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ORIGINAL PAPER

Comparison between corneal elevation maps using different reference surfaces with Scheimpflug–Placido topographer

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Abstract The purpose of this study was to compare the anterior and posterior elevation measurements using different reference surfaces (spheric, aspheric, and aspherotoric) with Scheimpflug–Placido topography in simple myopic and keratoconus patients. 600 eyes of 600 patients undergoing screening for keratorefractive surgery (500 simple myopic, 100 keratoconus stage 1 and 2) in Sohag refractive center, Egypt, were examined by Scheimpflug–Placido topography (Sirius, CSO, Italy) for both the anterior and posterior corneal elevation maps using the spheric, aspheric, and aspherotoric reference surfaces. 100 keratoconic eyes showed higher discriminating power using the aspherotoric reference surface in both the anterior and posterior elevation maps. The use of aspherotoric reference surface gives more data for eyes with keratoconus and its use is more informative in screening.

Keywords Keratoconus · Elevation maps · Spheric reference surface · Aspheric reference surface · Aspherotoric reference surface

A pilot study has been presented as a poster in the ASCRS 2014, Boston, USA.

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Introduction

Preoperative refractive screening is mainly concerned with the identification of susceptible corneas (keratoconus and its subclinical forms) for developing ectasia [1]. In keratoconus, the posterior corneal curvature is affected in addition to the anterior corneal surface [2–5]. In subclinical keratoconus, early morphological changes may develop on the posterior surface [2].

Scheimpflug technology provides information regarding the anterior corneal surface, the posterior corneal surface, and the corneal thickness. Elevation data are presented relative to reference shapes so that the clinician does not analyze the actual elevation data but only those data after omitting the reference shape. This method has been used to magnify the differences and allows for qualitative maps that will highlight clinically significant areas [6]. The reference shape from which the corneal surface height is measured is often chosen as a sphere without positioning constraint (reference surface mode) and is known as the best fit sphere (BFS). However, considering variable corneal toricity and asphericity, a reference surface that is both toric and aspherical would fit better to the real corneal shape and therefore might help to enhance local changes and underlying abnormalities more sensitively [6].

The combined 3D rotating Scheimpflug camera with a Placido disc as the SIRIUS (CSO, Florence, Italy) measures corneal curvature, elevation, and thickness measurements. Previous studies have reported that the system's pachymetric and shape measurements (curvature, eccentricity, elevation) have good repeatability [7, 8].

The purpose of this study was to detect difference between spheric, aspheric, and the aspherotoric reference surfaces in measuring elevation maps in simple myopic and keratoconus eyes using combined Scheimpflug–Placido technology.

Methods

In this retrospective observational study, 600 eyes from 600 patients undergoing screening for keratorefractive surgery were included. One eye was randomly selected when both were eligible. 500 eyes were categorized into the normal simple myopic (SE ≤ -6D with astigmatism $\leq$0.50D) group, while 100 eyes formed the keratoconus (KC) group (included KC stage 1 and 2 according to the Amsler-Krumeich classification). This study was in accordance with the Declaration of Helsinki and the approval of the local ethics committee of the Sohag University Hospital, Egypt.

Exclusion criteria in both groups were glaucoma, suspicion of glaucoma, intraocular pressure lowering medications, corneal scarring, severe dry eye, pregnancy or nursing, current corneal infection, and underlying autoimmune disease.

Elevation measurements were obtained using Scheimpflug–Placido topography (Sirius) which is a noninvasive diagnostic system designed to analyze the anterior eye segment using a rotating Scheimpflug camera integrated with a Placido topographer. The flash illumination is a 475-nm wavelength blue LED, and it measures more than 122 data points per scan. Three consecutive scans were obtained by an experienced operator. In all cases, at least 9.0 mm of corneal coverage was considered acceptable maps. Moreover, images with extrapolated data in the central 9.0 mm zone were excluded. All measurements were acquired between 12 and 3 p.m. Patients were asked to blink and then look at the fixation device. When the image was of low quality (lid closure, insufficient fixation, or corneal coverage), the procedure was repeated.

Anterior and posterior elevation map data were collected from three zones (3, 5, 7 mm zones), recording the maximum elevation for each. In elevation maps, the reference surfaces used were spheric, aspheric, and aspherotoric. For all measurements, the reference vertex coincided with the corneal vertex. The maximum elevation data of all zones were collected as the highest value of the multiple readings in each zone of the numerical elevation map. The comparison was of the most elevated point in each zone rather than a point-to-point comparison, which negated the variability. This was based on the fact that, in clinical practice, decisions are based on the most elevated points on the maps. Corneal elevation with different reference surfaces were also measured at the thinnest corneal point in both groups.

Statistical analysis

The measurements data were analyzed using SPSS software (version 11.5, SPSS, Inc.). The normality of all data distributions was confirmed with the Kolmogorov–Smirnov test. A paired t test was used to compare the elevation values obtained with different reference surfaces. A p value less than 0.05 was considered statistically significant. Receiver operator characteristic curves (ROCs) were used to compare discriminating ability and to determine cut-off values of posterior elevation measurements obtained by different reference surfaces. ROC curve is a plot of the true positive rate against the false positive rate for the different possible cutpoints of a diagnostic test.

Results

General characteristics of the patients in both groups are summarized in Table 1. There was no difference in age between both groups.

Maximum elevation values are averaged in every zone (3, 5, 7 mm) and represented in Table 2. In the simple myopic group, the maximum anterior elevation point was higher in the 3-mm zone using all reference surfaces. While in the keratoconus group, 5-mm zone

Table 1 Demographic characteristics of the patients by groups

Characteristics	Simple myopic group	Keratoconus group
No. of eyes	500	100
Mean age ± SD	22.1 ± 6.6	22.9 ± 8.2
Female sex (%)	282 (56.4 %)	55 (55 %)

Table 2 Mean of elevation values in different zones of anterior and posterior elevation maps

	Spherical MAE (μm)	Aspheric MAE (μm)	Asypherotoric MAE (μm)	Spherical MPE (μm)	Aspheric MPE (μm)	Aspherotoric MPE (μm)
Simple myopic eyes						
3-mm zone	5.2 ± 1.8	5.3 ± 2.1	5.6 ± 2.0	6.3 ± 2.1	6.4 ± 1.7	6.7 ± 2.1
5-mm zone	4.9 ± 1.2	5.0 ± 1.1	5.2 ± 1.1	6.3 ± 1.8	6.4 ± 1.9	7.0 ± 1.1
7-mm zone	4.8 ± 1.2	5.0 ± 1.6	5.1 ± 1.6	6.5 ± 1.1	6.5 ± 1.9	7.2 ± 1.2
Thinnest corneal point	5.2 ± 1.9	5.3 ± 2.5	5.6 ± 2.4	6.3 ± 2.0	6.4 ± 1.8	6.7 ± 2.3
Keratoconus eyes						
3-mm zone	20.1 ± 11.5	22.3 ± 11.1	23.1 ± 15.4	28.1 ± 17.2	28.9 ± 16.1	30.1 ± 19.9
5-mm zone	21.1 ± 11	22.7 ± 12.1	23.9 ± 13.4	28.9 ± 17.3	29.1 ± 17.2	31.1 ± 19.2
7-mm zone	21.5 ± 12.2	22.9 ± 13.5	23.3 ± 14.2	29.2 ± 17.7	30.3 ± 18	31.9 ± 19.9
Thinnest corneal point	21.2 ± 11.3	22.7 ± 12.4	23.9 ± 17.1	28.9 ± 18.1	29.8 ± 17	31.9 ± 19.9

MAE maximum anterior elevation, *MPE* maximum posterior elevation

showed higher values. These results revealed the fact that aspheric and aspherotoric reference surfaces yielded higher values in all zones and were at the thinnest corneal point when compared to the spheric reference surface.

Table 3 shows statistically significant differences between elevation values obtained with all reference surfaces for both anterior and posterior corneal surfaces in the keratoconus group. In the simple myopic group, there was a statistically significant difference between elevation values obtained with all reference surfaces as well, except for the anterior corneal elevation obtained with the spheric and aspheric reference surfaces.

Discriminating ability and roc curves

Cut-off values and discriminating ability of the analyzed corneal elevation parameters are summarized in Table 4 and Fig. 1. The use of an aspherotoric reference surface with the Sirius system enabled better detection of keratoconus with an area under the ROC curve of 0.99 with the aspherotoric reference surface and 0.96 with the spheric reference surface.

Discussion

Measurements of corneal shape, refractive power, and corneal thickness are important when designing vision correction surgery and diagnosing corneal disease. Moreover, accurate corneal vault measurements are helpful in diagnosing corneal ectatic disorders, avoiding complications of keratorefractive surgery, and monitoring postoperative recovery of the cornea [9].

Before the introduction of the Scheimpflug-based topography systems, Placido-based computer-assisted videokeratoscopy, rasterstereography, and Orbscan

Table 3 Means and intergroup comparison of anterior and posterior corneal parameters

	Mean ± SD					
	Spherical MAE (μm)	Aspheric MAE (μm)	Aspherotoric MAE (μm)	Sphere vs Aspheric	Aspheric vs Aspherotoric	Sphere vs Aspherotoric
Anterior surface						
Simple myopic eyes	5.0 ± 1.8	5.1 ± 1.4	5.3 ± 1.4	0.07	0.046	0.001
Keratoconus	20.9 ± 11.5	22.6 ± 12.2	23.4 ± 14.3	0.05	0.05	0.001
Posterior surface						
Simple myopic eyes	6.3 ± 2.1	6.7 ± 1.7	6.9 ± 2.1	0.03	0.01	0.001
Keratoconus	28.7.5 ± 17.6	29.4 ± 17.1	31.3 ± 19.1	0.001	0.01	0.001

SD standard deviation, *MAE* maximum anterior elevation, *MPE* maximum posterior elevation, *D* diopters

Table 4 Sensitivity/specificity for the anterior and posterior corneal elevation

	Sensitivity (%)	Specificity (%)	Cut-off values (μm)
Simple myopic eyes versus keratoconus			
Spherical MAE	91	92	24
Aspheric MAE	93	96	22
Aspherotoric MAE	98	99	19
Spherical MPE	92	93	15
Aspheric MPE	94	95	14
Aspherotoric MPE	98	99	12

MAE maximum anterior elevation, *MPE* maximum posterior elevation

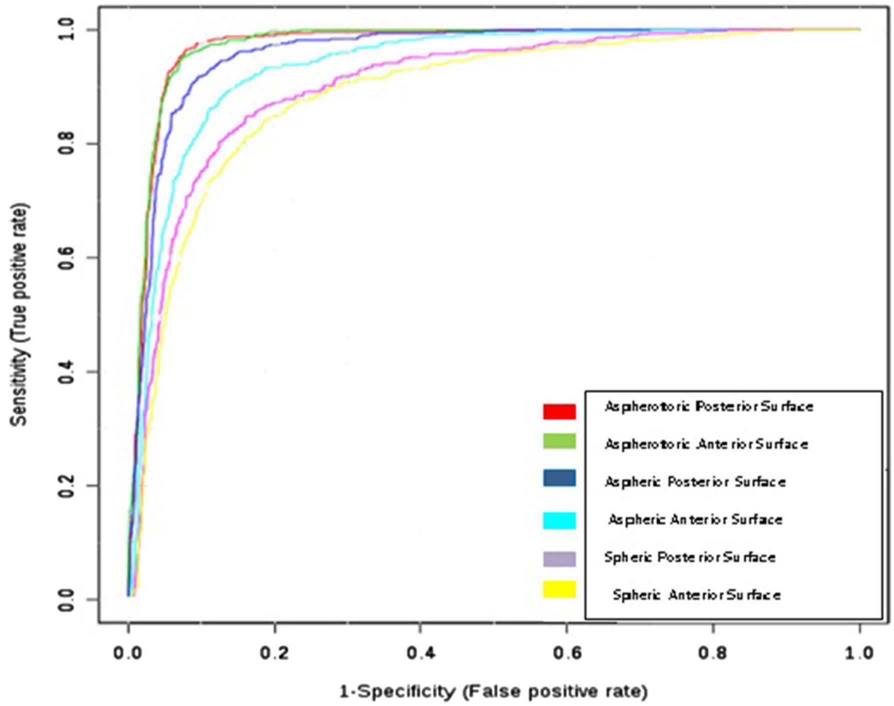

Fig. 1 Receiver operating characteristic curve (ROC curve) of keratoconus anterior and posterior corneal elevation maps with different reference surface

were the only commercially available modalities for clinical evaluation of corneal topography [10–12]. Yet the Scheimpflug technology offered better evaluation of the corneal elevations, which is more sensitive in detecting early keratoconus.

Scheimpflug camera software provides both anterior and posterior elevation maps by fitting a reference surface body, usually a sphere or an ellipsoid surface, to the corneal shape [6, 13]. The reason for viewing elevation data in this format is that the actual raw elevation data lack qualitative patterns that would allow the clinician to easily separate normal from abnormal corneas [6].

However, Galilei dual Scheimpflug–Placido topography has been widely evaluated [14, 15]. To the best of our knowledge, Sirius single-Scheimpflug–Placido topographer has not been evaluated as regards the elevation maps and the reference surfaces used. The aim of the current study is to compare the three reference surfaces (spheric, aspheric, and asphero-toric) regarding anterior and posterior corneal elevation in normal and keratoconus eyes.

Posterior elevation data were reported as useful indexes for the diagnosis of FFK [2, 16–19]. However, these reports used only the best fit sphere (BFS) or the best fit toric ellipsoid (BFTE) reference bodies. Kovacs et al. [8] explored the impact of sphere and toric ellipsoid reference bodies in the diagnostic capacity of the Pentacam-derived posterior elevation measurements. They found the maximal diagnostic capacity using the BFTE autodiameter reference body. Smadja et al. [16], in their Galilei-based study, proposed that maximum posterior corneal elevation had the greatest diagnostic capacity when using toric and aspheric reference bodies. These results were similar to our data where aspherotoric and aspheric reference surface, respectively, used in elevation maps were more informative than the spheric reference surface.

In the current study, we demonstrated that the use of the aspherotoric reference surface for calculating elevation (either anterior or posterior) is better than the BFS for discriminating between normal and keratoconus. Our results were similar to those of Sideroudi et al. [15]. This can be explained by the fact that the corneal natural shape would fit better to the aspherotoric reference surface which might be able to discriminate the subtle changes found in early cases of keratoconus.

We are aware that this study needs further elaboration to add subclinical keratoconus groups.

In summary, the Scheimpflug–Placido topography elevation maps led to higher diagnostic measurements when using the aspherotoric reference. Misinterpretation during clinical diagnoses and decision making can occur if the three references are considered to be interchangeable.

Compliance with ethical standards

Conflict of interest The author has no proprietary interests or conflicts of interest related to this submission.

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