SJIF Impact Factor: 5.464

WORLD JOURNAL OF ADVANCE HEALTHCARE RESEARCH

ISSN: 2457-0400
Volume: 7.
Issue: 7.
Page N. 93-100
Year: 2023

Original Article www.wjahr.com

INVESTIGATION OF THE RELATIONSHIP BETWEEN CORNEAL SURFACE CURVATURES AND AXIAL LENGTH OF THE EYE WITH ENDOTHELIUM OF THE CORNEA IN A GROUP OF ADULTS

***[1]Rawan Harfoush, [2]Yusuf Suleiman and [3]Mahmoud Rajab**

[1]Department of Ophthalmology, Tishreen University Hospital, Lattakia, Syria.
[2,3]Department of Ophthalmology, Professor, Tishreen University Hospital, Lattakia, Syria.

Received date: 08 April 2023 **Revised date:** 29 April 2023 **Accepted date:** 19 May 2023

***Corresponding Author: Rawan Harfoush**
Department of Ophthalmology, Tishreen University Hospital, Lattakia, Syria.

ABSTRACT

Objective: To study the relationship between axial length of the eye, corneal curvature, horizontal corneal diameter, central corneal thickness and corneal endothelial cell morphology in young adults. **Methods:** In this cross-sectional study, 616 eyes of 308 patients attending the ophthalmological clinic at Tishreen University Hospital were studied between the years 2022-2023. All participants underwent a complete ophthalmologic examination including examination for refractive errors, anterior and posterior sections of the eye, and intraocular pressure in accordance with the inclusion and exclusion criteria, with the use of non-contact specular microscopy (Perseus, Cso, Italy), where an average of three measurements were taken for central corneal endothelial density (ECD), percentage of hexagonal cells (HEX), and coefficient of variation (COV). The corneal topography device (CSO/Sirius) was used to measure the corneal curvature CC in mm, its horizontal diameter HCD in mm, and its central thickness CCT. While an Aviso ultrasound A scan was used to measure the axial length AL in mm. **Results:** The values of endothelial cell density (ECD) and percentage of hexagonal cells (HEX) decreased statistically significantly, while the value of the coefficient of variation (COV) increased with the increasing of axial length, increasing of corneal flattening and its diameters as well as decreaseing in its central thickness. **Conclusion:** As the eyeball elongates, the cornea becomes more flatness and its diameters increase while its thickness decreases, with significant changes occur in the morphology of the corneal endothelial cells. These changes should be taken into account in planning for refractive surgeries and for comparison in reference studies.

KEYWORDS: Corneal endothelial cell density, axial length of the eye, central corneal thickness, corneal curvature, horizontal corneal diameter.

INTRODUCTION

The corneal endothelium consists of a single layer of cuboidal and hexagonal cells, which line the posterior corneal surface.[1,2] The cornea is supplied with a relatively fixed population of endothelial cells (3500–4000 cells/mm2) at birth.[1]

The CEC cells are responsible for regulating fluid and ion transport between aqueous humor and corneal stroma to maintain corneal thickness and transparency.[3] Unlike the epithelial cells, CEC are incapable of mitosis thus the number of cells diminish over time due to factors such as age, surgery, and trauma.[4,5] CEC have also been reported to be affected in myopia particularly myopia of high refractive power < -6.0D.[6–8]

It is well established that there is a gradual decrease in endothelial cell density (ECD) and a corresponding increase in polymegathism and pleomorphism with advancing age.[1,9–13] Clinically, the assessment of ECD and morphology can provide valuable information in relation to the functional reserve of the corneal endothelium.

Surprisingly, there have been few reports in the literature of the possible impact or association of axial length and corneal parameters on ECD in the normal eye.

The possible impact of axial length of the eye, corneal size, shape, curvature, and thickness on changes in ECD throughout life has largely been ignored. While a large horizontal corneal diameter was shown to correlate with a lower ECD count during early teenage years,[14] ECD in young adults was reported to be lower in longer and flatter myopic eyes.[7]

As a result of the importance of the accurate evaluation of the corneal endothelium in patients in general and in patients who will undergo eye surgery such as cataract surgery, glaucoma and refractive surgery, the evaluation of the corneal endothelium is considered an urgent need to assess the situation and thus preserving the transparency of the cornea, as it is during ocular surgery on the anterior section should be minimal surgical trauma.[15] However, despite the growing interest in intraocular refractive surgery procedures in young adults, there have been no previous reports that have specifically assessed the relationship between corneal tomographic parameters on ECD in normal young adults. The aim of this study was to investigate the possible impact of corneal thickness, corneal curvature, horizontal corneal diameter and axial length of the eye on the measurement of ECD values in healthy young adults in their third decade, age range 20–39 years.

MATERIALS AND METHODS

This study took place in the Ophthalmology Clinic at Tishreen University Hospital.

The inclusion criteria for this study were age 20-40 years old, no anisometropia and best corrected visual acuity (BCVA) 10/10 on Snellen Chart in each eye, no history of ocular or systemic disease, nor previous refractive surgeries, no use for contact lenses, if there was an astigmatism so not more than -1.00D, no pregnancy and with excluding of uncooperative patients.

This study was a cross-sectional study conducted to examine the morphology of corneal of endothelial cells in healthy Syrian young adults with emmetropia, myopia and hyperopia and its association with axial length, corneal curvatures, horizontal corneal diameter and central corneal thickness.

The participating adults came to the Ophthalmology Clinic for a routine examination or for correcting refractive errors and others were recruited through advertisements placed around the optometry clinic and by words of mouth. Written consent was obtained from the participants prior to data collection. Participants were first screened for eligibility based on the inclusion criteria.

All participants underwent a complete eye examination, including evaluation of visual acuity using Snellen chart. One drop of local topical anesthetic (Proxymetacaine Hydrochloride 0.5%, Alcaine, Alcon,15 mL) followed by three drops of cycloplegic eye drop (Cyclopentolate Hydrochloride 1%, Cyclogyl, Alcon, 15 mL) at 10 minutes interval for each drop, used to paralyze the ciliary muscle and inhibit accommodation. The amplitude of accommodation was assessed using an RAF rule to ensure that accommodation was paralyzed and cycloplegic refraction was conducted when pupil size achieves ≥5 mm. Cycloplegic refraction using open-field autorefractor (Grand Seiko/ GR- 3500ka). Slit lamp (CSO/ SL990) was used to examine the anterior eye structure, and corneal topographer (CSO/Sirius) was used to map the curvature of the corneal surface (CC), its central thickness (CCT) and its horizontal diameter (HCD). Before measurement, the subject's head was aligned with the instrument and a head strap was placed around the back of the head. The subject was advised to keep both eyes open and fixate on the target. By viewing the live image of the eye on the monitor, the examiner aligned the two fixation markers reflected by the instrument on the corneal surface before performing the scan. Axial length (AL) was measured using A-scan ultrasound biometry (Aviso ultrasound A scan). The A-Scan result was calculated by a single continuous beep which automatically records the mean of ten measurements with the standard deviation of <0.10 mm.

Central CEC morphologies [ECD, HEX and COV] were evaluated by a single examiner using a non-contact specular microscope (CSO/ Perseus). All measurements were carried out in automatic mode at 9-11am in the morning to avoid diurnal variation. Three microphotographs were performed for every eye (the difference of ECD values did not exceed_5%), and the average value was calculated.

We used Analytic Study (Cross Sectional), Description Statistical and Inferential Statistical, with the use of Independent T student test, One Way Anova test and Pearson Correlation, and the results were statistically significant with p-value < 5%.

Participants were also divided based on mean of AL for each refractive group was calculated and three groups were arbitrarily divided as follows: 1)AL <23 mm, 2) AL between 23-24 mm and 3) AL >24 mm. One way ANOVA F test was employed to analyze the differences of CEC morphology between the three groups. Pearson's correlation and Simple linear regression test were performed to determine the relationship between each of AL,CC, HCD, CCT and CEC morphology.

RESULTS

A total of 308 Syrian young adults (126 males/182 females) were examined. Demographic profile for all participants is depicted in Table 1. The mean age of all participants was 25.82±3.1 years old (range, 20 to 39 years old). There was no significant difference between genders for any factors including the mean age, ECD, HEX, COV, CC, HCD, CCT and AL.

Table 1: Demographic profile for all participants.

Sex	Number	Percentage
Male	126	40.9%
Female	182	59.1%

Table 2: The relation between mean ECD and Sex.

Sex	Mean ± SD	P-value
Male	2911.4±259.8	0.08
Female	2954.1±263.2	

Axial Length

The mean axial length of the eyes studied was 23.16 (SD 0.93) mm (Range 21.71–27.12 mm). When axial length values were compared with central ECD, HEX, COV values. A negative trend was evident between AL, ECD (r=-0,81, P=0.0001) (Figure1), and HEX (r=-0,74, P=0.0001) (Figure2), while a positive trend was evident between AL and COV (r=0,68, P=0.0001) (Figure3). The trend suggested that eyes with longer axial length values are associated with a lower central ECD, HEX and increasing in COV values. Table 3 The relation between ECD, HEX, COV and AL.

Table 3: The relation between corneal variants and AL.

Variants	Pearson Correlation	P-value
ECD	- 0.81	0.0001
HEX	- 0.74	0.0001
COV	0.68	0.0001

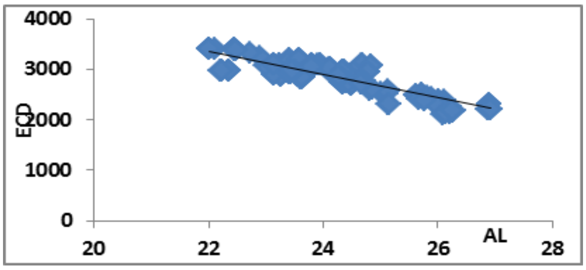

Figure 1: Relation between measured axial length and central endothelial cell density.

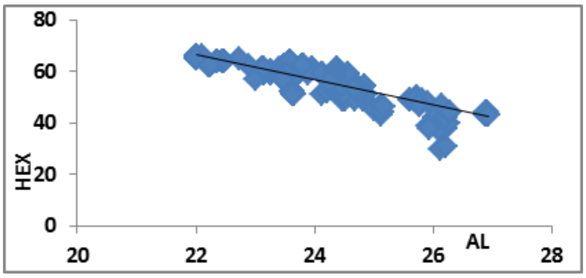

Figure 2: Relation between measured axial length and HEX.

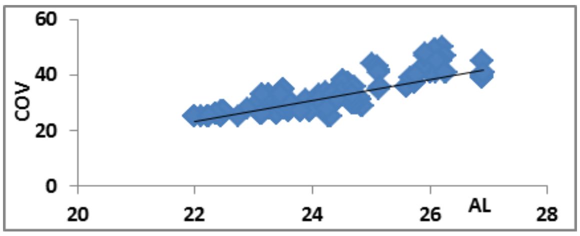

Figure 3: Relation between measured axial length and COV.

The patients were divided into three groups according to their axial length of the eye, in order to calculate the decrease between each group. We've found a statistically significant different between the mean central corneal ECD according to axial length of the eye. As the eye ball elongates, a decrease in central ECD was found for about 83.8 cells/mm^2 between the first two groups and for about 81,2cells/mm^2 between the last two groups as shown in (Table 4).

Table 4: The relation between mean ECD according to axial length.

AL	Mean ± SD(ECD)	P-value
<23	3099.6±192.04	0.002
23-24	3015.8±116.98	
>24	2934.6±248.7	

Corneal curvature

The mean corneal curvature for all corneas assessed was 7.825mm.

There was a statistically significant negative correlation identified between corneal curvature and central ECD (r=-0,41, P=0.0001) (Figure4), and HEX (r=-0,36, P=0.0001) (Figure5). whereas a statistically significant positive correlation identified between corneal curvature and central COV (r=0.33, P=0.005) as showed in (Figure6). Table 5 shows the relation between each variant and corneal curvature.

Table 5: The relation between ECD, HEX, COV and corneal curvatures.

Variants	Pearson Correlation	P-value
ECD	- 0.41	0.0001
HEX	- 0.36	0.001
COV	0.33	0.005

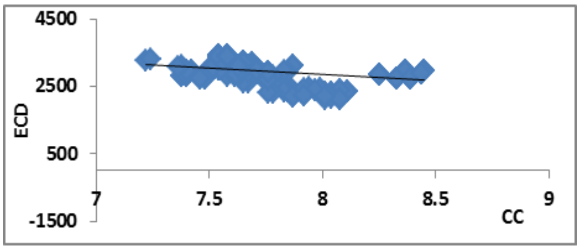

Figure 4: Relation between central ECD and CC.

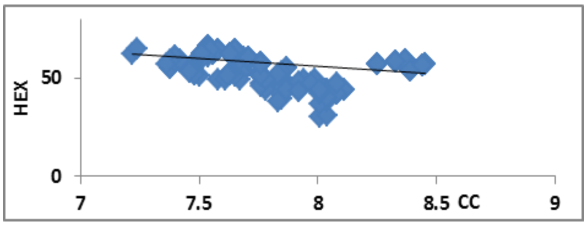

Figure 5: Relation between central HEX and CC.

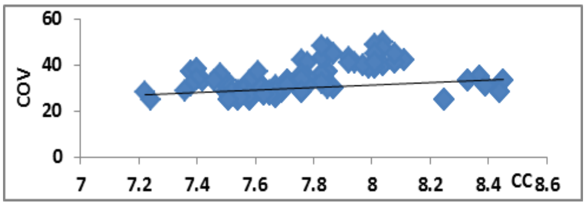

Figure 6: Relation between central COV and CC.

Horizontal corneal diameter

The mean horizontal corneal diameter (HCD) for the entire study group was 11.9±0.4mm and the range was 10.8–13.0mm. A statistically significant negative correlation between mean HCD and central ECD was identified (r=-0.58, P=0.0001) (Figure7). Analysis of the percentage of Hexagonality HEX and HCD revealed a significant negative relationship (r=-0.54, P=0.004) (Figure8). Whereas a statistically significant positive relation was found between COV and HCD (r=0.60, P=0.0001) (Figure9). Table 6 shows the relation between ECD,HEX,COV and HCD.

Table 6: The relation between ECD,HEX,COV and HCD.

Variants	Pearson Correlation	P-value
ECD	- 0.58	0.0001
HEX	- 0.54	0.004
COV	0.60	0.0001

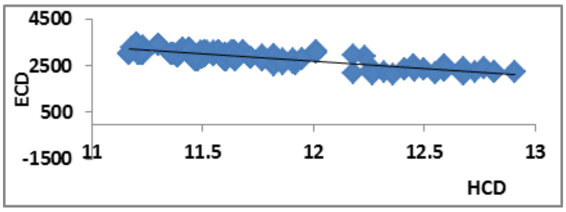

Figure 7: The relation between ECD and HCD.

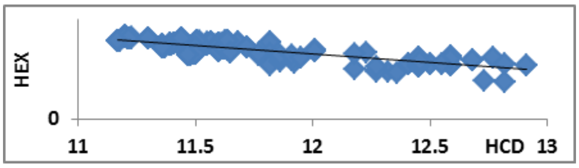

Figure 8: The relation between HEX and HCD.

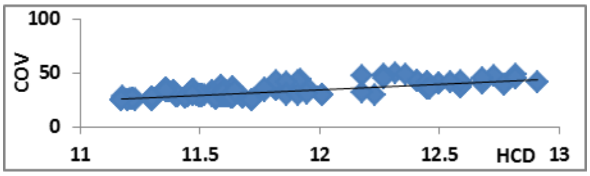

Figure 9: The relation between COV and HCD.

Corneal thickness

The mean central corneal thickness (CCT) was 540±43 mm (range 460–620 mm). When the mean central ECD values were compared with CCT values, a statistically significant correlation was identified (r=0.27, P=0.01) (Figure10). This indicates that lower ECD values were measured in thinner corneas. However, there was a clear trend for mean CCT to be positively correlated with the proportion of hexagonal cells HEX (indicating thinner corneas have a lower proportion of hexagonal cells (r=0.31, P=0.01) (Figure11). Whereas the relation between COV and CCT tended to be negative (r=-0.28, P=0.03) (Figure12). Table 7 shows the relations between these variants and CCT.

Table 7: The relation between corneal variants and CCT.

Variants	Pearson Correlation	P-value
ECD	0.27	0.01
HEX	0.31	0.01
COV	-0.28	0.03

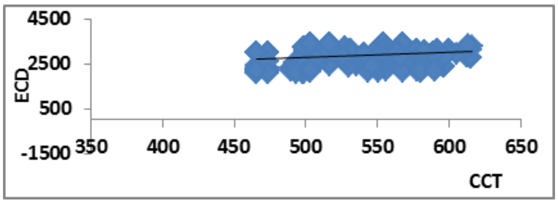

Figure 10: The relation between ECD and CCT.

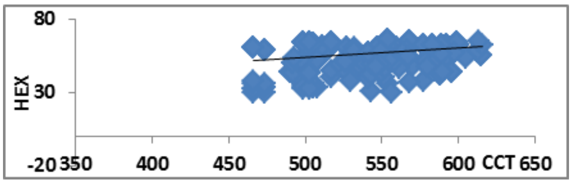

Figure 11: The relation between HEX and CCT.

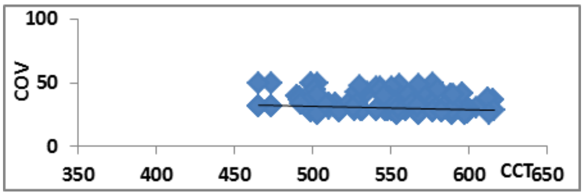

Figure 12: The relation between COV and CCT.

Axial length and corneal curvatures

By studying the relation between AL and CC, we found a statistically significant positive relation between the both variants which indicates that taller eyes are correlated with more flattened corneas (r=0.77, P=0.0001) (Figure13).

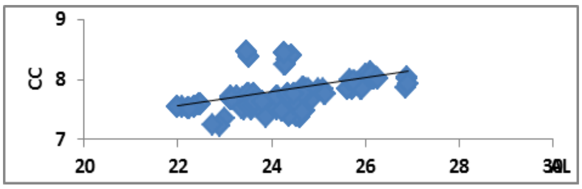

Figure 13: The relation between CC and AL.

And by studying the relation between AL/CC ratio and ECD we found a statistically significant negative correlation between them, which indicates that as the eye ball elongates the cornea tends to be more flattened with lower values of central ECD (r=-0.49, 0.001) (Figure14).

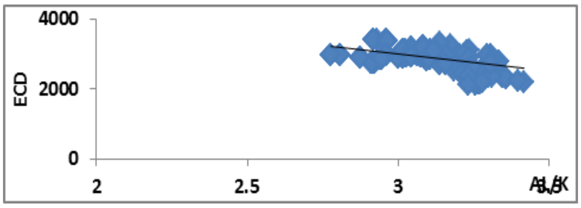

Figure 14: The relation between AL/CC ratio and ECD.

Endothelial cell density and age

The relation between central ECD and age was statistically significant with lower ECD values in older subjects. Which means that ECD values tends to decrease with advanced ages (r=-0.24, P=0.03) (Figure15).

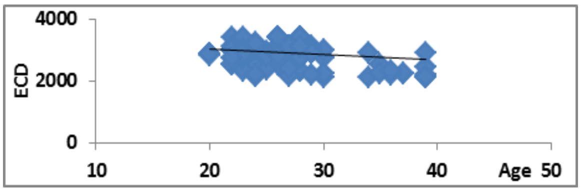

Figure 15: The relation between central ECD and age.

DISCUSSION

The mean value for ECD in this current study (3018±248.2 cells/mm2) was in concordance with that previously reported in the literature for young adults (range 2540-3411 cells/mm2).[7,16-20] When compared with mean ECD values reported for children (3400–4300 cells/mm2) and for elderly eyes (2324–3175 cells/mm2), a clear trend of decreasing mean ECD with advancing age is observed.[16,20-23,24-28] Consistent with the majority of other published reports, there was no significant difference in mean ECD based on gender in this study.[7,11,20,21,29,30]

In the present study, insignificant difference in CEC morphology was observed between genders, which support findings from other studies in adults[31,32] and children.[33,34] However in a study conducted in Japan,[35] it was shown that female participants had lower ECD values, increased COV and decreased HEX when compared to males. Their study was carried out among older adults with mean age 61.8_ 10.2 years with high myopia (SER ≤ -6D) and history of contact lens wear among its female participants. All these could contribute to the differences in findings since other studies have shown that increase in age,[34] presence high myopia,[36,37] contact lens wear[38] could affect CEC morphology.

CCT measurement in this study (540 µm) was slightly less than that reported by Sanchis-Gimeno et al[39] (554±16 µm), who studied the corneal thickness of 1000 young (range 20–30 years) emmetropic subjects using Orbscan II slit-scanning corneal topography system, while we used CSO/Sirius Italy in our study. Comparison of CCT with other published reports is limited due to differences in measurement technique.

Our study showed a statistically significant relationship between the axial length of the eye and corneal curvatures, as the axial length of the eye gets longer, the corneal curvatures increase, and hence increasing in the corneal flatness occurs.

These results can be explained by the fact that the corneal flattening may be a compensation to prevent the occurrence of myopia in spite of the elongation of the eye Park et al,[40] or considering the absence of an increase in the growth of corneal tissue, the corneal parenchyma may become thinner with the corneal flattening in a manner similar to what happens in Sclera in the context of increased axial length of the eye associated with myopia Chang el al.[7]

Our study was in concordant with Sang Hoon Park[40], who found that In shorter eyes, there was a tendency toward hyperopia, a steeper cornea, and a thicker RNFL, and in longer eyes toward myopia, a flatter cornea, and a thinner RNFL. Shu-Wen Chang[7] indicated that changes in the anterior segments as the eyeball elongates in myopia progression included flatter corneal curvature, decreased corneal thickness, as well as decreased endothelial density. In a study conducted to investigate the factors affecting corneal curvatures, Yue Ying Zhang et al[41] found an increase in corneal curvatures in conjunction with an increase of the axial length of the eye as well as an increase in the horizontal corneal radius, with many studies that confirmed the same idea in the medical literature a in children and adults. In a study conducted by Eghosasere Iyamu el al[42] they found that There was statistically significant inverse correlation between AL and CC, This was contrary to our study and the rest of the previous ones, and this difference may be due to the small number of the study sample used by them (70 patients) compared to our study (308 patients), in addition to the difference in race, and the difference in the device used in their study Bausch and Lomb Keratometer H-135A for corneal curvature, while we used CSO/Sirius Italy in our study.

We found a statistically significant correlation between the axial length and the morphology of the corneal endothelial cells, as the axial length increases, the ECD values and the percentage of hexagonal cells HEX decrease, and the COV increases. Where we found a decrease between the mean values of the corneal endothelial cell count by 84 cells/mm^2 between the first and second groups depending on the axial length and by 81 cells/mm^2 between the second and third groups.

Likewise, we found a statistically significant relationship between corneal curvatures and the morphology of the corneal endothelial cells, as corneal endothelial cell density decreased as corneal curvatures increased.

By studying of the relationship between the ratio of axial length of the eye and corneal curvatures AL/CC, with corneal endothelial cell density ECD, it turned out that with the increase of each of the axial length of the eye and corneal curvatures, the central corneal endothelial cell density decreases.

This decrease in the number of corneal endothelial cells can be attributed previously to the fact that the increase in the axial length of the eye results in a flattening of the cornea as a result of the circumferential tensile forces applied to it Chang W et al[7] and an increase in its area in conjunction with the subsequent increase in the size of the eyeball to be elongated by Delshad & Chun[36], and as a result, the endothelial cells will migrate and elongate to cover this expansion in the surface towards the periphery, which will result in a decrease in their central density, a decrease in the percentage of hexagonal cells, and an increase in the volume variation coefficient.

This is in agreement with a study conducted by Mohidin Norhani el al[43] which concluded that For every 1mm increase in axial length, endothelial cells density decreased by 73.27cells/mm2, hexagonality decreased by 2.32% and coefficient of variation increased by 1.75%. In a similar study by Delshad & Chun[36], they found a decrease in the corneal endothelial cell density ECD and the percentage of hexagonal cells HEX in eyes with high myopia with a longer axial length compared to eyes with mild myopia.

There are not many studies in the medical literature that have examined the morphology of corneal endothelial cells relative to the axial length. Rather, most of them focused on studying the relationship of the axial length to the ECD, as they noticed a decrease in central ECD as the axial length increases.[7,22,44]

While Vandana Panjwani[31] concluded that axial length has an indirect correlation with the corneal endothelial cell count which was statistically significant. Mei-Ru Chen[45] found a decrease in ECD values in only 7 eyes out of 50 patients without a statistically significant relationship, and this is probably due to their small sample size (50 patients) compared to our study (308 patients).

While Samaneh Delshad[46] and HY Patel[47], did not find a significant relationship between corneal curvatures and ECD, and this may be due to the small number of samples they studied, 154 right eyes of 154 patients and 62 patients, respectively, compared to our study of 616 eyes, and they used the Konan NSP-9900 device and the Confoscan 2 America device to measure ECD values, respectively, while we used the CSO/ Perseus device.

As for the study of the effect of the horizontal corneal diameter HCD on the corneal endothelial cell density ECD, we found a decrease in ECD and HEX, and an increase in COV as the HCD increases.

These changes can be understood as the HCD increases with the increase of the axial length of the eye Jiang2016 el al[48] and Park2010 el al.[40] And due to the association of corneal flatness with an increase in HCD, Zhang el al[41]; Therefore, we can say that an increase in the HCD when the eyeball elongates, results in an enlargement of the surface area of the cornea, and since the endothelial cells of the cornea cover the posterior surface of it, they extend towards the circumference to occupy the entire posterior surface of the cornea. Thus, a certain decrease in its central density was recorded as a result of this expansion.

This came in agreement with the results of the Muller 2002 el al[23], in which the relationship of HCD and ECD was studied in children 5-15 years old, and they found that every 1 mm increase in HCD, ECD decreases by 200cells/mm2. Uri Elbaz et al[49], studied children up to 5 years of age, found a significant decrease in ECD in the first two years of life, which was attributed to an increase in HCD, including an increase in the surface area of the cornea.

However, Giasson[50] and HY Patel[47] did not find a significant relationship between the two variables studied, and the reason could be the difference in the sample size of 35 and 62 patients, respectively, compared to our study of 308 patients, as well as the difference in the methods of measuring the HCD between the studies, Graphical tools and Orbscan II combined Placido, slit-scanning corneal tomography system and CSO/Sirius in our study.

We also found a significant decrease in ECD in patients with thinner corneas.

These results can be understood by hypothesizing the occurrence of biomechanical changes in the cornea similar to those that occur in the sclera with elongation of the eyeball in patients with axial myopia, which is due to a loss of the collagen fiber network.

Our results are consistent with what was found by HY Patel[47], who found a strong association between corneal thickness and corneal endothelial cell counts in adolescents, as well as Muller 2004 el al[22] in adults between 48-91 years of age. While our study did not agree with Mohidin Norhani el al[12], who did not find a relationship between the corneal endothelial cell count and its thickness. This may be a result of the different age groups studied, as well as the size of their sample used 111 children, and the fact that they relied on specular microscopy device to obtain the values of CCT, Topcon SP-2000P, while in our study we relied on the device CSO/Sirius.

CONCLUSION

We found statistically significant changes in corneal morphology with the elongation of axial length of the eye, as we found a decrease in ECD values HEX and an increase in COV with an increase in AL in the context of the development of axial myopia. These changes were also associated with an increase in CC, including an increase in corneal flatness, as well as an increase of HCD and a decrease in CCT.

ACKNOWLEDGMENTS

We wish to thank all medical staff in ophthalmology Department at Tishreen University Hospital for their hard work even with great difficulties.

REFERENCESE

1. Shaw E, Rao G, Arthur E. The functional reserve of the corneal endothelium. Trans Am Acad Ophthalmol Otolaryngol, 1978; 85: 640.
2. Kuwabara T. Current concepts in anatomy an histology of the cornea. Contact lens Intraoc Lens Med J., 1978; 4: 101.
3. Mishima S: Clinical investigations on the corneal endothelium- XXXVIII Edward Jackson Memorial Lecture. Am J. Ophthalmol, 1982; 93(1): 1–29.
4. Qazi Y, Wong G, Monson B, et al.: Corneal transparency: genesis, maintenance, and dysfunction. Brain Res. Bull, 2010; 81(2-3): 198–210.
5. Bourne WM: Corneal endothelium--past, present, and future. Eye Contact Lens, 2010; 36(5): 310–314.
6. Sheng H, Bullimore MA: Factors affecting corneal endothelial morphology. Cornea, Jun, 2007; 26(5): 520–525.
7. Chang SW, Tsai IL, Hu FR, Lin LL, Shih YF. The cornea in young myopic eyes. Br J Ophthalmol, 2001; 85: 916–920.
8. Urban B, Bakunowicz-Łazarczyk A, Kretowska M: Sródbłonekrogówki umłodziezy z krótkowzroczności̇a. Corneal endothelium in children and adolescents with myopia. Klin. Ocz, 2002; 104(5-6): 381–383.
9. Waring III G, Bourne W, Edelhauser H, Kenyon KR. The corneal endothelium. Normal and pathologic structure and function. Ophthalmology, 1982; 89: 531–590.
10. BourneM, Kaufman H. Specular microscopy of human corneal endothelium in vivo. Am J Ophthalmol, 1976; 81: 319–323.
11. Yee R, Matsuda M, Schultz R, Edelhauser HF. Changes in the normal corneal endothelial cellular pattern as a function of age. Curr Eye Res., 1985; 4: 671–678.
12. Sturrock G, Sherrard E, Rice N. Specular microscopy of the corneal endothelium. Br J Ophthalmol, 1978; 62: 809–814.
13. Cheng H, Jacobs P, McPherson K, Noble MJ. Precision of cell density and endothelial cell loss with age. Arch Ophthalmol, 1985; 103: 1478–1481.
14. Mu¨ller A. Assessment of eye growth-related changes in the corneal endothelium of children and young teenagers. Glasgow Caledonian University PhD Thesis, 2000.
15. Suleiman, Y. To investigate the relationship between the degree of astigmatism and the count of corneal endothel-cells and the proportion of hexagonal-cells. Tishreen University Journal for Research and Scientific Studies. Health Sciences SEies Syria, 2018; 40N(3): 409-17.
16. Doughty M, Muller A, Zaman M. Assessment of the reliability of human corneal endothelial cell density estimates using a noncontact specular microscope. Cornea, 2000; 19: 148–158.
17. Bigar F. Specular microscopy of the corneal endothelium: optical solutions and clinical results. Dev Ophthalmol, 1982; 6: 1–94.
18. Wilson R, Roper-Hall M. Effect of age on the endothelial cell count in the normal eye. Br J Ophthalmol, 1982; 66: 513–515.
19. Doughty M. Prevalence of 'non hexagonal' cells in the corneal endothelium of young Caucasian adults, and their inter-relationships. Ophthalmic Physiol Opt, 1998; 18: 415–422.
20. Rao S, Sen P, Fogla R, Gangadharan S, Padmanabhan P, Badrinath SS. Corneal endothelial cell density and morphology in normal Indian eyes. Cornea, 2000; 19: 820–823.
21. Laule A, Cable M, Hoffman C, Hanna C. Endothelial cell population changes of human cornea during life. Arch Ophthalmol, 1978; 96: 2031–2035.
22. Muller A, Craig J, Grupcheva C, McGhee C. The effects of corneal parameters on the assessment of endothelial cell density in the elderly eye. Br J Ophthalmol, 2004; 88: 325–330.
23. Muller A, Doughty M. Assessment of corneal endothelial cell density in growing children and its relationship to horizontal corneal diameter. Optom Vis Sci., 2002; 79: 762–770.
24. Snellingen T, Rao G, Shrestha J, Huq F, Cheng H. Quantitative and morphological characteristics of the human corneal endothelium in relation to age, gender, and ethnicity in cataract populations of South Asia. Cornea, 2001; 20: 55–58.
25. Johnston R, Hasany S, Rootman D. Endothelial cell analysis of corneas from donor eyes with an intraocular lens: a comparative study. Cornea, 1997; 16: 531–533.
26. Ventura A, Walti R, Bohnke M. Corneal thickness and endothelial density before and after cataract surgery. Br J Ophthalmol, 2001; 85: 18–20.
27. Azen SP, Smith RE, Burg KA, Reinig J. Variation in central and vertical corneal endothelial cell density in normal subjects. Acta Ophthalmol, 1981; 59: 94–99.
28. Price N, Barbour D. Corneal endothelial cell density in twins. Br J Ophthalmol, 1981; 65: 812–814.
29. Matsuda M, Yee R, Edelhauser H. Comparison of the corneal endothelium in an American and a Japanese population. Arch Ophthalmol, 1985; 103: 68–70.
30. Inoue K, Kimura C, Amano S, Oshika T, Tsuru T. Corneal endothelial changes twenty years after

penetrating keratoplasty. Jap J Ophthalmol, 2002; 46: 189–192.
31. Vandana P, Sachin D: A Comparative Study of Corneal Endothelial Cell Count and Central Corneal Thickness in Emmetropia and Axial Myopia. J. Evol. Med. Dent. Sci., 2020; 9(44): 3300–3304.
32. Yunliang S, Yuqiang H, Ying-Peng L, et al.: Corneal endothelial cell density and morphology in healthy Chinese eyes. Cornea., 2007; 26(2): 130–132.
33. Chen W, Li ZW, Zhao XM, et al.: Evaluation of corneal endothelium after UVA/riboflavin cross-linking in thin keratoconic corneas. Int. J. Ophthalmol, 2016; 9(2): 321–322.
34. Al Farhan H, Albaow W, Masoud W: Normal corneal endothelial morphology of healthy Saudi children aged 7-12 years. J. Egypt. Ophthalmol. Soc., 2014; 107: 63–66.
35. Aketa N, Uchino M, Kawashima M, et al.: Myopia, corneal endothelial cell density and morphology in a Japanese population-based cross-sectional study: the JPHC-NEXT Eye Study. Sci. Rep., 2021; 11: 6366.
36. Delshad S, Chun JM: Corneal endothelial cell density and morphology in low and moderate myopic Chinese eyes. Int. J. Ophthalmol, 2013; 6(4): 467–470.
37. Sanchis-Gimeno JA, Lieó-Pérez A, Alonso L, et al.: Corneal endothelial cell density decreases with age in emmetropic eyes. Histol. Histopathol, 2005; 20(2): 423–427.
38. Mohd-Ali B, Chen LY: The morphology of corneal endothelial cells in long term soft contact lens wearers in Kuala Lumpur. Cont. Lens Anterior Eye., 2021; 44(1): 72–75.
39. Sanchis-Gimeno JA, Lleo-Perez A, Alonso L, Rahhal MS. Anatomic study of the corneal thickness of young emmetropic studies. Cornea, 2004; 23: 669–673.
40. Park SH, Park KH, Kim JM, Choi CY. Relation between axial length and ocular parameters. Ophthalmologica., 2010; 224(3): 188-93. doi: 10.1159/000252982. Epub 2009 Oct 28. PMID: 19864929.
41. Zhang YY, Jiang WJ, Teng ZE, Wu JF, Hu YY, Lu TL, Wu H, Sun W, Wang XR, Bi HS, Jonas JB. Corneal curvature radius and associated factors in Chinese children: the Shandong Children Eye Study. PLoS One. Feb 6, 2015; 10(2): e0117481. doi: 10.1371/journal.pone.0117481. PMID: 25658095; PMCID: PMC4319968.
42. Iyamu E, Iyamu J, Obiakor CI. The role of axial length-corneal radius of curvature ratio in refractive state categorization in a nigerian population. ISRN Ophthalmol, Jul 13, 2011; 138941. doi: 10.5402/2011/138941. PMID: 24527225; PMCID: PMC3912816.
43. Norhani M, Low YC, Bariah MA, Mizhanim MS, Norlaili A. Corneal endothelial morphology of healthy myopic Malaysian children of Chinese ethnicity aged 8-9 years and its association with axial length. F1000Res, Sep, 7, 2022; 11: 339. doi: 10.12688/f1000research.110560.2. PMCID: PMC9459173.
44. Gincy Thomas, Padma B Prabhu, Prasannakumary.C, Jyothy.P.T, Charmaine B Solomon. Corneal Changes in Myopia in a Tertiary Centre in South India. JMSCR, *July, 2018; 06(07):* 889-894.
45. Mei-Ru Chen, Chih-Chiau Wu, Chieh-Chih, Sui-Mei Lee. Corneal Endothelial Density in High Myopes. Airity library, 1995/12/01. 440-446.
46. Samaneh Delshad. Corneal endothelial cell density and morphology are not correlated with corneal curvature, corneal thickness and gender. National Institutes of Ophthalmic Sciences, School of Optometry, Petaling Jaya, Selangor, Malaysia. Eur. J., 12.
47. Patel HY, Patel DV, McGhee CN. Identifying relationships between tomography-derived corneal thickness, curvature, and diameter and in vivo confocal microscopic assessment of the endothelium in healthy corneas of young adults. Eye (Lond), Feb, 2009; 23(2): 270-8. doi: 10.1038/sj.eye.6703091. Epub 2008 Feb 8. PMID: 18259207.
48. Jiang WJ, Wu H, Wu JF, Hu YY, Lu TL, Sun W, Guo DD, Wang XR, Bi HS, Jonas JB. Corneal diameter and associated parameters in Chinese children: the Shandong Children Eye Study. Clin Exp Ophthalmol, Mar, 2017; 45(2): 112-119. doi: 10.1111/ceo.12821. Epub 2016 Sep 28. PMID: 27527118.
49. Elbaz U, Mireskandari K, Tehrani N, Shen C, Khan MS, Williams S, Ali A. Corneal Endothelial Cell Density in Children: Normative Data From Birth to 5 Years Old. Am J Ophthalmol, Jan, 2017; 173: 134-138. doi: 10.1016/j.ajo.2016.09.036. Epub 2016 Oct 14. PMID: 27746297.
50. Giasson CJ, Gosselin L, Masella A, Forcier P. Does endothelial cell density correlate with corneal diameter in a group of young adults? Cornea, Jul, 2008; 27(6): 640-3. doi: 10.1097/QAI.0b013e31815e4062. PMID: 18580253.