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Original research

Correlation of corneal elevations measured by Scheimpflug corneal imaging with severity of keratoconus

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Abstract

Purpose: To evaluate the correlation of corneal elevation and difference elevation with severity of keratoconus.
Methods: Anterior and posterior corneal elevations with both conventional and enhanced best-fit spheres (using rotating Scheimpflug camera) were measured. Front and back difference elevation were extrapolated from difference map of Belin/Ambrǒsio Enhanced Ectasia Display of the Scheimpflug system. Data from corneal elevations and difference elevations were correlated with maximum keratometry, minimal corneal thickness, and severity of keratoconus as assessed by Amsler-Krumiech classification of keratoconus.
Results: Ninety eyes of 55 keratoconus patients of different clinical stages were evaluated. There was a significant positive correlation between keratoconus severity and corneal elevations (anterior and posterior elevation as measured with both conventional and enhanced best-fit spheres) and also between keratoconus severity and corneal elevation differences ($P < 0.001$ and $r > 0.625$ for all). Maximum keratometry (Kmax), mean keratometry (Kmean), and all corneal elevations and difference elevations were highly correlated ($P < 0.001$ and $r > 0.840$ for all). A significant negative correlation was found between minimum corneal thickness and all corneal elevations and difference elevations ($P < 0.001$ and $r < 0.711$ for all). Receiver operating characteristic (ROC) curve analyses showed that anterior and posterior difference elevations have the best predictive accuracy for grading keratoconus severity.
Conclusion: Evaluation of corneal elevation and difference elevation data obtained from Scheimpflug corneal imaging is useful for grading severity of keratoconus.

Keywords: Keratoconus; Corneal elevation; Corneal difference elevation; Pentacam

Introduction

Keratoconus is a bilateral non-inflammatory corneal thinning disorder leading to cone-like protrusion of the central cornea and decreased vision because of myopia, irregular astigmatism, and corneal scarring. Keratoconus is diagnosed clinically with biomicroscopic examination of the cornea.[1] Placido disk−based corneal topography which has been traditionally used to diagnose keratoconus evaluates only the anterior corneal surface.[2]

Evaluation of the posterior corneal surface which has been made possible by Scheimpflug imaging and slit-scanning topography is especially important for detection of subclinical and early keratoconus.[3−5] Pentacam as a rotating Scheimpflug imaging instrument measures both surfaces' elevation by fitting the best-possible sphere to both surfaces of the cornea, which can miss small protrusions on the posterior cornea because the cone or apical protrusion steepens the best fit sphere (BFS), and this steepened BFS minimizes the elevation difference between the apex of the cone and the

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BFS.[6] A Software known as Belin/Ambrȯsio Enhanced Ectasia Display overcomes this problem by utilizing an enhanced reference which excludes thinnest portion of cornea from calculation of reference shape.[7] In conical cornea, this enhanced reference results in a significantly flatter BFS based more on the normal peripheral cornea. The map generated this way is known as exclusion map. The difference maps (anterior and posterior) show the relative change in elevation from the baseline elevation map to the exclusion map. Although this software was originally invented to rule out the possibility of forme fruste keratoconus before laser keratorefractive surgeries, it seems that this software may have some other utilities, especially in keratoconus patients.

As different treatment modalities have been developed in recent years for management of keratoconus patients,[8–10] precise assessment of keratoconus severity is important in the management of these patients. The aim of this study was to evaluate the correlation of corneal elevation and difference elevation as measured by Scheimpflug corneal imaging with severity of keratoconus. Corneal elevations were measured with both conventional and enhanced BFSs and difference elevations were extrapolated from difference map of Belin/Ambrȯsio Enhanced Ectasia Display of the Scheimpflug system.

Methods

In this cross-sectional study, patients referred to the Cornea Clinic, Amiralmomenin Hospital, Guilan University of Medical Sciences, were enrolled from September 2013 to February 2014. The study was performed in accordance with the Declaration of Helsinki, and the protocol of the study was approved by the Ethics Committee of Guilan University of Medical Sciences. All patients were provided informed consent.

Keratoconus was defined as at least one keratoconus sign (eg, stromal thinning, conical protrusion of the cornea at the apex, Fleischer ring, Vogt striae, or anterior stromal scar) on slit-lamp examination in addition to the topographic findings.

Using rotating Scheimpflug camera (Pentacam® HR Typ70900; oculus D-35582 Wetzlar, made in Germany), anterior and posterior corneal elevations with both conventional and enhanced BFS camera were measured. Enhanced BFS were calculated from Belin/Ambrȯsio Enhanced Ectasia Display software of Pentacam system. Elevation differences which are the differential change of elevation between the BFS and enhanced BFS were also extrapolated from this map. Exclusion criteria were eyes with post refractive surgery ectasia, pellucid marginal degeneration, pellucid like keratoconus, and any history of anterior segment surgery.

Severity of keratoconus was graded according to Amsler–Krumeich classification (Table 1).[11] Data from corneal elevations and difference elevations were correlated with maximum keratometry, minimal corneal thickness, and severity of keratoconus using spearman correlation. A probability of 0.05 was regarded as statistically significant.

Table 1
Amsler–Krumeich classification.[11]

Severity	Mean keratometry (Kmean) (D)	Thickness (μ)	Spherical equivalent	Cornea
IV	>55	<200	Not measurable	Central scars
III	54–55	200–400	> − 8D	No central scars
II	48–53	400–500	[−5,−8]D	No central scars
I	<48	>500	< − 5D	No central scars

D: Diopter.

Results

90 eyes of 55 keratoconus patients (63 male and 27 female eyes) of different clinical stages were enrolled in this cross-sectional study. Mean patient age was 24.16 ± 7.2 years. Considering Amsler–Krumeich classification, 30 eyes were in stage I, 25 in stage II, 26 in stage III, and 9 in stage IV of keratoconus severity. There was a significant positive correlation between keratoconus severity and corneal elevations (anterior and posterior elevation as measured with both conventional and enhanced BFS) and also between keratoconus severity and corneal elevation differences ($P < 0.001$ and $r > 0.625$ for all) (Table 2).

The correlation between maximum keratometry (Kmax), mean keratometry (Kmean), minimal corneal thickness (as Pentacam indices of corneal severity assessment), and corneal elevations has been shown in Table 3. Kmax, Kmean, and all corneal elevations and difference elevations were highly correlated ($P < 0.001$ and $r > 0.840$ for all). A significant negative correlation was found between minimum corneal thickness and all corneal elevations and difference elevations ($P < 0.001$ and $r < -0.711$ for all).

Fig. 1 shows receiver operating characteristic (ROC) curve analyses of all corneal elevations and difference elevations with reference to keratoconus staging (according to the Amsler–Krumeich classification) and indicates that anterior and posterior difference elevations have the best area under curve (AUC) in this regard.

We preformed ROC curve analyses to assess the predictive accuracy of anterior and posterior corneal elevation differences in discriminating different stages of keratoconus, the result of which is shown in Table 4. The results indicate that its predictive accuracy is good for discriminating stage II from III and III from IV but not stage I from II.

Discussion

Although Amsler–Krumeich classification has been traditionally used for grading keratoconus severity, recently many other methods including topographic data,[12–15] higher-order aberrations,[11] combinations of topographic pattern, and slit-lamp evaluation have been evaluated in this regard.[16]

As mentioned above, the aim of this study was to evaluate the correlation of corneal elevation and difference elevation

Table 2
Correlation of cornea variables and keratoconus severity.

		Anterior elevation (Regular BFS)	Anterior elevation (Enhanced)	Posterior elevation (Regular BFS)	Posterior elevation (Enhanced)	Anterior elevation differences	Posterior elevation differences
Keratoconus severity	*P*-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Spearman correlation	0.683	0.727	0.625	0.730	0.786	0.771

BFS: Best fit sphere.

Table 3
Correlation of maximum keratometry (Kmax), mean keratometry (Kmean), minimum corneal thickness, and all corneal elevations and difference elevations.

Variable	Kmax		Kmean		Thinnest point thickness	
	Spearman correlation	*P*-value	Spearman correlation	*P*-value	Spearman correlation	*P*-value
Anterior elevation (Regular BFS)	0.916	<0.001	0.844	<0.001	−0.743	<0.001
Posterior elevation (Regular BFS)	0.895	<0.001	0.844	<0.001	−0.711	<0.001
Anterior elevation (Enhanced)	0.952	<0.001	0.905	<0.001	−0.711	<0.001
Posterior elevation (Enhanced)	0.931	<0.001	0.905	<0.001	−0.730	<0.001
Anterior elevation differences	0.950	<0.001	0.933	<0.001	−0.756	<0.001
Posterior elevation differences	0.921	<0.001	0.916	<0.001	−0.718	<0.001

BFS: Best fit sphere; Kmax: Maximum keratometry; Kmean: Mean keratometry.

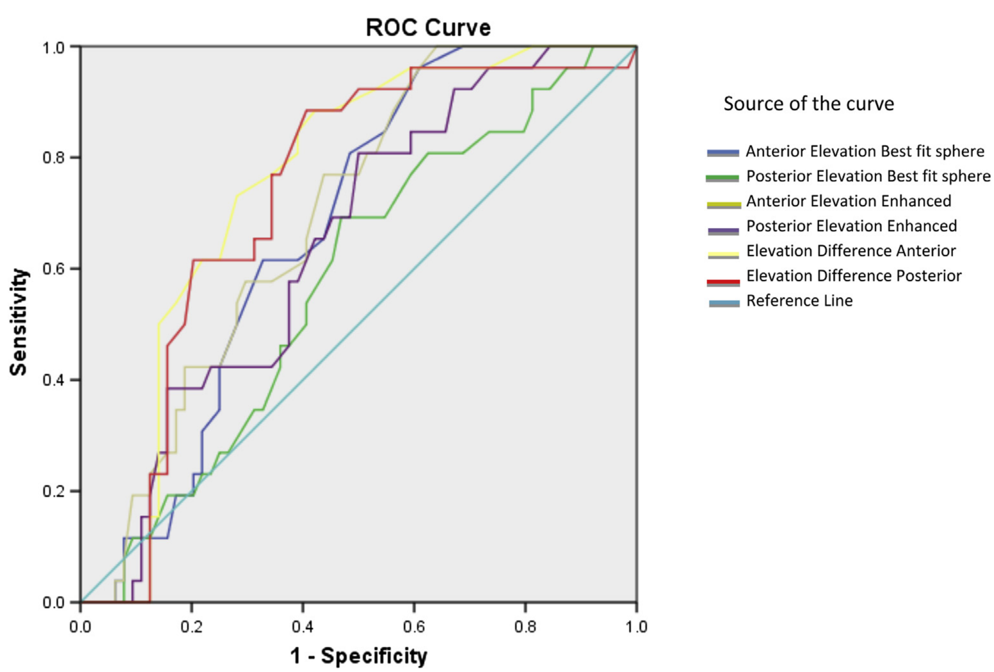

Fig. 1. Receiver operating characteristic (ROC) curve showed the sensitivity and specificity of the elevation differences. Data points in the upper left portion of the graph represent higher sensitivity and specificity. Area under curve (AUC) as close as 1.0 is better in diagnostic ability.

(extrapolated from Belin/Ambrȏsio EnhancedEctasia Display of the Scheimpflug system) with severity of keratoconus. The result of this study demonstrates significant positive correlation between keratoconus severity and corneal elevations (anterior and posterior elevation as measured with both conventional and enhanced best-fit spheres) and also between keratoconus severity and corneal elevation differences. ROC curve analyses showed that anterior and posterior difference elevations have the best AUC with reference to keratoconic staging, indicating that corneal elevation differences extrapolated from BAD display of Pentacam have the best predictive accuracy for keratoconus grading.

Ishii et al.[17] evaluated the correlation between anterior and posterior elevation differences and keratoconus severity and showed positive correlation between them (Pearson correlation coefficient, r = 0.66; $P < 0.001$; r = 0.74; $P < 0.001$, respectively. Their study revealed a significant correlation between Keratoconus Severity Index (KSI) and Amsler−Krumeich classification and the elevation differences, but they did not evaluate correlation of corneal elevations with keratoconus severity. Du et al.[18] reported that in the subclinical stage of keratoconus, posterior elevation value (PEV), thickness, and posterior I-S had important diagnostic values, and elevation values remained most efficient when keratoconus developed to

Table 4
Receiver operating characteristic (ROC) curve analyses of anterior and posterior corneal elevation differences in discriminating different stages of keratoconus.

Area under the curve								Sensitivity	Specificity
Keratoconus severity	Variables	Area	Std. error[a]	Asymptotic Sig.[b]	Asymptotic 95% confidence interval		Cut off optimal		
					Lower bound	Upper bound			
Grade i-ii	Elevation difference anterior	0.454	0.058	0.496	0.339	0.568	–	–	–
	Elevation difference posterior	0.483	0.059	0.801	0.367	0.599	–	–	–
Grade ii-iii	Elevation difference anterior	0.753	0.052	0.000	0.651	0.855	19.5 μm	73%	72%
	Elevation difference posterior	0.730	0.056	0.001	0.621	0.840	37.5 μm	80%	63%
Grade iii-iV	Elevation difference anterior	0.995	0.006	0.000	0.982	1.000	32 μm	100%	96%
	Elevation difference posterior	0.991	0.010	0.000	0.972	1.000	64 μm	100%	92%

[a] Standard deviation error.
[b] Asymptotic significant.

the moderate stage. The anterior curvature indices were most characteristic when keratoconus became severe. Keratoconus first appeared in the inferior cornea of posterior surface, but the feature of protrusion formed at the moderate stage.

In the study performed by Miháltz et al.,[19] the keratometric, pachymetric, and elevation parameters of keratoconic and normal corneas (all measured by Pentacam) were evaluated. ROC curve analyses showed the best predictive accuracy for posterior and anterior elevation (area under the curve, 0.97 and 0.96) followed by minimal and central pachymetry (0.89 and 0.88), again emphasizing the clinical significance of elevation data. Falavarjani et al.[20] stated that in normal population, the mean interocular difference was 2.17 μm for maximum anterior elevation and 3.62 μm for maximum posterior elevation. One study previously reported that corneal elevation differences were significantly correlated with the keratoconus severity index, suggesting that corneal height information was also useful for indicating keratoconus severity.[17] Piñero et al. reported that the anterior and posterior BFS measurements were highly correlated in the healthy eyes and subclinical groups, but that the correlation was weaker in the two clinical keratoconus groups.[21]

In conclusion, according to our study, the measurements of anterior and posterior elevation differences were effective indices in aiding for grading severity of keratoconus in moderate and advanced stages (II-IV). Our study also showed the best predictive accuracy is for anterior and posterior difference elevations in this regard.

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