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Original Article

PENTACAM STUDY OF ANTERIOR AND POSTERIOR CORNEAL ASTIGMATISM IN PATIENTS WITH KERATOCONUS AND HEALTHY CONTROLS

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Abstract

Introduction: *Keratoconus is a chronic, noninflammatory, progressive, ectatic corneal disorder that degrades vision due to myopia and irregular astigmatism. Recently, the priority of posterior corneal astigmatism has been identified when toric IOL is considered. The aim of the study was to assess and correlate the power and axis orientation of anterior and posterior corneal astigmatism in keratoconus patients and healthy controls.* ***Patients and methods:*** *This was a retrospective cross sectional comparative study which involve 100 eyes of 50 KC patients and 100 eyes of 50 control group. Which they have a scans of corneal tomography maps of good-quality that analyzed by pentacam.* ***Results****: The mean magnitudes of the ACA and PCA in KC group were higher than controls and the axis orientation of corneal astigmatism was 71% WTR for ACA and 73% ATR for PCA and there were significant correlations between ACA and PCA with TCA, the effect of ACA on TCA was 6.1% and of PCA on TCA was 9.2%.* ***Conclusion:*** *In KC magnitudes of the ACA and PCA were significantly higher than controls, and we found a significant correlation between the magnitudes of ACA, PCA to the magnitudes of TCA in both groups. The axis orientations of the ACA and PCA were WTR and ATR, respectively in most of KC cases.*

Keywords: *Keratoconus, Anterior corneal astigmatism, Posterior corneal astigmatism*

1. Introduction

Keratoconus (KC) is an idiopathic bilateral but usually asymmetric non-inflammatory progressive thinning process of the cornea. It manifests as characteristic central or paracentral cone-like ectasia of the cornea associated with irregular stromal thinning, which causing irregular astigmatism and vision impairment [1]. KC can be diagnosed in late stage by abnormal signs detected on slit lamp examination as Munson's sign and Rizzuti's sign which associated with decreased visual acuity. However, in early stages, prior to the appearance of slit lamp findings or visual affection, corneal topographical and tomographical analysis is important to detect signs of KC. Nowadays, Recent advanced corneal imaging techniques can assess the thickness and elevation of anterior and posterior corneal surfaces, providing valuable information. One of these techniques is Pentacam which used to diagnose & observe progression in keratoconus patients and also afford a detailed information about corneal tomography and

topography [2,3]. KC is the most common form of corneal ectasia, with an incidence of 50–230 per 100,000 persons [4]. It is potentially sight-threatening condition due to the associated visual problems which is variable according to the progression of the disease it may be asymptomatic in early stage up to significant loss of visual acuity due to irregular astigmatism, myopia, and corneal scarring in advanced stage. The management of keratoconus depends on its severity, in early stage, spectacles or soft contact lenses may be effective but in mild to moderate stage rigid gas-permeable contact lenses (RGPCLs) and scleral RGPCLs that cover the entire cornea are required. Also, corneal collagen cross-linking (CXL) and intracorneal rings (ICRs) is an effective. Furthermore, keratoplasty is confined for severe and advanced stage with impaired vision who could not use contact lenses [5, 6]. In the last few years, it has been shown that in healthy individuals the posterior corneal surface has not only a different amount of astigmatism but also a different alignment of the steep meridian [7,8]. This study aimed to assess and compare power and axis orientation of anterior and posterior corneal astigmatism in eyes with keratoconus and healthy controls.

2. Patients and Methods

This retrospective cross sectional comparative study involved 100 eyes of 50 KC patients and 100 eyes of 50 controls group (23 male, 27 female and 17 male, 33 female), respectively with mean age (28.02 ± 8.7 and 28.34 ± 6.4), respectively fig. (1). The involved subjects had a scans of corneal tomography maps of good-quality that analyzed by a rotating Scheimpflug imaging instrument (Pentacam HR; Oculus, Wetzlar, Germany) in the period from Oct. 2018 to Oct. 2020. The study was approved by the Institutional Review Board\Ethics Committee of the Faculty of Medicine at Assiut University, and was conducted in accordance with Declaration of Helsinki. The study was carried out at Alforsan eye center in Assiut where the equipment was available, after approval of its administration. Complete ophthalmic examination was performed for all patients, it included anterior segment examination with a slit lamp and dilated fundus examination.

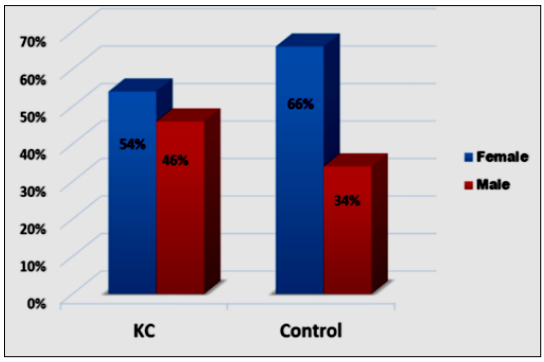

Figure 1: Demographic characteristics of the study groups**.**

2.1. *Inclusion criteria*

***)** Pateints with KC were included. KC was diagnosed by presence of characteristic topographic finding of KC (eg, corneal topography with asymmetric bow-tie pattern with or without skewed axis, paracentral or central steepening), and at least 1 KC sign (eg, stromal thinning, conical protrusion of the cornea at the apex, Fleischer ring, Vogt striae, or anterior stromal scar) on slit-lamp examination or asymmetric refractive errors with high progressive or irregular astigmatism. *) Eyes of Control group subjects in which the only ocular problem was refractive error.

2.2. *Exclusion criteria*

***)** Corneal scarring. ***)** Any ectatic conditions that were not clearly KC such as keratoglobus and PMD**. *)** Previous ocular surgery. ***)** For eyes of control group, history or diagnosis of ocular pathology as dry eye, glaucoma, retinal disease, or any previous ocular surgery led to exclusion.

2.3. *Assessment and diagnosis of keratoconus*

History: Detailed history was taken to document onset and progression of symptoms, other ocular diseases (such as recurrent epithelial erosions, dry eye syndrome, herpetic keratitis), history of autoimmune diseases, history of previous ocular surgery (such as keratorefractive surgeries). ***Ophthalmological examination:*** Included refraction, slit-lamp biomicroscopic examination of anterior and posterior segments and dilated fundus examination. ***Topographical examination:*** was done using the rotating Scheimpflug imaging instrument (Pentacam HR®; Oculus, Wetzlar, Germany). The patient was asked to place his/her chin on the chin rest and the forehead against the forehead strap, then to open both eyes and stare at the fixation target. After attaining a perfect positioning, the instrument automatically took 25 Scheimpflug images within 2 seconds. Image quality was checked, and for each eye only 1 examination with a high quality factor was recorded. The diagnosis of KC was based on the following parameters [9].

2.4. *Axial map abnormalities*

***)** Curvature power K > 48 D. ***)** Skewed radial axis (SRAX) > 21 degrees. ***)** Inferior -superior value (I-S) > 1.42D. ***)** Corneal astigmatism on anterior or posterior surface > 6 D. ***)** Against the rule astigmatism. ***)** Superior-Inferior (S-I) difference at the 5-mm zone >2.5 D.

2.5. *On the elevation maps:*

***)** Isolated island or tongue-like extension on either surface (Best fit sphere (BFS) mode). ***)** Elevation values >12 µm on the anterior elevation map in the central 5mm zone (Best fit toric ellipsoid (BFTE) mode). ***)** Elevation values >15 µm on the posterior elevation map (BFTE mode).

2.6. *Pachymetry/corneal thickness map*

)** Thinnest location < 470 µm. ***)** Displacement of the thinnest point > 500 µm from the center. ***)** Pachymetry difference asymmetry in two eyes at thinnest point >30 µm. ***)** S-I difference at the 5 mm circle >30 µm. ***)** Cone-like pattern on the thickness map. ***Classification: KC patients included in this study classified according to the Amsler-Krumeich classification (grade I, 46 eyes, grade II, 43 eyes, grade III, 11 eyes and grade IV, 0 eye). The Amsler‑Krumeich classification is based on astigmatism, myopia, keratometry, corneal transparency, and pachymetry. These results may vary in the advanced stages of KC [10]. Axis orientation of the anterior corneal astigmatism (ACA) and total corneal astigmatism (TCA) was considered as with the role (WTR) when the steep meridian was within 60-120 degrees and as against the role (ATR) when the steep meridian was within 0-30 degrees or 150-180 degrees. Otherwise, the remaining astigmatism was considered as oblique astigmatism. Since the dioptric power of the posterior corneal surface was negative, posterior corneal astigmatism (PCA) was considered as WTR when the steep meridian was within 0-30 degrees or 150-180 degrees, and as ATR when the steep meridian was within 60-120 degrees. Otherwise, the remaining astigmatism was considered as oblique astigmatism [11].

2.7. *Statistical analysis*

Data were verified, coded by the researcher and analyzed using IBM-SPSS 21 (Statistical Package for Social Science for Windows. Ver.21. Standard version. Copyright© IBM-SPSS Inc., 2012. Armonk, NY, USA. 2012). A p-value equals or less than 0.05 means statistically significant.

3. Results

The mean manifest refraction was (-3.54 ± 2.6) sphere, (-3.06 ± 2.1) cylinder and spherical equivalent (-5.09 ± 2.7) in KC group while (-2.65 ± 2.5) sphere, (-1.06 ± 1.0) cylinder and spherical equivalent (-3.18 ± 2.5) in control group. The manifest refraction was significant high in KC group than control (P= 0.014), (P < 0.001) and (P < 0.001) for sphere, cylinder power and spherical equivalent respectively, tab. (1). There was a significant increase in keratometry reading in the steepest meridian (K_1), keratometry reading in the flattest meridian (K_2) (front), mean keratometry reading (Km) (front and back), maximum keratometry reading (Kmax), ACA and PCA in KC group in comparison to controls (P< 0.001), while the other parameters K_1 (back) and K_2 (back) show no significant increase in KC group in comparison to controls (P= 0.926) and (P= 0.782), respectively, tab. (2). In KC group, WTR, ATR, and oblique astigmatism of anterior corneal surface were found in 71, 9 and 20 eyes, respectively. Whereas WTR, ATR, and oblique astigmatism of the posterior corneal surface were found in 6, 73 and 21 eyes, respectively. Also, in controls WTR, ATR, and oblique astigmatism of anterior corneal surface was found in 82, 4 and 14, respectively, whereas WTR, ATR, and oblique astigmatism of the posterior corneal surface was found in 0, 96 and 4, respectively, tab. (3). TCA was significantly higher in KC than controls (-3.31 ± 2.2) and (-1.13 ± 0.8) in each group, respectively (P < 0.001). Also, TCA shows a trend of a high prevalence of WTR astigmatism in the two groups, tab. (4). We found significant correlations between the magnitudes of ACA, PCA and TCA. In the both group magnitudes of ACA to those of TCA (Pearson correlation coefficient r = 0.352, P < .001) about 12.4% and between PCA to those of TCA (r = 0.424, P < .001) about 17.9%. In KC group, we found significant correlations between the magnitudes of ACA, PCA and TCA. The magnitudes of ACA to TCA (r = 0.248, P = 0.013) about 6.1% and the PCA to those of TCA (r = 0.304, P = 0.002) about 9.2%. In controls, there was a significant correlation (r = 0.829, P < .001) 68.7% and (r = 0.669, P < .001) 44.8% for ACA and PCA to TCA, respectively. Effects of ACA and PCA on TCA in the two groups, tab. (5). The mean corneal thickness at thinnest location (TL) was significantly lower in KC group than control group (451.05 ± 35.8) and (536.39 ± 31.9), respectively (P< 0.001). On the other hand, there was no significant difference in anterior chamber (AC) depth between the two groups. The difference in TL and AC depth between the study groups, tab. (6). There was a significant correlation between the ACA and PCA in both groups. In KC (r = 0.431, P < .001) and in control (r = 0.682, P < .001). Figures (2 & 3) show the correlation between ACA, PCA and TCA in KC and control group.

Table 1: Comparison of mean manifest refraction between the KC group and control group.

	KC Case (n=100)	Control (n=100)	P-value*
Sphere (D)			
• Mean ± SD	-3.54 ± 2.6	-2.65 ± 2.5	**= 0.014**
• Median (Range)	-3.4 (1.5: -14.8)	-2.5 (5.5: -7.3)	
Cylinder (D)			
• Mean ± SD	-3.06 ± 2.1	-1.06 ± 1.0	**< 0.001**
• Median (Range)	-3.0 (2.5: -9.8)	-0.75 (0.0: -4.0)	
Axis			
• Mean ± SD	82.28 ± 64.9	74.12 ± 70.0	= 0.369
• Median (Range)	75.5 (0 - 177)	50 (0 - 180)	
Spherical Equivalent (D)			
• Mean ± SD	-5.09 ± 2.7	-3.18 ± 2.5	**< 0.001**
• Median (Range)	-4.6 (0.0: -16.8)	-3.2 (4.8: -7.6)	

Mann Whitney U-test was used to compare the median differences.

Table 2: Comparison of anterior and posterior corneal parameters between the KC group and control group.

(Mean ± SD)	KC Case (n=100)	Control (n=100)	P-value*
Anterior			
• K_{1flat} (D)	45.89 ± 3.7	43.06 ± 1.9	**< 0.001**
• Axis1(flat)	83.97 ± 17.9	84.91 ± 15.1	**< 0.001**
• $K_{2\ steep}$ (D)	49.30 ± 4.0	44.33 ± 2.0	**< 0.001**
• $Axis_{\ 2\ steep}$	90.97 ± 22.7	92.11 ± 25.3	**< 0.001**
• Km (D)	47.52 ± 3.7	43.69 ± 1.9	**< 0.001**
• ACA (D)	-2.07 ± 0.3	-1.12 ± 0.1	**= 0.010**
• Kmax (D)	52.97 ± 6.2	44.86 ± 1.8	**< 0.001**
Posterior			
• K1 flat (D)	-6.65 ± 0.6	-5.87 ± 1.3	= 0.926
• $Axis_{1(flat)}$	85.90 ± 19.9	85.03 ± 16.8	= 0.935
• $K_{2\ steep}$ (D)	-7.33 ± 0.7	-6.41 ± 0.3	= 0.782
• $Axis_{2(steep)}$	90.67 ± 21.0	90.43 ± 14.1	= 0.923
• Km (D)	-6.96 ± 0.7	-6.24 ± 0.3	**< 0.001**
• PCA(D)	0.57 ± 0.05	0.34 ± 0.02	**< 0.001**

Independent t-test was used to compare the mean differences.

Table 3: Axis orientations of ACA vs. PCA between the KC group and control group.

(Mean ± SD)	KC Case (n=100)	Control (n=100)	P-value*
ACA			
• WTR	71 (71%)	82 (82%)	
• ATR	9 (9%)	4 (4%)	= 0.116
• OBLIQ	20 (20%)	14 (14%)	
PCA			
• WTR	6 (6%)	0 (0%)	
• ATR	73 (73%)	96 (96%)	**= 0.042**
• OBLIQ	21 (21%)	4 (4%)	
• P-value**	**< 0.001**	**< 0.001**	

Chi-square analysis was used to compare the frequency among groups.
****Mc-Nemar test was used to compare the proportion differences over time.***

Table 4: Total corneal astigmatism comparisons between the KC group and control group.

	KC Case (n=100)	Control (n=100)	P-value
TCA			
• Mean ± SD	-3.31 ± 2.2	-1.13 ± 0.8	**< 0.001***
• Median (Range)	-2.9 (-10.4: -0.3)	-0.90 (-3.3: -0.1)	
Axis			
• Mean ± SD	88.80 ± 67.2	81.00 ± 68.3	= 0.337*
• Median (Range)	80.5 (0 - 180)	67.5 (0 - 180)	
TCA axis orientations			
• WTR	65 (65%)	66 (66%)	
• ATR	12 (12%)	15 (15%)	= 0.624**
• OBLIQ	23 (23%)	19 (19%)	

Mann Whitney U-test was used to compare the median differences.
****Chi-square analysis was used to compare the frequency among groups.***

Table 5: Effect of ACA and PCA on TCA in the studied cohort.

	TCA		
	All Cases (n=200)	***KC (n=100)***	***Control (n=100)***
ACA r*	0.352	0.248	0.829
P-value**	< 0.001	= 0.013	< 0.001
R^2	12.4%	6.1%	68.7%
PCA r*	0.424	0.304	0.669
P-value**	< 0.001	= 0.002	< 0.001
R^2	17.9%	9.2%	44.8%

***Pearson correlation coefficient.*
****Based on normal approximation.*

Table 6: TL and AC depth comparisons between the KC group and control group.

	KC Case (n=100)	Control (n=100)	P-value
TL (µm)			
➢ **Mean ± SD**	451.05 ± 35.8	536.39 ± 31.9	**< 0.001***
➢ **Median (Range)**	455 (340 - 540)	532.5 (476 - 606)	
AC Depth (mm)			
➢ **Mean ± SD**	4.03 ± 3.3	3.64 ± 0.3	= 0.274**
➢ **Median (Range)**	3.7 (3 – 3.7)	3.6 (3 – 4.5)	

***Independent t-test was used to compare the means among groups.*
****Mann Whitney U-test was used to compare the median differences.*

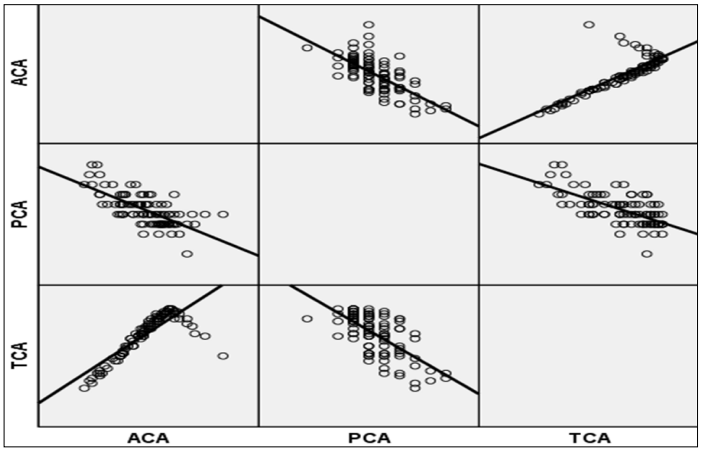

Figure 2: Correlation between ACA, PCA and TCA in control group.
***ACA:** Anterior corneal astigmatism; **PCA:** Posterior corneal astigmatism; **TCA**: Total corneal astigmatism.*

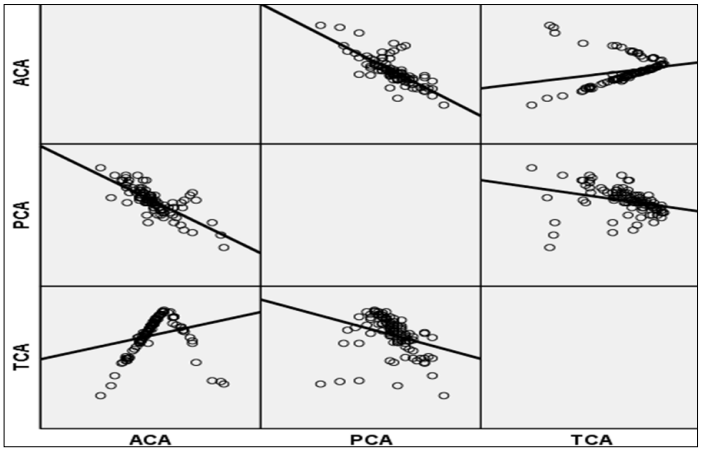

Figure 3: Correlation between ACA, PCA and TCA in KC group.
***ACA:** Anterior corneal astigmatism; **PCA**: posterior corneal astigmatism; TCA: total corneal astigmatism.*

Case (1)

Male patient, 22 years old his four-map refractive and topometric data are shown in figs. (4-7).

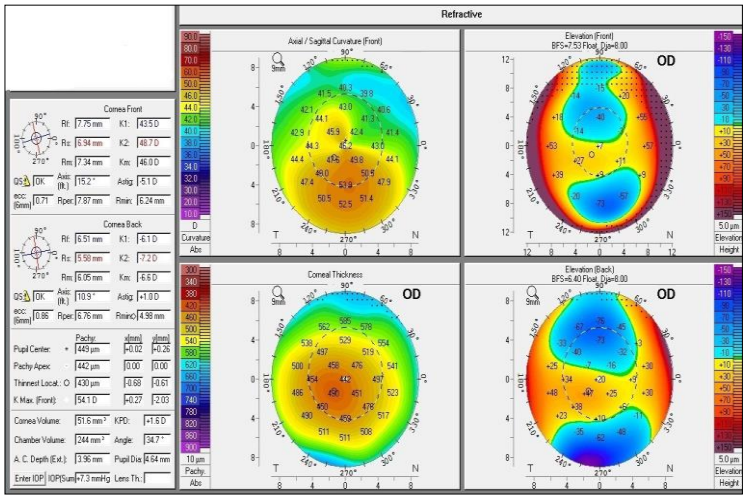

Figure 4: Four map refractive (right eye).
***ACA**= -5.1 D; PCA= 1.0 D; **Kmax** = 54.1 D; corneal thickness at **TL**= 430µm.*

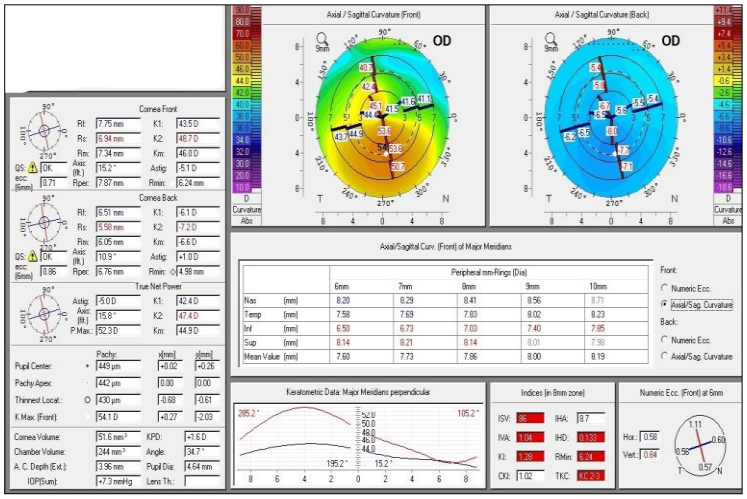

Figure 5: Topometric map (right eye).
TCA= -5 D

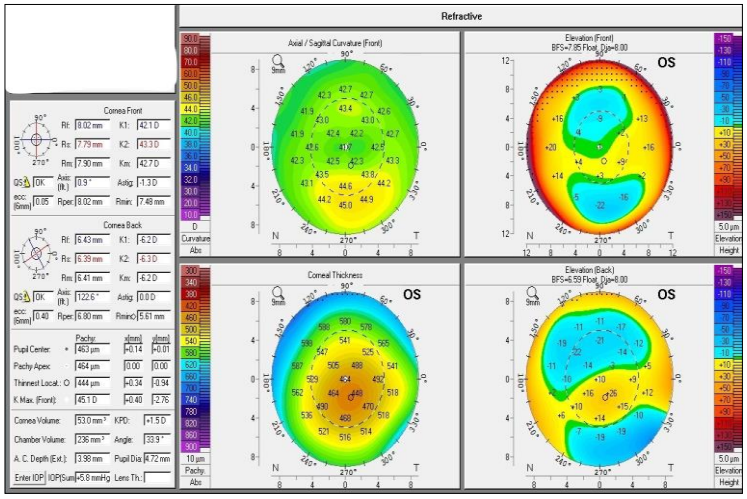

Figure 6: Four map refractive (left eye).
***ACA**= -1.3 D; **PCA**= 0; **Kmax**= 45.1 D; corneal thickness at **TL**= 444 µm*

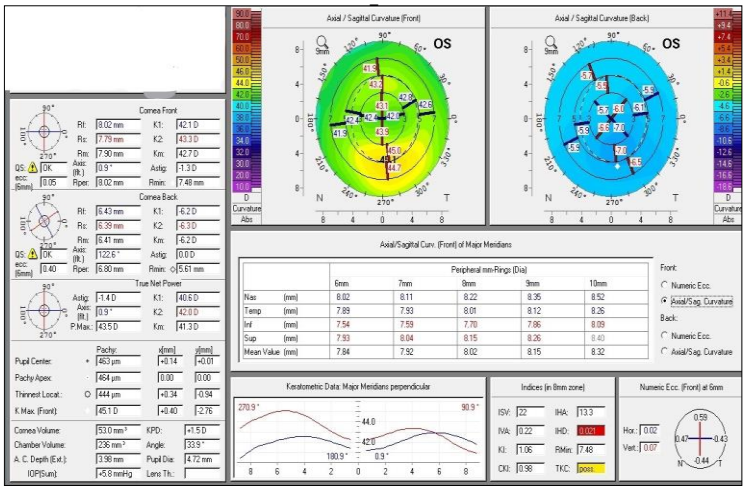

Figure 7: Topometric map (left eye).
TCA*= -1.4 D.*

Case (2)

Female patient, 38years old her four-map refractive and topometric data are shown in figs. (8-11).

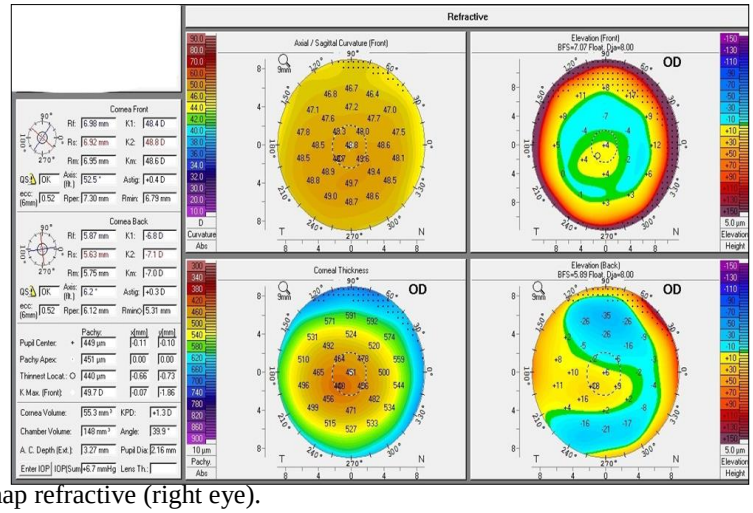

Figure 8: Four map refractive (right eye).
ACA*= 0.4 D;* ***PCA****= 0.3 D;* ***Kmax*** *= 49.7 D;* ***corneal thickness at TL****= 440 μm.*

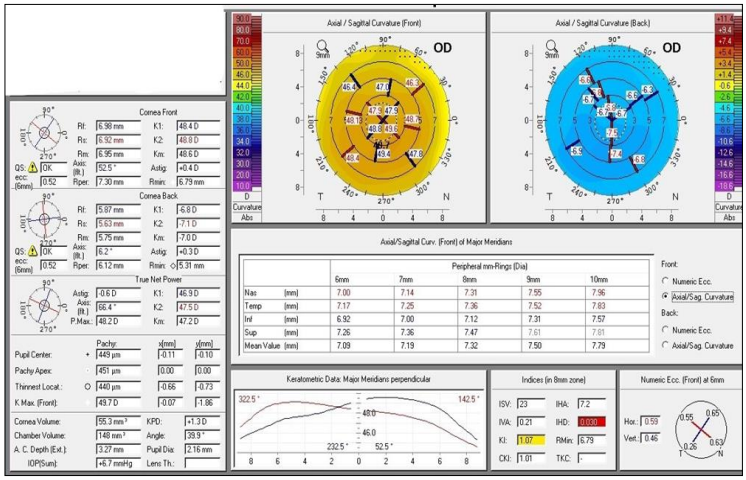

Figure 9: Topometric map (right eye).
TCA*= -0.6 D*

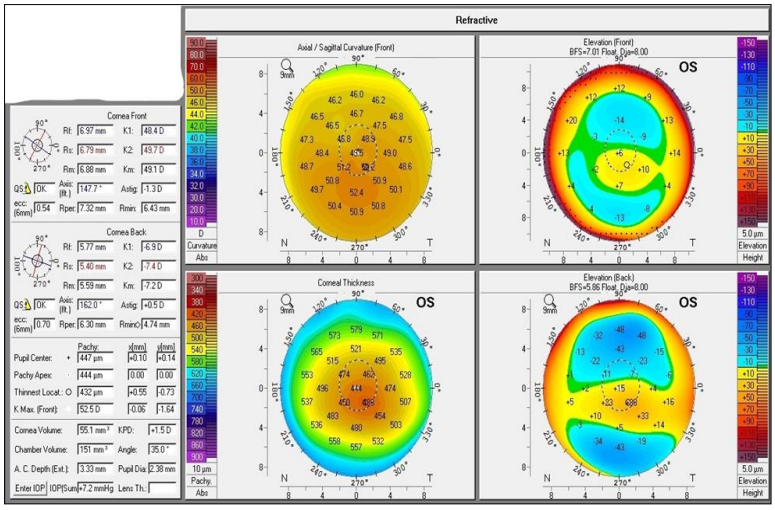

Figure 10: Four map refractive (left eye).
ACA *= -1.3 D;* ***PCA*** *= 0.5;* ***Kmax*** *= 52.5 D;* ***corneal thickness at TL*** *= 432 µm.*

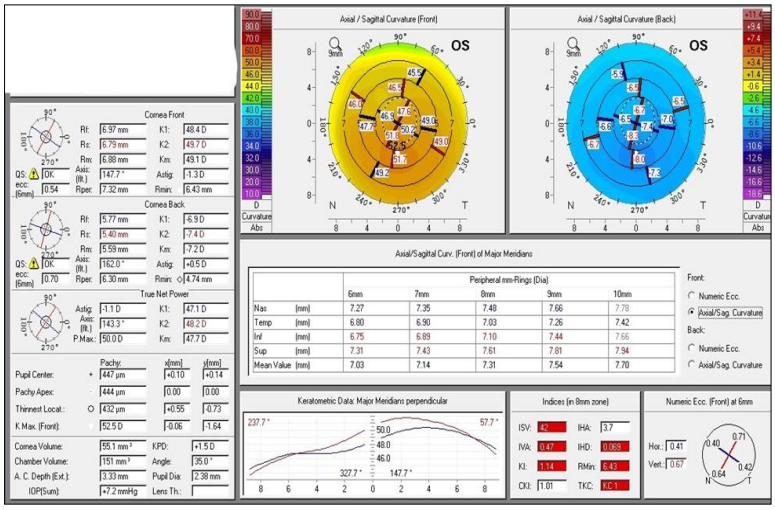

Figure 11: Topometric map (left eye).
TCA *= -1.1 D.*

4. Discussion

In our study, the keratometry reading of the anterior corneal surface was significant higher in KC group than control group in consist with Mihaltz, et al. [12]. AC depth is a major parameter of the Pentacam and one of the most important factors in ocular surgery [12]. In our study, the mean AC depth in all KC eyes was (4.03 ± 3.3) mm, relative higher than the mean (3.64 ± 0.3) mm in the control group but show no significant difference between the both groups (P = 0.274). This result is in consist with Montalban, et al. [13] and Reddy, et al. [14] they reported that there was no significant difference in the AC depth between KC and controls. But in contrast with Edmonds, et al. [15], Abolbashari, et al. [16] and many studies [17-19], shown that the AC depth is significantly deeper in KC patients than normal controls and reported that along with progression of the KC, the AC depth will be deeper. The difference in result can't be explained by the difference in measurement system as Hashemi, et al. [12] do, because our result is in consist with Montalban, et al. [13] with Sirius system (CSO, Florence, Italy) and Reddy, et al. [14] with Galilei dual Scheimpflug imaging system (Ziemer Ophthalmic Systems AG). On the other hand, in contrast with Edmonds, et al. [15], Abolbashari, et al. [16] and they both use Pentacam®

HR (OCULUS, Wetzlar, Germany) as we do in our study for AC depth measurement. The difference in result may explain by stage of KC in each study, most of the KC patients included in our study from stage I and II, stage I: 46 eyes, stage II: 43 eyes, stage III: 11 eyes and stage IV: 0 eye. In our study the mean corneal thickness at TL in KC group was significantly lower than the mean corneal thickness at TL in control group ($P < 0.001$). In consist with Abolbashari, et al. [16], Safarzadeh, et al. [18] and Emre, et al. [17]. In our study we tried to find if there is a relation between the cornel thickness at TL and the AC depth which may explain that the AC depth will be deeper along with progression of the KC in some studies [17-19], these studies include a higher number of KC patients in sever stage with mean corneal thickness at TL lower than the mean thickness at TL in KC group in our study. In this study, we found that the mean magnitudes of the ACA and PCA were significant higher in KC than controls ($P = 0.010$) and ($P< 0.001$) for ACA and PCA, respectively. This result is in consist with Feizi, et al. [20] that found the magnitude of mean PCA was significantly higher in KC corneas than in normal corneas. Also, Aslani, et al. [21] found that the PCA was more affected than ACA in an early stage of KC. We found a significant correlation between the magnitudes of ACA and PCA to the magnitudes of TCA in both groups; in consist with Kamiya, et al. [22]. The results of our study show that the magnitude of PCA is significantly related to the magnitude of ACA in KC eyes this can be refered to the fact that manifestations of KC occur at the posterior corneal surface in early stages of the disease, when the anterior surface demonstrates subtle topographic changes [20]. These results indicated that mean posterior corneal power and astigmatism are strong enough to determine eyes with KC from normal eyes. In our study we found significant correlation between the axis orientations of ACA and PCA in both KC and control group ($P< 0.001$) in consist with Feizi, et al. [20] and Aslani, et al. [21] they found a significant correlation between the axis orientations of ACA and PCA in their KC patients but our results are different from those of Naderan, et al. [23] results in which there was a significant compliance between the axis orientations of ACA and PCA in KC patients ($p<0.001$), but not in control group ($p= 0.626$). For toric IOLs implantation negligence of the PCA may overcorrects or undercorrects the astigmatism. So, controlling the magnitude and orientation of the PCA is vital for the best outcome in toric IOLs implantation especially in KC eyes.

5. Conclusion

In conclusion, in KC magnitudes of the ACA and PCA were significantly higher than controls, there were significant correlations between ACA and PCA with TCA, the effect of ACA on TCA was 6.1% and of PCA on TCA was 9.2%. Our finding helpful for more accurate correction of astigmatism by toric IOLs implantation or RGPCLs in KC patient by adoption of TCA instead of ACA to avoid residual refractive astigmatism because the magnitude of PCA in KC eyes is larger than normal eyes. Based on the data in our study, we think the KC affects all anterior segment parameters of the eye and results in significant alterations with the progression of the disease not only limited to corneal thickness, to more clearly understand these alterations, but a large series study with long term follow-up are also needed.

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