4 refractive surgery assessment,5 and detection of any ectatic disorders after refractive surgeries.6 In addition, accurate corneal assessment is of great importance to improve vision following rigid contact lens fitting in irregular corneas, corneal ring implantation, and cornea transplantations following corneal ecstasies.2

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: WKLHRPMedknow_reprints@wolterskluwer.com

How to cite this article: Moghadas Sharif N, Yazdani N, Shahkarami L, Ostadi Moghaddam H, Ehsaei A. Analysis of age, gender, and refractive error-related changes of the anterior corneal surface parameters using oculus keratograph topography. J Curr Ophthalmol 2020;32:263-7.
With the advent of corneal topographers and their clinical application, the analysis of corneal measurement produces a variety of quantitative indices about which knowledge is appreciated in detecting early abnormalities. There are several commercially available corneal topography instruments for either clinical or research goals, such as Pentacam, Orbscan, Galilei Tomography System, and Oculus Keratograph.\cite{7,11} Several published studies have investigated the repeatability and reproducibility of Pentacam, Orbscan, and Galilei Tomography systems.\cite{10,12,13}

Oculus Keratograph 4 (OCEULUS, Wetzlar, Germany) is a new corneal topography which uses Placido ring-based videokeratography to provide corneal topography. This tool is universally used and is a computerized and examiner-independent system for corneal topography. Several studies report that Oculus Keratograph 4 provides repeatable measurements of corneal topography parameters in healthy eyes\cite{11,14,17} and has a high agreement with other topography devices.\cite{15}

Refractive error, gender, and age-related differences are considered to play a key role in tissue structures changes;\cite{16,17} hence, evaluation of corneal features in a normal population should be precisely investigated. To the best of our knowledge, this article is the first to study the normality of oculus topography parameters as a function of gender, refractive error, and age in a large healthy population.

**METHODS**

Among all healthy individuals who came for routine optometry examination, 500 participants were recruited for the present study considering inclusion and exclusion criteria and based on the simple random sampling technique. The study followed the tenets of the Declaration of Helsinki and was approved by the Research Ethics Committee of the institute (Grant code: 930431). After a complete explanation, written informed consent was obtained from each participant. Inclusion criteria were as follows: no ocular surgery, no ocular diseases, no refractive surgery, no contact lens usage, best corrected visual acuity 20/25 or better, and no ophthalmic drugs (especially dry eye drugs) usage. A slit-lamp examination was performed for all individuals to rule out apparent corneal diseases. All examinations were performed by the same experienced examiner (N.M.). All participants underwent detailed ocular examinations, including measurement of visual acuity, slit-lamp examination, evaluation of refractive error, and corneal topography. After slit-lamp examination of the anterior segment, refractive error was determined with an auto-refractometer (AR-610, Nidek Co, Ltd., Tokyo, Japan) and was refined with subjective refraction. Maximum plus to maximum visual acuity was determined as an endpoint in subjective refraction. Myopia was defined as a mean spherical equivalent (MSE) $<-0.50$ Diopter (D), emmetropia was defined as MSE between $-0.50$ and $+0.50$ D, and MSE more than $+0.50$ D was considered hyperopia.\cite{18} All participants were divided into six groups by age: 10–20 years, 21–30 years, 31–40 years, 41–50 years, 51–60 years, and 61–70 years. The cornea was evaluated using Keratograph 4 (OCEULUS, Wetzlar, Germany) corneal topography. Mire uniformity reflected from cornea was evaluated to check the image quality. Any participants with any irregularity in mires (i.e., those with dry eye) were excluded from the study population. Measurements were repeated three times for each participant. Oculus Keratograph 4 (OCEULUS, Wetzlar, Germany), a new corneal topography, is a Placido disc-based device which consists of 22 rings and measures 22,000 points on anterior corneal surface by reflecting illuminated rings on the cornea. It could assess tear film, contact lens fitting pattern, lid-angle, and pupil diameter. It is also equipped with a camera that can capture both videos and still images.\cite{19,20}

Evaluated indices are the following (Oculus Keratograph Instruction Manual, version 1.53, 2002):

- Index of surface variation: The corneal surface irregularity
- Index of vertical asymmetry (IVA): The value of curvature symmetry, with respect to the horizontal meridian as the axis of reflection
- Keratoconus index: The ratio between mean radius values in the upper and lower segment
- Central keratoconus index: The ratio between mean radius values in a peripheral ring divided by a central ring
- Index of height asymmetry (IHA): The degree of symmetry of height data with respect to the horizontal meridian as the axis of reflection
- Index of height decentration (IHD): The degree of decentration in the vertical direction, calculated on a ring with a radius 3 mm
- Minimum radius curvature ($R_{\text{min}}$): The smallest radius of sagittal corneal curvature.

**Statistical analysis**

Statistical analyses were performed with SPSS software for Windows version 11.5 (SPSS Inc., Chicago, IL, USA). All data were reported as means and standard deviation. Normality for continuous variables was determined using the Kolmogorov–Smirnov test. The data were analyzed based on gender, refractive error, and age groups using independent sample $t$-test and one-way analysis of variance (ANOVA). Bonferroni post hoc corrections were applied for multiple comparisons. The level of statistical significance was set at 0.05. To avoid statistical bias and due to the similar nature of the two eyes, data from only the right eyes were included in all analyses.

**RESULTS**

Of a total of five hundred participants (age: $29.51 \pm 11.53$ years) recruited for the study, 332 (66.4%) were female (age: $27.39 \pm 9.94$ years), and 168 (33.6%) were male (age: $33.79 \pm 13.26$ years). The MSE of the refractive error was $-0.98 \pm 1.65$ D (range, $-7.88$ D to $+4.75$ D). Topographic and refractive data were analyzed according to age, refractive
error, and gender. The topographic parameters based on gender are summarized in Table 1. The average of steep keratometry showed significant differences toward flattening in males ($P = 0.035$). Corneal astigmatism also presented statistically significant changes in the result ($P = 0.014$). However, other corneal parameters did not show any significant differences according to gender.

Table 2 shows the topographic parameters according to the refractive errors in view of post hoc results. One-way ANOVA showed that both the IHA and IVA significantly increased with increasing refractive error toward hyperopia ($P = 0.003, P < 0.001$, respectively). However, post hoc multiple comparisons illustrated that the difference in IHA was only statistically significant between myopia and hyperopia ($P = 0.003$). Multiple comparisons of the IVA between the three refractive groups also exhibited a statistically significant difference between myopia and hyperopia ($P < 0.001$) and between emmetropia and hyperopia ($P = 0.003$). In addition, the evaluation of IHD showed significant differences between the refractive groups ($P = 0.011$). Multiple comparisons showed that the differences between myopia and hyperopia ($P = 0.008$) and emmetropia and hyperopia ($P = 0.029$) were statistically significant. No other significant differences were observed between other corneal parameters based on refractive error.

Table 3 shows topographic parameters in each age group, taking into consideration post hoc results. One-way ANOVA analysis illustrated a significant steepening of the flat keratometry with increasing age ($P < 0.001$). However, post hoc multiple comparisons demonstrated significant differences in flat keratometry between the 10–20 years’ subgroup with 41–50, 51–60, and 61–70 years ($P = 0.006, P < 0.001$, and $P = 0.005$, respectively). Significant differences were also noted between the 21–30 and 51–60 years’ subgroups ($P = 0.004$). The mean corneal astigmatism significantly decreased with increasing age ($P = 0.02$). Multiple comparisons showed a significant difference between 10–20 years and 51–60 years ($P = 0.003$). $R_{	ext{min}}$ and apex power presented a significant steepening with increasing age ($P = 0.037$ and $P < 0.001$, respectively). A detailed assessment of apex power showed a distinct difference between 10–20 years with the 51–60 and 61–70 years’ subgroups toward increasing power with increasing age ($P = 0.009, P = 0.043$, respectively).

## Discussion

The present study aimed to evaluate the age, gender, and refractive error-related changes in corneal parameters. Although several studies have evaluated the corneal parameters in a normal population with other topographic systems and also investigate the repeatability and reproducibility of diagnosis devices, there are few which comprehensively evaluate the Oculus Keratograph 4 in a large normal population. Oculus Keratograph was used to measure the corneal anterior surface parameters in a large, healthy population.

In an investigation of corneal parameters, we found significant differences in steep keratometry between male and female participants in agreement with Orucoglu et al.’s study. Orucoglu et al. evaluated the anterior segment of the eye with Pentacam Scheimpflug imaging in 666 healthy eye individuals. Similar to the previous studies, present findings also demonstrated that cornea was steeper in female group.15,21–24 Hoffmann and Hütz25 evaluated biometry parameters by IOLMaster biometer in 15448 patients and stated that female eyes tend to have steeper cornea and shallower anterior chamber that could be explained by shorter eyes in females.

Mean corneal astigmatism was significantly different between male and female groups. The opposite results were reported in Khabazkhoob et al.’s study using Orbscan, which found no significant difference in mean corneal astigmatism between genders. Moreover, Orucoglu et al. also stated that there was no significant difference between genders with respect to corneal astigmatism. The conflicting results may be due to different applied devices.

In the evaluation of corneal parameters according to the refractive errors, the present study found significant differences in some corneal components. In agreement with previous studies,26,27 no statistically significant change in corneal curvature radius was observed in the study population with respect to refractive errors. Dogan et al. assessed anterior segment parameters of myopic, hypotropic, and emmetropic children using optical biometry and reported no associations between the mean keratometric values and refractive states. Nieto-Bona et al.27 also measured corneal parameters using Atlas videokeratoscope among adults and stated no significant corneal curvature radius between refractive groups. Hashemi et al.28 also determined the distribution of axial length to the corneal radius of curvature (AL/CRC) ratio and evaluated its association with refractive errors in the Iranian population. They reported that the correlation between refractive errors

### Table 1: Topographic parameters based on gender

| Factor   | Female ($n = 332$) | Male ($n = 168$) | P     |
|----------|--------------------|-----------------|-------|
| Kf (D)   | 43.45±1.43         | 43.39±1.54      | 0.676 |
| Ks (D)   | 44.37±1.44         | 44.07±1.61      | 0.035 |
| C.Ast (D)| −0.94±0.56         | −0.81±0.51      | 0.014 |
| Ecc     | 0.51±0.10          | 0.52±0.11       | 0.621 |
| ISV     | 18.72±5.40         | 18.69±5.27      | 0.958 |
| IVA     | 0.11±0.05          | 0.11±0.05       | 0.937 |
| KI      | 1.01±0.01          | 1.01±0.01       | 0.075 |
| CKI     | 1.00±0.005         | 1.00±0.005      | 0.921 |
| Rmin (mm)| 7.48±0.25          | 7.52±0.28       | 0.114 |
| IHA     | 6.13±4.08          | 6.35±4.44       | 0.588 |
| IHD     | 0.00±0.00          | 0.01±0.00       | 0.06  |
| Apex (D)| 44.26±1.44         | 44.06±1.54      | 0.171 |

All data has normal distribution. Bold text indicates a statistically significant value. Kf: Flat keratometry, Ks: Steep keratometry, C.Ast: Corneal astigmatism, Ecc: Eccentricity, ISV: Index of surface variation, IVA: Index of vertical asymmetry, Kf: Keratoconus index, CKI: Central keratoconus index, Rmin: Minimum radius curvature, IHA: Index of height asymmetry, IHD: Index of height decentration, D: Diopter
was significantly stronger with the AL/CRC ratio than with AL and CRC alone.

IHA and decentration showed a significant difference between the three refractive groups, and it was greater in hyperopia. IHA and decentration are the main factors in keratoconus diagnosis and staging.29 Overall, this information may help clinicians better define normal from abnormal in the clinical setting and in refractive surgery screenings.

With regard to age, statistically significant changes were observed in some of the corneal anterior surface parameters. With aging, flat keratometry reading showed a significant change towards steepening. In contrast, Shukur30 reported no considerable differences in flat keratometry with age. The results of the present study showed that the average corneal astigmatism significantly decreased with age. However, Lyle31 reported that corneal astigmatism increased up to the third decade of life and showed a decrease in older individuals.

The minimum radius of curvature and apex power in the present study had a gradual trend toward steepening with aging; however, Hashemi et al.32 reported no significant age-related changes in corneal radius. The most likely explanation of the controversy may be explained by various mean age and different measurement devices.

One of the limitations of the current study is an unequal number of individuals with respect to refractive error, gender, and age subgroups. Moreover, further studies using other topographic devices for the assessment of the corneal surface are recommended to compare with Oculus topographer.

In summary, the strong aspects of the present study include the assessment of gender, refractive error, and age-related changes on the anterior corneal surface in a relatively extended normal population assessed by Oculus Keratograph 4. Given that corneal anterior surface parameters showed considerable variation in relation to age, gender, and refractive error, these

---

**Table 2: Topographic parameters based on refractive error**

| Factor | Myopia (1) \(n=255\) | Emmetropia (2) \(n=209\) | Hyperopia (3) \(n=36\) | Comparison pair by pair | \(P\) |
|--------|-----------------|-----------------|-----------------|-----------------|----------|
| Kf (D) | 43.48±1.48      | 43.32±1.44      | 43.79±1.58      | Not statistically significant | 0.169    |
| Ks (D) | 44.37±1.54      | 44.15±1.47      | 44.34±1.55      | Not statistically significant | 0.264    |
| C.Ast (D) | −0.95±0.60 | −0.88±0.50     | −0.74±0.43      | Not statistically significant | 0.074    |
| Ecc   | 0.53±0.10       | 0.52±0.11       | 0.52±0.12       | Not statistically significant | 0.579    |
| ISV   | 18.76±5.44      | 18.44±5.24      | 19.97±5.47      | Not statistically significant | 0.277    |
| IVA   | 0.11±0.05       | 0.12±0.05       | 0.15±0.05       | 1<3*, 2<3* <0.001            |
| IHD   | 0.00±0.00       | 0.01±0.00       | 0.01±0.00       | 1<3*, 2<3* 0.01±0.00         |
| Apex (D) | 44.28±1.51 | 44.06±1.45      | 44.36±1.43      | Not statistically significant | 0.222    |

*Bonferroni post hoc test \(P<0.05\). All data have normal distribution. Bold text indicates a statistically significant value. Kf: Flat keratometry, Ks: Steep keratometry, C.Ast: Corneal astigmatism, Ecc: Eccentricity, ISV: Index of surface variation, IVA: Index of vertical asymmetry, KI: Keratoconus index, CKI: Central keratoconus index, \(R_{min}\): Minimum radius curvature, IHA: Index of height asymmetry, IHD: Index of height decentration, D: Diopter

---

**Table 3: Topographic parameters based on age**

| Factor | 10-20 years (1) \(n=71\) | 21-30 years (2) \(n=270\) | 31-40 years (3) \(n=71\) | 41-50 years (4) \(n=46\) | 51-60 years (5) \(n=30\) | 61-70 years (6) \(n=12\) | Comparison pair by pair | \(P\) |
|--------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----------|
| Kf (D) | 42.91±1.55      | 43.31±1.38      | 43.56±1.40      | 43.88±1.44      | 44.32±1.61      | 44.53±1.22      | 1<4*, 1<5*, 1<6*, 2<5* <0.001 |
| Ks (D) | 43.94±1.63      | 44.20±1.41      | 44.40±1.52      | 44.49±1.52      | 44.75±1.91      | 44.91±1.32      | Not statistically significant | 0.06    |
| C.Ast (D) | −1.04±0.74 | −0.92±0.53      | −0.86±0.48      | −0.81±0.46      | −0.68±0.39      | −0.70±0.40      | 1<5* 0.02      |
| Ecc   | 0.53±0.11       | 0.53±0.10       | 0.51±0.10       | 0.51±0.14       | 0.51±0.12       | 0.46±0.14       | Not statistically significant | 0.170   |
| ISV   | 19.63±4.74      | 18.98±5.62      | 17.22±4.45      | 18.67±6.23      | 18.30±4.59      | 17.33±4.68      | Not statistically significant | 0.101   |
| IVA   | 0.12±0.05       | 0.12±0.05       | 0.10±0.04       | 0.12±0.06       | 0.13±0.04       | 0.13±0.06       | Not statistically significant | 0.141   |
| CKI   | 1.01±0.01       | 1.01±0.02       | 1.01±0.01       | 1.01±0.02       | 1.01±0.02       | 1.01±0.03       | Not statistically significant | 0.294   |
| CKI   | 1.01±0.00       | 1.01±0.00       | 1.00±0.00       | 1.01±0.01       | 1.01±0.01       | 1.01±0.01       | Not statistically significant | 0.052   |
| R_{min} (mm) | 7.56±0.30 | 7.50±0.25       | 7.47±0.24       | 7.46±0.28       | 7.41±0.30       | 7.36±0.22       | Not statistically significant | 0.037   |
| IHA   | 6.14±3.90       | 6.25±4.25       | 5.53±3.78       | 6.12±4.24       | 7.96±5.06       | 5.57±4.63       | Not statistically significant | 0.192   |
| IHD   | 0.01±0.00       | 0.01±0.00       | 0.00±0.00       | 0.01±0.00       | 0.01±0.00       | 0.01±0.00       | Not statistically significant | 0.058   |
| Apex (D) | 43.72±1.60 | 44.13±1.41      | 44.31±1.39      | 44.48±1.49      | 44.82±1.71      | 45.08±1.06      | 1<5*, 1<6* <0.001       |

*Bonferroni post hoc test \(P<0.05\). All data have normal distribution. Bold text indicates a statistically significant value. Kf: Flat keratometry, Ks: Steep keratometry, C.Ast: Corneal astigmatism, Ecc: Eccentricity, ISV: Index of surface variation, IVA: Index of vertical asymmetry, KI: Keratoconus index, CKI: Central keratoconus index, \(R_{min}\): Minimum radius curvature, IHA: Index of height asymmetry, IHD: Index of height decentration, D: Diopter
data will hopefully prove useful for future studies of various corneal diseases.

**Acknowledgments**

This work was supported by Refractive Errors Research Center of Mashhad University of Medical Sciences, and grant received from Deputy of Research of Mashhad University of Medical Sciences, Iran (Grant code: 930431).

**Financial support and sponsorship**

This work was supported by Refractive Errors Research Center of Mashhad University of Medical Sciences and a grant received from the Deputy of Research of Mashhad University of Medical Sciences, Iran (Grant code: 930431).

**Conflicts of interest**

There are no conflicts of interest.

**REFERENCES**

1. Mashige K. A review of corneal diameter, curvature and thickness values and influencing factors. S Afr Optom 2013;72:185-94.
2. Li X, Yang H, Rabinowitz YS. Keratoconus: Classification scheme based on videokeratography and clinical signs. J Cataract Refract Surg 2009;35:1597-603.
3. Levy D, Hutchings H, Rouland JF, Guell J, Burillon C, Arné JL, et al. Videokeratographic anomalies in familial keratoconus. Ophthalmology 2004;111:867-74.
4. Bhatoo NS, Hau S, Ehrlich DP. A comparison of a topography-based rigid gas permeable contact lens design with a conventionally fitted lens in patients with keratoconus. Cont Lens Anterior Eye 2010;33:128-35.
5. Alessio G, Boscia F, La Tegola MG, Sborgia C. Topography-driven excimer laser for the retreatment of decentralized myopic photorefractive keratectomy. Ophthalmology 2001;108:1695-703.
6. Randleman JB. Post-laser in situ keratomileusis ectasia: Current understanding and future directions. Curr Opin Ophthalmol 2006;17:406-12.
7. Salouti R, Nowroozzadeh MH, Zamani M, Ghoreyshi M, Salouti R. Comparison of horizontal corneal diameter measurements using Galilei, eyessys and Orbscan II systems. Clin Exp Optom 2009;92:429-33.
8. Martin R, Ortiz S, Rio-Cristobal A. White-to-white corneal diameter differences and highly myopic eyes: Partial coherence interferometry versus scanning-slit topography. J Cataract Refract Surg 2013;39:585-9.
9. Shankar H, Taranath D, Santhirathelagan CT, Pesudovs K. Anterior segment biometry with the Pentacam: Comprehensive assessment of repeatability of automated measurements. J Cataract Refract Surg 2008;34:103-13.
10. Meyer JJ, Gokul A, Vellara HR, Prime Z, McGhee CN. Repeatability and agreement of Orbscan II, Pentacam HR, and Galilei tomography systems in corneas with keratoconus. Am J Ophthalmol 2017;175:122-8.
11. Ortiz-Toquero S, Rodriguez G, de Juan V, Martin R. Repeatability of placido-based corneal topography in keratoconus. Optom Optom 2014;91:1467-73.
12. Guilbert E, Saad A, Elluard M, Grise-Dulac A, Rouger H, Gatinel D. Repeatability of keratometry measurements obtained with three topographers in keratoconic and normal corneas. J Refract Surg 2016;32:187-92.
13. Crawford AZ, Patel DV, McGhee CN. Comparison and repeatability of keratometric and corneal power measurements obtained by Orbscan II, Pentacam, and Galilei corneal tomography systems. Am J Ophthalmol 2013;156:53-60.
14. Goto T, Klyce SD, Zheng X, Maeda N, Kuroda T, Ide C. Gender-and age-related differences in corneal topography. Cornea 2001;20:270-6.
15. Orucoglu F, Akman M, Oral S. Analysis of age, refractive error and gender related changes of the cornea and the anterior segment of the eye with scheimpflug imaging. Cont Lens Anterior Eye 2015;38:345-50.
16. Mashige KP. Repeatability and reproducibility of horizontal corneal diameter and anterior corneal power measurements using the oculus keratograph 4: Original research. African Vis Eye Health 2016;75:1-5.
17. Mao X, Savini G, Zhuo Z, Feng Y, Zhang J, Wang Q, et al. Repeatability, reproducibility, and agreement of corneal power measurements obtained with a new corneal topographer. J Cataract Refract Surg 2013;39:1561-9.
18. Hashemi H, Rezvan F, Beiranvand A, Papi OA, Hoseini Yazdi H, Ostadamoghaddam H, et al. Prevalence of refractive errors among high school students in Western Iran. J Ophthalmic Vis Res 2014;9:232-9.
19. Best N, Drury L, Wolfsohn JS. Clinical evaluation of the oculus keratograph. Cont Lens Anterior Eye 2012;35:171-4.
20. Ngo W, Srinivasan S, Schulze M, Jones L. Repeatability of grading meibomian gland dropout using two infrared systems. Optom Vis Sci 2014;91:658-67.
21. Southwaithe WA. The asphericity, curvature and tilt of the human cornea measured using a videokeratoscope. Ophthalmic Physiol Opt 2003;23:141-50.
22. Hoffmann PC, Hütz WW. Analysis of biomey and prevalence data for corneal astigmatism in 23,239 eyes. J Cataract Refract Surg 2010;36:1479-85.
23. Scholz K, Messner A, Eppig T, Bruehner H, Langenbacher A. Topography-based assessment of anterior corneal curvature and asphericity as a function of age, sex, and refractive status. J Cataract Refract Surg 2009;35:1046-54.
24. Wong TY, Foster PJ, Ng TP, Tielsch JM, Johnson GJ, Seah SK. Variations in ocular biometry in an adult Chinese population in Singapore: The Tanjong Pagar survey. Invest Ophthalmol Vis Sci 2001;42:73-80.
25. KhabazKhoob M, Hashemi H, Yazdani K, Mehravar A, Yekt A, Fotouhi A. Keratometry measurements, corneal astigmatism and irregularity in a normal population: The Tehran eye study. Ophthalmic Physiol Opt 2010;30:800-5.
26. Dogan M, Elgin U, Sen E, Tekin K, Yilmazbas P. Comparison of anterior segment parameters and axial lengths of myopic, emmetropic, and hyperopic children. Int Ophthalmol 2019;39:335-40.
27. Nieto-Bona A, Lorente-Velázquez A, Móntes-Micó R. Relationship between anterior corneal asphericity and refractive variables. Graefes Arch Clin Exp Ophthalmol 2009;247:815-20.
28. Hashemi H, KhabazKhoob M, Miraflab M, Emanian MH, Shariati M, Abdolahi-Nia T, et al. Axial length to corneal radius of curvature ratio and refractive errors. J Ophthalmic Vis Res 2013;8:220-6.
29. Kanellopoulos AJ, Asimellis G. Revisiting keratometric diagnosis and progression classification based on evaluation of corneal asymmetry indices, derived from scheimpflug imaging in keratoconic and suspect cases. Clin Ophthalmol 2013;7:1539-48.
30. Shukur ZY. Relationship of age and keratometry readings of the cornea to central corneal thickness among 98 patients performing refractive surgery in Ibsar center for refractive surgery. J Kerbala Univ 2015;13:49-52.
31. Lyle WM. Changes in corneal astigmatism with age. Am J Ophthalm 2019;171:75-83.
32. Hashemi H, Jafarzadeh P, Ghaderi S, Yekt A, Ostadamoghaddam H, Norouzirad R, et al. Ocular components during the ages of ocular development. Acta Ophthalmol 2015;93:e74-81.