Objective Assessment of Corneal Backscattered Light in Myopic, Hyperopic, and Emmetropic Children

Pinar Nalcacioglu (drpinarnalcaci@yahoo.com)
Ankara Yildirim Beyazit University Faculty of Medicine: Ankara Yildirim Beyazit Universitesi Tip Fakultesi
https://orcid.org/0000-0002-1582-6580

Emine Sen
Ankara Ulucanlar Goz Egitim ve Arastirma Hastanesi: SBU Ulucanlar Goz Egitim Ve Arastirma Hastanesi

Emre Aydemir
Adiyaman University Training and Research Hospital: Adiyaman Universitesi Egitim ve Arastirma Hastanesi

Hasan Kiziltoprak
Bingol Obstretrics and Pediatrics Research HospitalTrainig

Hakan Halit Yasar
Ankara Ulucanlar Eye Training and Research Hospital: SBU Ulucanlar Goz Egitim Ve Arastirma Hastanesi

Research Article

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Abstract

Purpose: To determine the corneal densitometry values by using Scheimpflug imaging in myopic, and hyperopic children and to compare the results with emmetropic children.

Methods: The corneal densitometry measurements of the subject were obtained with Pentacam Scheimpflug tomography. The values were automatically measured in standardized grayscale units (GSU) over an area 12 mm in diameter, which was subdivided into 4 annular concentric zones (0-2 mm, 2-6 mm, 6-10 mm, 10-12 mm) and 3 corneal depths (anterior layer: anterior 120 µm; central layer: from 120 µm to the last 60 µm; posterior layer: last 60 µm). In addition, we evaluated the correlation between spherical equivalence and anterior corneal morphological parameters and the corneal densitometry values.

Results: A total of 216 participants were included in this prospective cross-sectional study. The eyes were divided into three groups related to their spherical equivalent (SE) refractive error values as follows: 89 (41.2%) hyperopic eyes, 66 (30.6%) myopic eyes, and 61 (28.2%) emmetropic control eyes. The hyperopic eyes were found to have lower corneal densitometry values in 4 annular zones and the total diameter of all depths except the central layer. However, only the 6-10 mm annular zone of the central and posterior layers of the myopic eyes had lower corneal densitometry values than emmetropic eyes. There was also a significant correlation between spherical equivalence and corneal densitometry values in some zones of the hyperopic eyes.

Conclusion: Backward scattering of light was lower in hyperopic eyes and this could affect the visual quality.

Introduction

The cornea makes up the major part of the focusing power of the eye. The cornea and lens work together to focus the light entering the eye onto the retina. The cornea's refractive power depends on its smooth and stable curvature and its transparency [1].

Corneal transparency is related to the highly regular structure based on a uniform diameter of the collagen fibrils and the regular interfibrillar distance [2, 3]. Changes in this complex configuration results in an increased amount of light backscattering, reducing the amount of light reaching the retina and impairing the visual acuity [1]. Light scattering, diffraction, and wavefront aberrations are known to decrease the quality of the retinal image [4]. During a routine eye examination, the visual acuity measurements cannot reflect the effect of light backscattering on the visual quality [5]. However, a good level of vision may be dependent on the transparency and appropriate refractive shape of the cornea [6].

Corneal backscattering measurements are a reflection of corneal transparency. The Pentacam Scheimpflug system analysis can measure corneal densitometry values to enable quantification of corneal transparency. This non-invasive, rapid and reproducible optical system provides a map of the amount of backscattered light in various regions of the cornea. The system automatically gives quantitative values for corneal optical densitometry over an area 12 mm in diameter and analyzes the measurements in 4 annular zones and 3 layers.

Since corneal densitometry represents the health of the cornea, we therefore aimed to investigate whether these values were associated with refractive values and whether they could contribute to the optical quality of the cornea or enable balancing of refractive errors. To best of our knowledge, corneal densitometry values in children with various refractive errors have not previously been reported. Our aim in this study was to describe the corneal densitometry values in relation to the age and refractive errors in a group of children by using the Pentacam Scheimpflug system.

Materials And Methods

The 216 eyes of 216 children who had presented consecutively to our Ophthalmology Clinic for a routine eye examination at the Ulucanlar Eye and Training Research Hospital between January and June 2019 were included in this prospective cross-sectional study. All of the study procedures were conducted in accordance with the Declaration of Helsinki, and informed consent was obtained from the parents. The study was approved by the Local Ethics Committee.

All subjects underwent a comprehensive ophthalmologic examination including the best-corrected Snellen visual acuity, pupillary light reflex, slit-lamp biomicroscopy examination of the anterior and posterior segments without pupillary dilatation and using a 90-D lens, and intraocular pressure (IOP) measurement by non-contact tonometry.

Children aged 6 to 18 years were enrolled in the study. The groups were classified according to refractive error such as emmetropic, myopic, and hyperopic. Before enrolling the participants in the study, we performed a slit-lamp examination to make sure there was no corneal opacity or corneal epithelial problem. We excluded the cases with any ocular problems other than simple refractive errors resulting in the exclusion of those with ocular surface disease, corneal diseases, glaucoma, ocular surgery or trauma, cataract, uveitis, posterior segment abnormalities, and amblyopia. The patients who had any systemic diseases such as diabetes mellitus or autoimmune diseases were also not included in the present study. The children who did not cooperate and were not able to fixate with their eyes sufficiently for good image quality were also excluded.

Corneal densitometry was evaluated by using the rotating Scheimpflug anterior segment analyzer (Pentacam HR, OCULUS, GmbH, Germany), which automatically provides quantitative values with the Pentacam software. The measurement consisted of 25 images (1003 X 520 pixels) over different meridians, with a uniform blue light source, taken under a uniform ambient light level of 4 lux in a windowless clinical room. The system automatically locates the corneal apex and analyzes an area with a diameter of 12 mm around it. The software algorithm shows the data in grayscale units (GSU). The units are graded as a minimum light scatter of 0 (maximum transparency) and a maximum light scatter of 100 (minimum transparency). An area 12 mm in diameter was divided into 4 annular concentric zones

(0–2 mm, 2–6 mm, 6–10 mm, and 10–12 mm in diameter) centered at the apex of the cornea. In addition, the system provides the quantitative measurements of 3 different depth layers of the cornea that include the anterior layer (anterior 120 μm), central layer (from the first 120 μm to the posterior 60 μm), and the posterior layer (posterior 60 μm). We also analyzed anterior and posterior corneal curvature, corneal thickness, corneal volume and white-to-white (WTW) diameter, and anterior chamber volume, depth and iridocorneal angle.

All examinations using the Scheimpflug system were performed by a single experienced technician, and in the same examination room. No contact ocular examination or pupil dilation was performed before this examination. In order to obtain a reflex-free image, all measurements were performed under standard dim-light conditions using the automatic-release mode to reduce examiner-dependent errors and during the same period of the day (between 9 and 12 am). We asked the participants to put their chin on the chin rest and touch their forehead to the forehead band. The eye was aligned with the visual axis using a central black fixation target. A total of 25 single Scheimpflug images were obtained over approximately 2 seconds. Scans with a quality factor < 95% were excluded from the study. A single experienced grader (ES) who was blind to the groups reviewed all the Pentacam HR images. The cases with acceptable image quality were taken into account for statistical analysis.

Statistical analysis

Statistical analysis was performed using the SPSS software for Windows, version 22 (SPSS Inc., Chicago, IL, USA). The continuous variables were reported as mean ± standard deviation (SD) while the categorical variables were summarized with the use of frequencies. The normality of all data samples was checked with the Kolmogorov–Smirnov test. Only the right eye values were used for statistical purposes. The chi-square test was used in the analysis of categorical variables. Comparisons of the parametric values among the groups were performed with One-Way ANOVA. Comparisons of the nonparametric values among the groups were performed with the Kruskal-Wallis test. Tukey HSD and the Bonferroni-adjusted Mann-Whitney U-test were used as a post-hoc test for multiple comparisons between the groups. The Spearman rank test was used to investigate any relationship between both age and refractive errors and the anterior segment and corneal optical densitometry parameters. A two-tailed p value < 0.05 was considered significant.

Results

A total of 216 participants were enrolled in the present study: 61 (28.2%) were emmetropic, 66 (30.6%) were myopic, and 89 (41.2%) were hyperopic. All of the participants were Caucasian. There were 48 (22.2%) females and 168 (77.8%) males. The mean age was 11.7 ± 2.8 (6–16) years in the myopic cases, 10.9 ± 2.3 (7–18) years in the hyperopic cases, and 11.5 ± 2.1 (7–16) years in the emmetropic cases. There were no statistically significant differences related to age or gender between the three groups (p > 0.05). The demographic characteristics of the subjects are summarized in Table 1.

Among the anterior segment parameters, the anterior, posterior and maximum mean corneal curvature values, the iridocorneal angle, and the anterior chamber volume and depth were statistically different between the groups ($p < 0.001$, $p = 0.002$, $p = 0.007$, $p = 0.013$, $p < 0.001$, and $p < 0.001$, respectively). Conversely, the central and thinnest corneal thickness, the corneal volume, and the white-to-white corneal diameter were not statistically different ($p = 0.290$, $p = 0.492$, $p = 0.258$, $p = 0.400$, respectively). The differences between the groups are summarized in Table 2.

The densitometry of the anterior layer of the 0–2 mm concentric annular zone, and the posterior layer of the 0–2 mm and 2–6 mm concentric annular zones were statistically significantly lower in hyperopic group (the Bonferroni-adjusted Mann-Whitney U-test, $p < 0.0166$). Also, the anterior, posterior, and total layers of the total 0–12 mm diameter, and the total corneal layer of 10–12 mm diameter were statistically significantly lower in hyperopic group (the Bonferroni-adjusted Mann-Whitney U-test, $p < 0.0166$). The results of corneal densitometry values are summarized in Fig. 1 and Table 3.

Evaluation of the correlation between the anterior segment parameters and age revealed a significant positive correlation only between the age and anterior chamber depth ($r = 0.218$, $p = 0.04$) in hyperopic cases. When we evaluated the correlation between the corneal densitometry values and age, we only found a statistically significant positive correlation in emmetropic participants. The 0–2 mm and 2–6 mm zones for all depth layers were found to especially show a statistically significant positive correlation ($p < 0.05$). The correlation between corneal densitometry values and age was not statistically significant in myopic or hyperopic eyes. These parameters are summarized in Table 4.

We evaluated the correlation between the refractive errors and corneal morphological parameters in myopic and hyperopic patients. There was a significant negative correlation with maximal corneal curvature in myopic cases and with anterior chamber depth in hyperopic cases ($p < 0.05$) (Table 5). In addition, there was a significant correlation between spherical equivalence and corneal densitometry, which was negative in the anterior and central 0–2 mm layer, and positive in the central 10–12 mm, and posterior 6–10 mm, 10–12 mm and total values in hyperopic eyes. The correlation values between spherical equivalence and corneal densitometry are summarized in table 6.

In addition, the white-to-white corneal diameter showed a statistically significant negative correlation in all annular zones except the 0–2 mm zone and the 2–6 mm zone in all three groups (data not shown, Spearman rank test, $p < 0.05$, $r > -0.380$ for emmetropic cases, $r > -0.298$ for myopic cases, and $r > -0.297$ for hyperopic cases).

We also investigated the correlation between the central corneal thickness and corneal optical densitometry values and found no correlation between these parameters in emmetropic cases. However, there was significant negative correlation in the 0–2 mm and 2–6 mm zones with different layers in myopic cases. Conversely, we found a significant positive correlation in all depth layers of the 6–10 mm annular zones in hyperopic patients. Table 7 shows the distribution of the correlation values between central corneal thickness and corneal optical densitometry values.

Discussion

Corneal densitometry is accepted to reflect both corneal clarity and health. Light scattering is minimal in the normal cornea thanks to its internal structure [7]. Increased corneal light backscattering has been reported in various corneal disorders such as bacterial keratitis, keratoconus, pseudoexfoliation syndrome, Fuchs endothelial dystrophy, and rheumatoid arthritis [7–11]. Light entering the cornea scatters either in a forward or backward direction. Backward light scattering results in a reduction in the amount of light reaching the retina [1]. Increased backward scattering decreases the quality of vision and degrades the retinal images [4]. We wanted to evaluate corneal light backscattering in healthy eyes with various refractive values by using corneal densitometry measurements. A literature survey did not reveal any other study that investigated the morphological structure of the cornea and optical densitometry values in the presence of various refractive errors in children. Our aim in the current study was to investigate whether a relationship was present between corneal densitometry values and refractive values as well as other ocular structure parameters and thus to identify whether these factors contributed to the optical status.

The main corneal scattering of light occurs at the interfaces between air and the tear film, and between the tear film and the cornea. The anterior superficial corneal epithelial cell layer and the posterior corneal endothelium are the major sources of light backscattering with the superficial epithelial layer making the highest contribution. The corneal stroma provides the cornea's transparency with the regular arrangement of collagen fibrils, the homogenous interfibrillar distance, and the uniform diameter [1, 12]. The posterior stroma with a more regular structural organization has more corneal transparency than the anterior stroma with a weaving structural pattern. In concordance with this, we found hyperopic cases had lower corneal optical density (COD) values in the 0–2 mm and 2–6 mm areas compared to both the myopic and emmetropic cases in the posterior layer, and lower densitometry throughout the total diameter was also seen in the anterior, posterior and total layers. This indicates a lower degree of scatter in the total diameter in all layers except the central corneal layer in hyperopia.

The zones where the hyperopic cases were not different than the myopic cases but had lower COD values than the emmetropic cases were the central 0–2 and 2–6 mm zones considering the total of these all corneas, this difference was significant in the 2–6 mm zone. These results indicated that the decisive corneal zones in terms of COD were the corneal apex (0- to 2-mm zone) and the pericentral cornea (2–6 mm zone) in eyes with refractive values. A small number of studies investigating corneal densitometry values in normal healthy corneas have reported a wide range of results in various ages without differentiating between refractive errors [5, 13–15]. Although comparison of the studies is difficult, Cankaya et al. found the lowest COD values to be in the total 0–12 mm total diameter of the posterior layer and the highest backscattering value to be in the anterior layer [5]. They reported the lowest COD value to be in the central 0–6 mm zone and to show a gradual significantly increase while advancing towards the limbus [5].

We observed higher COD values in the corneal apex, and pericentral cornea instead of the peripheral zones of 6–10 mm in all corneal layers for each group. However, the annular zone of 10–12 mm diameter in all layers for each group had the highest mean COD value. Furthermore, the total corneal layer of the 10–12 mm diameter was statistically significantly lower in the hyperopic group. Due to the non-homogenous distribution of endothelial cell density in the cornea, the highest value is found in the 10–12 mm annulus [14], which means more corneal transparency because of the water pumping and barrier function of the endothelium. So, we can speculate that endothelial cell density in the 10–12 mm annulus has the highest value in hyperopic eyes. On the other hand, analysis of the 10–12 mm zone by using Scheimpflug devices had the lowest repeatability and reproducibility [15]. The assessment of COD values according to the position of the limbus and sclera during the measurement, especially in cases with corneas smaller than the 12-mm zones, can result in increased COD values in the peripheral zones. This could explain the negative statistically significant correlation between the WTW diameter and the COD values in all annular zones except the 0–2 mm and the 2–6 mm zones in all three groups in this study.

Evaluation of the correlation between the spherical equivalent values and COD values revealed a statistically significant correlation only in the hyperopic group. A significant but weak negative correlation was present between the spherical equivalent and corneal densitometry values in hyperopic cases, especially in the central 0–2 mm zone of the anterior, central and total layers. However, we saw that the COD value increased as the spherical equivalent value increased when the measurements were advanced towards the limbus and periphery (central layer of 10–12 mm) and towards deeper areas (posterior layer of 6–10 mm, 10–12 mm). This could result in decreased image quality on the retina in high hyperopic cases. In addition, the lower mean COD over the 12 mm diameter area in the anterior, posterior and total layers in only the hyperopic eyes suggested that this could have an effect on the balance of the formation of the optical qualities of the cornea in hyperopic children. In a study where high myopic values (> -6 dioptric (D) spherical refractive errors) were compared with age- and gender-matched < 5 D spherical cases, a high COD value was found in the 10–12 mm peripheral zone, while the 0–12 mm total diameter had lower corneal densitometry values in the other zones and in total in the high myopic group [13]. Although the groups we compared were different, we observed in our study that the myopic cases were not different than the hyperopic cases, but had lower COD values in the central and posterior 6–10 mm pericentral zone compared to emmetropic cases. However, high-diopter and pathologic cases were not included in our study.

We found a negative correlation between the central corneal thickness (CCT) and COD for the all depth layers of the central and pericentral annular zones in myopic cases in this study. Unlike our study, Dong et al. have found a positive correlation between the central corneal thickness and total corneal densitometry in highly myopic cases [13]. Cankaya et al. have found no correlation between CCT and corneal densitometry values [5]. We observed that the corneal densitometry values for all corneal depth layers increased only in the 6–10 mm zone as the CCT value increased, thus causing more corneal backscattering in hyperopic cases. This has raised the question of whether the COD values of the zones that are flattened during refractive surgery have a possible effect on the resultant image quality as the mid-peripheral zone is targeted in hyperopic eyes while the central zone is targeted in myopic eyes.

COD values increasing with age have been found in studies conducted with subjects at an advanced age where corneal densitometry values in various refractive errors were evaluated in healthy corneas [5, 14, 15]. Changes occurring in the structure of the cornea with age were presented as the reason for this result, due to the following changes: thickening of the epithelial basal membrane, reformation of the stromal collagen fibers increasing the thickness of Descemet's membrane, and decreased endothelial cell function accompanied by increases in stromal hydration. A COD value increasing with age was only found in emmetropic cases in the age group of < 18 years in our study, but no correlation was found between the age and corneal densitometry values in myopic and hyperopic cases. The contrasting results in the literature may be due to the investigation of different age groups and different refractive errors. The emmetropization process seems to depend on the visual input being normal, and the lack of a normal input could disturb the process, resulting in refractive errors [16–19]. This made us consider that COD values may contribute to the development of refractive errors due to the lack of clear visual input.

The presence of COD values in various zones in myopic and hyperopic cases that are different than emmetropes may be balanced by various optical factors in eyes with different refractive errors. The main part of the emmetropization process is known to be completed within the first 6 years of life [16]. Considering that the major part of ocular development had already been completed in our study that included pediatric patients above the age of 6 years, it would be appropriate to investigate with longitudinal studies how light backscattering in the 0–6 years age range can change during the emmetropization process.

The ocular biometric parameters including axial length (AL), anterior chamber depth (ACD), and lens thickness (LT) are known to be significantly correlated with refractive errors. These parameters have been found to be lower in hyperopic eyes than in myopic and emmetropic eyes [20]. Tomomatsu et al. have shown that the degree of hyperopia inversely correlates with the AL [21]. The increase in axial length during ocular growth in myopic eyes has been shown to be balanced by the decrease in the lens thickness [22]. Lee et al. have found the deepest ACDs in myopic eyes and the shallowest ACDs in hyperopic eyes in children [23]. Similarly, we observed ACD and anterior chamber volume values to be lowest in the hyperopic cases and highest in the myopic cases in our study, while both parameters were significantly different than in the emmetropic cases. Again similar to the same study [23], we encountered a shallower ACD in hyperopic eyes as the degree of hyperopia increased.

In conclusion, increased light backscattering results in the reduction of the amount of light reaching the retina and impairs the quality of vision. In the present study, the COD values were significantly lower in hyperopic eyes than in myopic and emmetropic eyes in children. The COD values also increased with age in emmetropic eyes. We believe that further and longitudinal studies are needed to support the significance of this result in clinical practice and its relevance for the optical system.

Declarations

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Competing Interests:

The authors declare that there is no competing of interest regarding the publication of this paper.

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Ethics approval: All procedures performed in studies involving human participnts were in accordance with the ethical standarts of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the local Ethics Committee of Ulucanlar Reseaarch and Education Hospital.

Consent to participate: Informed consent was obtained from all individual participants included in the study.

Consent to publish: Informed consent was obtained from all individual participants included in the study.

Animal research: None

References

1. Spadea L, Maraone G, Verboschi F, Vingolo EM, Tognetto D (2016) Effect of corneal light scatter on vision: a review of the literature. Int J Ophthalmol 9(3):459–464
2. Marshall GE, Konstas AG, Lee WR (1991) Immunogold fine structural localization of extracellular matrix components in aged human cornea. II. Collagen types V and VI. Graefes Arch Clin Exp Ophthalmol 229(2):164–171
3. Müller LJ, Pels E, Lucas RH, Schurmans M, Gijs F, Vrensen JM (2004) A new three-dimensional model of the organization of proteoglycans and collagen fibrils in the human corneal stroma. Exp Eye Res

78(3):493–501
4. Applegate AR, Marsack JD, Ramos R, Sarver EJ (2003) Interaction between aberrations to improve or reduce visual performance. J Cataract Refract Surg 29(8):1487–1495
5. Cankaya AB, Tekin K, Kiziltoprak H, Karahan S, Yilmazbas P (2018) Assessment of corneal backward light scattering in the healthy cornea and factors affecting corneal transparency. Jpn J Ophthalmol 62(3):335–341
6. Nishida T (2008) The cornea: stasis and dynamics. Nippon Ganka Gakkai Zasshi 112(3):179–212; discussion 213
7. Otri AM, Fares U, Al-Aqaba MA, Dua HS (2012) Corneal densitometry as an indicator of corneal health. Ophthalmology 119(3):501–508
8. Anayol MA, Bostancı B, Şekeroğlu MA, Şimşek M, Günaydın S, Yılmazbaş P (2017) Assessment of Corneal Densitometry in Rheumatoid Arthritis Patients. Turk J Ophthalmol 47(3):125–129
9. Chu HY, Ching-Hsi Hsiao CH, Chen PY, Ma DH, Chang CJ, Hsin-Yuan Tan HY (2017) Corneal Backscatters as an Objective Index for Assessing Fuchs' Endothelial Corneal Dystrophy: A Pilot Study. J Ophthalmol 8747013. doi:10.1155/2017/8747013
10. Lopes B, Ramos I, Ambrósio R Jr (2014) Corneal densitometry in keratoconus. Cornea 33(12):1282–1286
11. Sekeroglu MA, Anayol MA, Gulec M, Atalay M, Ozgul Yilmazoglu M, Yilmazbas P (2016) Corneal Densitometry: A New Technique for Objective Assessment of Corneal Clarity in Pseudoexfoliation Syndrome. J Glaucoma 25(9):775–779
12. Clare O'Donnell C, Wolffsohn JS (2004) Grading of corneal transparency. Cont Lens Anterior Eye 27(4):161–170
13. Dong J, Zhang Y, Zhang H, Jia Z, Zhang S, Sun B, Han Y, Wang X (2018) Corneal densitometry in high myopia. BMC Ophthalmology 18:182–188
14. Garzón N, Poyales F, Illarramendi I, Mendicute J, Jáñez Ó, Caro P, López A, Argüeso F (2017) Corneal densitometry and its correlation with age, pachymetry, corneal curvature, and refraction. Int Ophthalmol 37(6):1263–1268
15. Dhubhghaill SN, Rozema JJ, Jongenelen S, Hidalgo IR, Zakaria N, Tassignon MJ (2014) Normative Values for Corneal Densitometry Analysis by Scheimpflug Optical Assessment. Invest Ophthalmol Vis Sci 55:162–168
16. Flitcroft DI (2014) Emmetropisation and the aetiology of refractive errors. Eye (Lond) 28(2):169–179
17. Charman WN, Radhakrishnan H (2010) Peripheral refraction and the development of refractive error: a review. Ophthalmic Physiol Opt 30(4):321–338
18. SmithEL 3rd, Hung LF (1999) The role of optical defocus in regulating refractive development in infant monkeys. Vision Res 39(8):1415–1435
19. Smith EL 3rd, Hung L-F, Arumugam LF B (2014) Visual regulation of refractive development: insights from animal studies. Eye (Lond) 28(2):180–188

20. Dogan M, Elgin U, Sen E, Tekin K, Yilmazbas P (2019) Comparison of anterior segment parameters and axial lengths of myopic, emmetropic, and hyperopic children. Int Ophthalmol 39(2):335–340
21. Tomomatsu T, Kono S, Arimura S, Tomomatsu Y, Matsumura T, Takihara Y, Inatani M, TakamuraY (2013) Relationship between lenticular power and refractive error in children with hyperopia. Clin Ophthalmol 7:601–606
22. Shih YF, Chen TC, Chiang TH, Lin LLK, Hung PT (2011) Changes of Anterior Segment During Childhood: A Biometric Study. J Med Ultrasound 19(2):33–40
23. Lee JW, Yau GS, Woo TT, Yick DW, Tam VT, Yuen CY (2014) The anterior chamber depth and retinal nerve fiber layer thickness in children. Sci World J 2014:538283

Tables

Table 1. The demographic characteristics of the subjects

	Emmetropic	Myopic	Hyperopic	p
Number of subjects, %	61 (28.2)	66 (30.6)	89 (41.2)	
Age (mean±SD), years	11.5±2.1	11.7±2.8	10.9±2.3	0.091*
(min-max)	(7 to 16)	(6 to 16)	(7 to 18)	
Sex (n)				
Female/Male, %	16 (26.2)/45 (73.8)	13 (19.7)/53 (80.3)	19 (21.3)/70 (78.7)	0.654**
Refraction errors	0	-2.2±3.4	3.5±1.9	**<0.001***
(min-max)		(-13 to -0.25)	(0.25 to 8.25)	
LogMAR visual acuity	0	0.07±0.2	0.1±0.1	**<0.001***
(min-max)		(0 to 1)	(0 to 1.3)	

*: Kruskal-Wallis test; **: Chi-square test, Boldfaced values are statistically significant (p<0.05).

Table 2. The anterior segment parameters of the subjects

Parameters (mean±SD), (min-max)	Emmetropic (n=61)	Myopic (n=66)	Hyperopic (n=89)	p value	Bonferroni-adjusted p value
Mean corneal curvature anterior, D	43.5±1.3	43.8±1.3	42.7±1.7	<0.001	0.124[a], **0.007[b], <0.001[c]**
Mean corneal curvature posterior, D	-6.3±0.2	-6.3±0.3	-6.2±0.3	0.002	0.919[a], **0.002[b], 0.003[c]**
Maximal corneal curvature, D	44.6±1.4	44.9±1.4	44±1.8	0.007	0.332[a], 0.047[b], **0.002[c]**
Central corneal thickness, µm	561.4±26.8	553.8±31.6	561.4±33.5	0.290	---
Thinnest corneal thickness, µm	555.6±26.2	547.4±34.2	548.7±38.4	0.492	---
Corneal volume, mm^3	62.5±3.1	61.5±3.7	61.6±4	0.258	----
Anterior chamber depth, mm	3.2±0.3	3.3±0.3	3±0.4	<0.001	**0.005[a], 0.006[b], <0.001[c]**
Anterior chamber volume, mm^3	191.4±32.6	210.8±31.9	175.7±34.9	<0.001	**0.007[a], 0.008[b], <0.001[c]**
Iridocorneal angle, degrees	39.1±6.9	39.6±7.1	36.7±5.7	0.013	0.667[a], 0.029[b], **0.007[c]**
White-to-white corneal diameter, mm	11.9±0.4	11.8±0.4	11.9±0.6	0.400	---

p[a]: p value difference from emmetropic to myopic participants; p[b]: p value difference from emmetropic to hyperopic participants; p[c]: p value difference from myopic to hyperopic participants. Boldfaced values are statistically significant (p<0.016).

Table 3. The mean corneal densitometry values in gray scale units for the concentric zones of the anterior, central and posterior, and total corneal layers in 4 concentric annular zones.

Zones (mean±SD)	Emmetropic	Myopic	Hyperopic	p* value	Bonferroni-adjusted p value**
Anterior layer, 120 µm					
0-2 mm	17.3±1.2	17.7±1.5	17±1.3	0.045	0.309[a], 0.190[b], **0.014[c]**
2-6 mm	15.7±1.2	15.8±1.3	15.3±1.2	0.067	---
6-10 mm	14.8±3.5	14±1.6	14.7±3.7	0.303	---
10-12 mm	27±8.3	26.3±8.4	23.5±9.1	0.02	0.732[a],**0.012[b]**, 0.03[c]
0-12 mm (total)	17.4±2.3	17.2±1.7	16.6±2.3	0.013	0.755[a], **0.011[b], 0.016[c]**
Central layer					
0-2 mm	11.4±0.9	11.3±1	11.1±0.8	0.012	0.189[a], **0.003[b]**,0.114[c]
2-6 mm	10.3±0.6	10.2±0.9	10±0.8	0.016	0.064[a], **0.004[b]**, 0.365[c]
6-10 mm	9.6±1.4	9.1±0.9	9.7±2	0.013	**0.002[a]**, 0.257[b], 0.078[c]
10-12 mm	15.2±3.3	15.5±4	14.2±5.2	0.015	0.633[a], 0.025[b], **0.009[c]**
0-12 mm (total)	11.6±0.9	10.9±1.1	10.6±1.2	0.015	0.281[a], **0.005[b]**, 0.079[c]
Posterior layer, 60 µm					
0-2 mm	9.6±1.0	9.3±0.9	8.7±0.8	<0.001	0.048[a], <**0.001[b]**, <**0.001[c]**
2-6 mm	15.7±1.2	15.9±1.3	15.3±1.2	<0.001	0.011[a], **<0.001[b], 0.013[c]**
6-10 mm	8.8±0.9	8.3±0.9	8.5±1.3	0.003	**0.001[a], 0.005[b]**, 0.798[c]
10-12 mm	11.1±1.9	11.5±2.5	10.7±2.6	0.029	0.524[a], 0.084[b], **0.010[c]**

0-12 mm (total)	9.4±1.4	9.0±0.8	8.7±0.9	<0.001	0.116[a], <**0.001**[b], **0.006**[c]
Total Thickness					
0-2 mm	13±2.1	12.8±1.1	12.3±0.9	0.001	0.696[a], **0.001**[b], **0.003**[c]
2-6 mm	11.6±1	11.5±1	11.2±0.9	0.006	0.261[a], **0.002**[b], 0.059[c]
6-10 mm	11.1±1.9	10.5±1.1	11±2.3	0.123	---
10-12 mm	17.8±4.1	17.8±4.6	16.1±5.3	0.013	0.925[a], **0.014**[b], **0.012**[c]
0-12 mm(total)	12.6±1.2	12.4±1.1	12±1.4	0.003	0.472[a], **0.002**[b], **0.015**[c]

*:Kruskal-Wallis test (p<0.05), **: Bonferroni-adjusted Kruskal-Wallis test (p<0.016), boldfaced values are statistically significant. p^a: p value difference from emmetropic to myopic participants; p^b: p value difference from emmetropic to hyperopic participants ; p^c: p value difference from myopic to hyperopic participants. Boldfaced values are statistically significant (p<0.016).

Table 4. Correlation values for age and corneal optical densitometry

		Age		
		Correlation coefficient, r; p* value		
	Zones	Emmetropic (n=61)	Myopic (n=66)	Hyperopic (n=89)
Anterior layer (120 µm)	0-2 mm	**0.442; <0.001**	0.161; 0.196	0.079; 0.463
	2-6 mm	**0.445; <0.001**	0.113; 0.365	0.043;0.687
	6-10 mm	0.039; 0.736	-0.037; 0.768	0.025; 0.818
	10-12 mm	-0.102; 0.370	0.146; 0.810	0.158; 0.138
	0-12 mm (total)	0.083; 0.469	0.138; 0.196	0.138; 0.196
Central layer	0-2 mm	**0.468; <0.001**	0.024; 0.851	0.141; 0.187
	2-6 mm	**0.479; <0.001**	-0.007; 0.955	0.066; 0.538
	6-10 mm	**0.242; 0.031**	0.016; 0.898	-0.013; 0.904
	10-12 mm	0.001; 0.994	0.196; 0.115	0.148; 0.165
	0-12 mm (total)	**0.264; 0.019**	0.145; 0.247	0.150; 0.160
Posterior layer (60 µm)	0-2 mm	**0.225; 0.046**	0.005; 0.969	0.149; 0.163
	2-6 mm	**0.303; 0.007**	-0.007; 0.958	0.127; 0.236
	6-10 mm	**0.238; 0.035**	-0.003; 0.983	0.016; 0.884
	10-12 mm	0.141; 0.214	0.157; 0.208	0.011; 0.915
	0-12mm (total)	**0.263; 0.019**	0.125;0.316	0.115; 0.282
Total thickness	0-2 mm	**0.409; <0.001**	0.097; 0.438	0.148; 0.166
	2-6 mm	**0.431; <0.001**	0.050; 0.692	0.081; 0.448
	6-10 mm	0.157; 0.167	-0.030; 0.810	0.017; 0.877
	10-12 mm	-0.019; 0.871	0.179; 0.151	0.156; 0.145
	0-12 mm (total)	0.195; 0.085	0.109; 0.383	0.180; 0.091

*: Spearman rank test, Boldfaced values are statistically significant (p<0.05).

Table 5. Correlations between spherical equivalent values and corneal morphological parameters in myopic and hyperopic patients

	Spherical equivalent	
	Correlation coefficient, r; p value	
	Myopic (n=66)	Hyperopic (n=89)
Mean corneal curvature anterior, D	-0.077; 0.538	-0.036; 0.737
Mean corneal curvature posterior, D	0.001; 0.992	-0.024; 0.826
Maximal corneal curvature, D	**-0.281; 0.022**	0.052; 0.628
Central corneal thickness, µm	-0.040; 0.751	0.042; 0.698
Thinnest corneal thickness, µm	-0.006; 0.960	-0.036; 0.738
Corneal volume, mm^3	-0.031; 0.807	0.056; 0.600
Anterior chamber depth, mm	0.109; 0.383	**-0.310; 0.003**
Anterior chamber volume, mm^3	0.210; 0.091	0.420; 0.063
Iridocorneal angle, degrees	-0.097; 0.439	-0.916; 0.066
White-to-white corneal diameter, mm	-0.019; 0.882	-0.100; 0.361

Boldfaced values are statistically significant ($p<0.05$).

Table 6. Correlation values for spherical equivalent and corneal optical densitometry

		Spherical equivalent	
		Correlation coefficient, r; p value	
	Zones	Myopic (n=66)	Hyperopic (n=89)
Anterior layer	0-2 mm	-0.054; 0.665	**-0.282; 0.008**
(120 µm)	2-6 mm	0.005; 0.971	**-0.222; 0.036**
	6-10 mm	-0.007; 0.957	-0.023; 0.833
	10-12 mm	0.139; 0.266	0.111; 0.300
	0-12 mm (total)	0.014; 0.912	0.021; 0.846
Central layer	0-2 mm	-0.048; 0.699	**-0.210; 0.048**
	2-6 mm	-0.004; 0.975	-0.050; 0.640
	6-10 mm	-0.007; 0.957	0.130; 0.225
	10-12 mm	0.022; 0.860	**0.252; 0.017**
	0-12 mm (total)	-0.091; 0.465	0.193; 0.069
Posterior layer	0-2 mm	0.063; 0.614	-0.218; 0.232
(60 µm)	2-6 mm	0.110; 0.377	-0.079; 0.461
	6-10 mm	0.033; 0.796	**0.220; 0.038**
	10-12 mm	-0.016; 0.900	**0.398; <0.001**
	0-12 mm (total)	0.004; 0.972	**0.226; 0.033**
Total thickness	0-2 mm	0.018; 0.888	**-0.231; 0.029**

2-6 mm	0.042; 0.736	-0.157; 0.142
6-10 mm	0.008; 0.949	0.086; 0.425
10-12 mm	0.077; 0.540	0.193; 0.069
0-12 mm (total)	0.009; 0.940	0.113; 0.293

Boldfaced values are statistically significant (p<0.05).

Table 7. Correlation values for central corneal thickness and corneal optical densitometry

		Central corneal thickness	
		Correlation coefficient, r; p value	
	Zones	Myopic (n=66)	Hyperopic (n=89)
Anterior layer (120 µm)	0-2 mm	-0.237; 0.055	0.068; 0.525
	2-6 mm	**-0.275; 0.025**	0.111; 0.298
	6-10 mm	-0.104; 0.408	**0.238; 0.025**
	10-12 mm	0.030; 0.814	0.047; 0.660
	0-12 mm (total)	-0.130; 0.300	0.110; 0.306
Central layer	0-2 mm	**-0.410; 0.001**	-0.180;0.091
	2-6 mm	**-0.417; <0.001**	-0.087; 0.420
	6-10 mm	-0.211; 0.089	**0.234; 0.028**
	10-12 mm	-0.040; 0.752	0.128; 0.231
	0-12 mm (total)	-0.239; 0.053	0.122; 0.256
Posterior layer (60 µm)	0-2 mm	**-0.370; 0.002**	0.029; 0.790
	2-6 mm	**-0.316; 0.010**	0.112; 0.296
	6-10 mm	-0.195; 0.116	**0.222; 0.037**
	10-12 mm	-0.109; 0.382	0.077; 0.474
	0-12 mm (total)	-0.213; 0.085	0.151; 0.158
Total thickness	0-2 mm	**-0.351; 0.004**	-0.007; 0.949
	2-6 mm	**-0.383; 0.002**	0.072; 0.501
	6-10 mm	-0.157; 0.207	**0.215; 0.043**
	10-12 mm	-0.001; 0.992	0.081; 0.453
	0-12 mm (total)	-0.210; 0.091	0.122; 0.255

Boldfaced values are statistically significant (p<0.05).

Figures

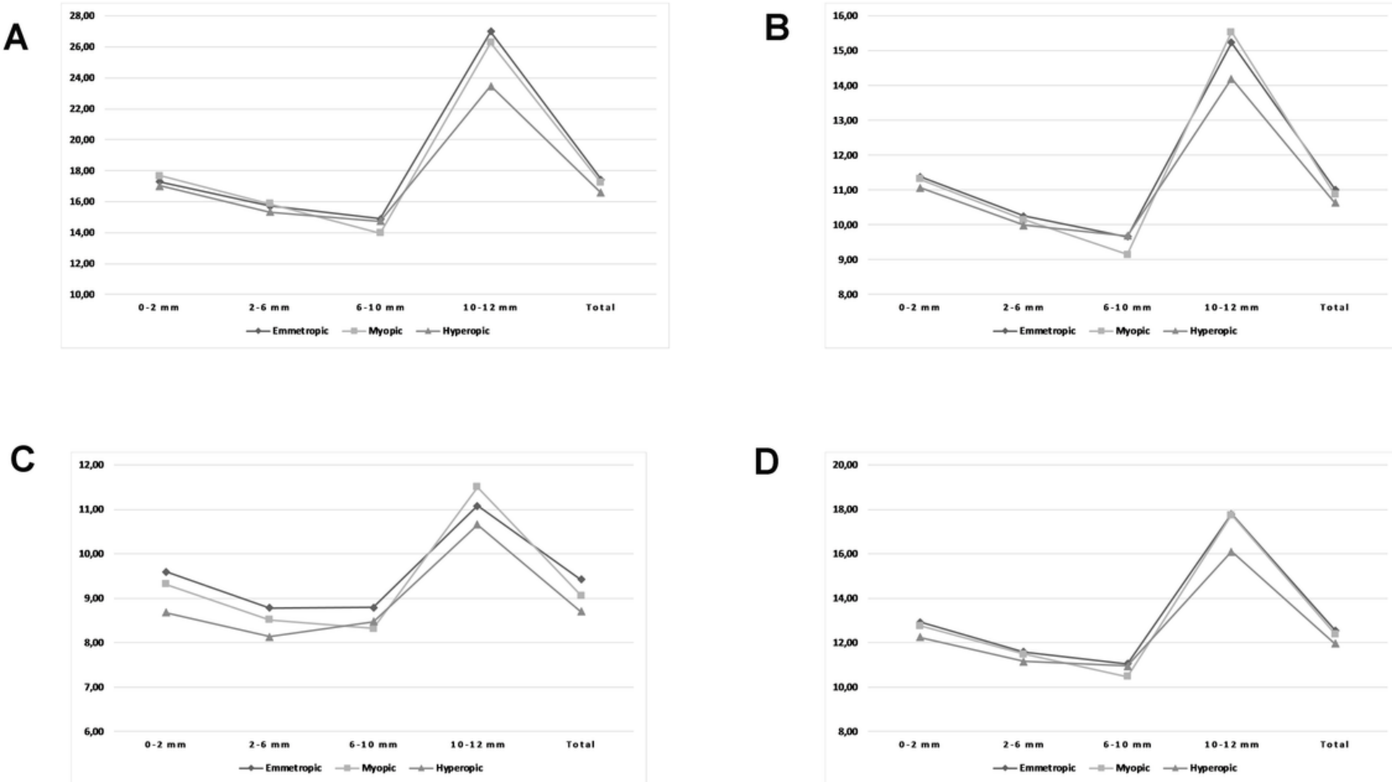

Figure 1

A: The mean densitometry values of the anterior layer for all annular zones in emmetropic, myopic and hyperopic children. B: The mean densitometry values of the central layer for all annular zones in emmetropic, myopic and hyperopic children. C: The mean densitometry values of the posterior layer for all annular zones in emmetropic, myopic and hyperopic children. D: The mean densitometry values of the total corneal thickness for all annular zones in emmetropic, myopic and hyperopic children.