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ORIGINAL ARTICLE

Comparison of Topographic Technologies in Anterior Surface Mapping of Keratoconus using Two Display Algorithms and Six Corneal Topography Devices

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ABSTRACT

Purpose: To evaluate anterior surface topographic technologies and display algorithms in mapping keratoconus.

Materials and methods: A total of 27 eyes of 17 subjects clinically diagnosed with keratoconus were imaged on six topographers: EyeSys, Alcon EyeMap, Keratron, TMS-1, Orbscan and PAR corneal topography system. Axial distance (AD) and instantaneous radius of curvature (IROC) algorithms were generated, and the cone apex was determined manually using a cursor. Intermachine comparisons for cone magnitude (steepest curvature), as well as cone location in radius and meridian were performed for each display algorithm using both AD and IROC. Significance ($p < 0.05$) was determined using repeated measures analysis of variance (ANOVA) on successive mean values. Maps were also evaluated for processability, defined by the ability to reconstruct a reasonable map for each subject, not map quality.

Results: There were no significant differences between successive means for cone location in either radial or meridional directions. For AD, Orbscan was greater than both small mire Placido devices (Keratron and TMS-1), which were not different from each other. The small mire devices had significantly greater curvature magnitude than the large mire placido devices (EyeSys, Alcon EyeMap) which were not different from each other. Finally, PAR was significantly lower than the large mire Placido devices. For IROC, the pattern was the same with the exception that the Orbscan was not different than the small mire Placido devices in curvature magnitude. For processing success, the PAR had 100% processability, and all other devices were between 73 and 77%.

Conclusion: In monitoring keratoconus, evaluation of change over time is fundamental to treatment decisions, making understanding of topographic technology differences in mapping keratoconic corneas extremely important.

Keywords: Corneal topography, Keratoconus, Axial curvature, Tangential curvature, Instantaneous radius of curvature, Placido, Scanning slit, Rasterstereography.

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INTRODUCTION

There are many devices that measure anterior surface corneal topography which are commonly used in clinical practices. Newer devices have been introduced based on Scheimpflug imaging, with or without an integrated Placido. Although these newer devices include posterior surface and pachymetric analysis that are critically important for keratoconus screening, the mainstay of evaluating known keratoconus for management and treatment is using anterior surface analysis. Each topographer has various hardware and technological differences, which could lead to differences in corneal mapping. Since no standard topographer exists, it is important to know how these technologies compare to one another so that clinicians can interpret maps from referred patients, or share study results with colleagues who use different topographers, particularly in the case of corneal collagen cross-linking in either multicenter trials or even in comparing outcomes of different trials.

Keratoconus is a progressive corneal degenerative disease of unknown etiology that is characterized by a local, noninflammatory corneal ectasia. This localized thinning causes the cornea to bulge due to decreased mechanical stability opposing intraocular pressure. Because the keratoconic cornea is relatively unstable and markedly thinner than normal corneas, refractive surgery is generally contraindicated since it would risk further mechanical instability of an already thin cornea and possibly yield more variable results. Although advanced keratoconus is easy to detect clinically in the presence of pathological signs, such as Vogt's striae, Fleischer's ring, corneal scarring and scissoring on retinoscopy, early subclinical keratoconus can be very difficult to detect without the aid of corneal topography.[1,2] Thus, due to its unique morphology, and its clinical relevance in conjunction with corneal topography, keratoconus can be used to quantify topographic changes in magnitude (dioptric value or height) and position (radius and meridian) between different topography machines. It is also useful to know the error associated with the topographic technologies in processing keratoconic maps.

Commonly used anterior surface corneal topography machines employ one of three methods for obtaining base corneal measurements: Placido-ring, rasterstereography or scanning slit. Placido ring topographers use ring mires composed of concentric rings that reflect off the surface of the cornea.[3] Differences between ring spacing in the image are measured and then converted to curvature via a reconstruction algorithm. Two different mire design categories exist for Placido ring topographers: Large and small. Large ring topographers have smaller corneal coverage due to blocking of ring mires by the nose and eyebrows, as well as a decreased spatial resolution from having a smaller number of rings.[4,5] However, large ring topographers are less sensitive to focus errors. Conversely, small ring topographers have greater corneal coverage, and better spatial resolution from having a greater number of rings, but are more sensitive to focus errors.[4,6]

Rasterstereography, on the other hand, projects a green grid onto the cornea, which causes instilled fluorescein to fluoresce at a longer wavelength along the grid pattern.[7] A detector arm at the same angle of incidence with respect to the normal of the cornea as the projector arm then captures an image of the distorted grid pattern on the cornea. Comparison of these captured images with the known dimensions of the projected grid, allow the rasterstereographer to measure the height of the cornea relative to a reference plane by triangulation.[8] The PAR is the only rasterstereographic corneal topographer that was produced, but is no longer commercially available. Finally, the scanning-slit topographer uses two slit beams from opposite directions that move across the corneal surface with some overlap in the central cornea, with 20 slit images captured from each slit.[9,10] Both the scanning slit and rasterstereographic technologies are considered elevation systems, since the base measurement is corneal elevation relative to a reference. From the elevation data, curvature can be calculated.

The two most commonly used display algorithms, axial, and instantaneous radius of curvature (IROC), also called tangential, were used for this study.[8,10,11] The axial algorithm is a running average of data points from the central to the paracentral cornea along any given meridian.[12] This method of averaging causes the algorithm to be less sensitive to curvature fluctuations, making the axial algorithm a good global shape descriptor. On the other hand, decreased sensitivity to fluctuations can significantly hamper the detection of corneal abnormalities that may be early clinical signs of corneal pathology, such as keratoconus. The IROC algorithm is curvature-based and measures the radius of curvature along the orthogonal to the tangent of a given point on the cornea. The IROC algorithm closely follows the corneal surface and more easily detects subtle features than with the axial algorithm.

The purpose of the current study is to compare representative large mire and small mire Placido devices, as well as scanning slit and rasterstereographic technologies, in representing keratoconic anterior surface topographies, both in magnitude of curvature and location of cone apex defined by maximum curvature.

MATERIALS AND METHODS

On the same day, 27 eyes from 17 subjects clinically diagnosed with keratoconus by a corneal specialist (RGL) were imaged on six topographers: EyeSys (EyeSys Vision, Inc, Houston, TX), Alcon EyeMap (Alcon Laboratories, Ft. Worth, TX), Keratron (Optikon, Rome, Italy), Topographic Modeling System (TMS-1; Tomey, Nagoya, Japan), Orbscan (Bausch & Lomb, Rochester, NY) and PAR Corneal Topography System (Vision Optimization, LLC, Columbus, OH). Axial distance (AD) and instantaneous radius of curvature (IROC) algorithms[3] (also called 'tangential' by some devices)[3] were generated from each topographer and the cone apex (steepest curvature) was determined manually using a cursor. IROC on the TMS-1 was calculated from software provided by the manufacturer. Intermachine comparisons for cone magnitude, cone radius and cone meridian were performed for each display algorithm. In maps containing two peaks within the cone pattern, an average value for the cone apex was used. Comparisons of cone magnitude (diopters), radial distance (mm) and meridian (degrees) were then made between each machine using both AD and IROC. Significance ($p < 0.05$) was determined using repeated measures analysis of variance (ANOVA) on successive mean values (e.g. the mean values for each topographer were ordered from lowest to highest and ANOVA was performed between adjacent columns). Maps were also evaluated for processability. Maps with processing errors were discarded leaving 16 eyes from 12 subjects for AD, and 15 eyes from 11 subjects for IROC.

RESULTS

Results for interdevice processability of data from keratoconic corneas are displayed in Table 1. Image processing performance was fairly uniform ($75 \pm 2\%$) for all topographers, with the exception of the PAR CTS (100%), which encountered no processing errors for any of the subjects studied, demonstrating the advantage of this technology in corneas with poor surface quality. The curvature magnitude, as well as the radial and meridional location of the cone apex, for each topographer is shown in Table 2 for the axial algorithm, and in Table 3 for IROC. Successive means for curvature magnitude showed no significant differences in the axial algorithm within small mire Placido devices and within large mire Placido devices, but all technologies were significantly different from each other. For the IROC algorithm, the scanning slit technology was not different from either of the small mire Placido devices, but this grouping was significantly different from the large mire Placido devices, as well as the

Table 1: Intermachine image processability

Image processability			
Machine	*# Eyes*	*# Track Err*	*Process (%)*
Keratron	22	6	73
TMS	22	6	73
Alcon	22	5	77
EyeSys	22	5	77
Orbscan	22	5	77
PAR	22	0	100

rasterstereographic technology. There were no significant differences between successive means for cone location in either radial or meridional directions.

DISCUSSION

Results showed that all topographers were generally consistent regarding the cone location, but differed according to their technology regarding the magnitude of the steepest curvature at the cone apex. Small mire Placido devices (TMS-1, Keratron), were similar to each other in representation of the cone, but were different from large mire Placido devices as well as from scanning slit and rasterstereographic topographers in the axial algorithm. Analogously, large mire devices (EyeSys, Alcon EyeMap) were similar to each other in representation of the curvature magnitude of the cone, but different from small mire devices and other technologies, also in the axial algorithm. Interestingly, the scanning slit technology (Orbscan) was similar to the small mire Placido devices in the IROC algorithm, which were different from the other two categories. Furthermore, the Orbscan and the two small mire topographers consistently represented the cone as steeper than either the two large mire topographers or the PAR. This may be related to greater spatial resolution of these small mire Placido devices. However, it is not possible to determine which device is the most accurate in a clinical study, since the true curvature is not known. Examples of the IROC (AKA Tangential) algorithm from all devices are shown in Figures 1 to 3.

Limitations of this study include using two devices that are no longer commercially available, the Alcon Eyemap and the PAR Corneal Topography System. However, the Alcon Eyemap remains in clinical use, so the results remain relevant. It also demonstrates how large mire devices have similar performance. In addition, the rasterstereographic technology is under redevelopment for screening donor eyes for anterior surface pathology, including keratoconus as well as the presence of previous refractive surgery, and therefore, these results also remain relevant. Other limitations include manual determination of the location of maximum curvature in the maps, which might have led to variability. In addition, the use of successive means did not include intermediate comparisons, including the highest value to the lowest value.

Finally, some of the newer devices were not evaluated in the current study, such as Scheimpflug imaging and optical coherence tomography (OCT). It would be expected that these devices would also exhibit differences in representing keratoconic patterns. Comparison between a small mire Placido device and two Scheimpflug devices, one with and one without an integrated Placido has been reported in the literature in keratoconus.[13] Interestingly, maximum anterior surface curvature using the axial algorithm was greatest in small mire Placido device, and lowest in the pure Scheimpflug device. The integrated

Table 2: Intermachine corneal statistics for the axial algorithm

Machine	*MAG (D)*	*SEM*	*Machine*	*RD (mm)*	*SEM*	*Machine*	*ME (deg)*	*SEM*
Orbscan	60.30	0.79	Alcon	1.75	0.26	EyeSys	258.28	12.70
Keratron	55.51	1.01	Keratron	1.72	0.27	Alcon	252.94	14.85
TMS	55.37	1.13	EyeSys	1.50	0.25	PAR	244.78	21.49
Alcon	53.55	1.00	Orbscan	1.45	0.18	Keratron	241.84	17.53
EyeSys	53.51	1.22	TMS	1.38	0.25	Orbscan	233.55	22.29
PAR	51.49	0.75	PAR	1.13	0.27	TMS	213.14	23.09

Note: Machines that share the same color are not statistically different;
MAG: Curvature magnitude; RD: Radial direction; ME: Meridional direction

Table 3: Intermachine corneal statistics for the IROC algorithm

Machine	*MAG (D)*	*SEM*	*Machine*	*RD (mm)*	*SEM*	*Machine*	*ME (deg)*	*SEM*
Orbscan	62.03	0.86	Keratron	1.48	0.20	Orbscan	267.39	9.34
Keratron	61.22	1.72	Alcon	1.37	0.23	Alcon	244.00	14.70
TMS	58.20	1.22	TMS	1.24	0.14	Keratron	240.43	16.84
EyeSys	55.64	1.01	EyeSys	1.14	0.18	EyeSys	217.44	23.02
Alcon	55.46	1.05	Orbscan	0.99	0.10	TMS	207.98	22.59
PAR	52.38	0.74	PAR	0.78	0.22	PAR	180.73	31.45

Note: Machines that share the same color are not statistically different;
MAG: Curvature magnitude; RD: Radial direction; ME: Meridional direction

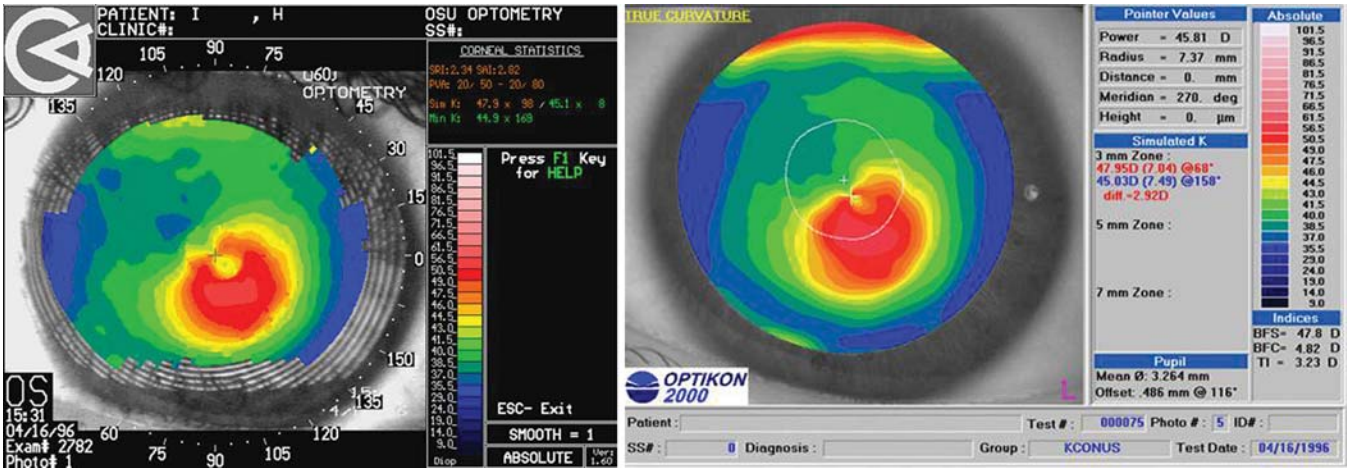

Fig. 1: Examples of IROC (or tangential) displays on small mire Placido devices, with TMS-1 on the left and Keratron on the right

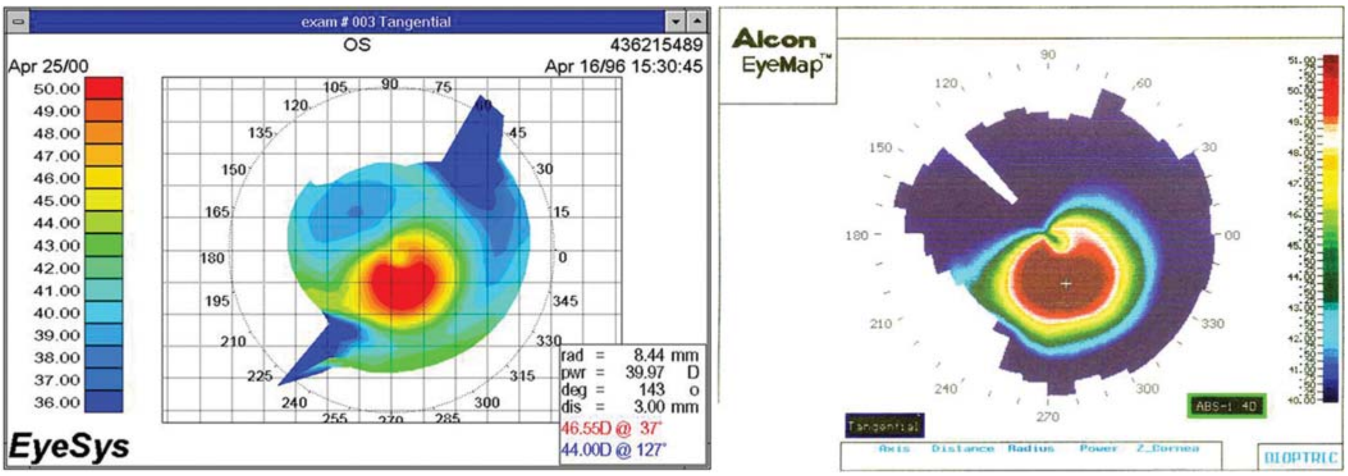

Fig. 2: Examples of IROC (or tangential) displays on large mire Placido devices, with EyeSys on the left and Alcon EyeMap on the right

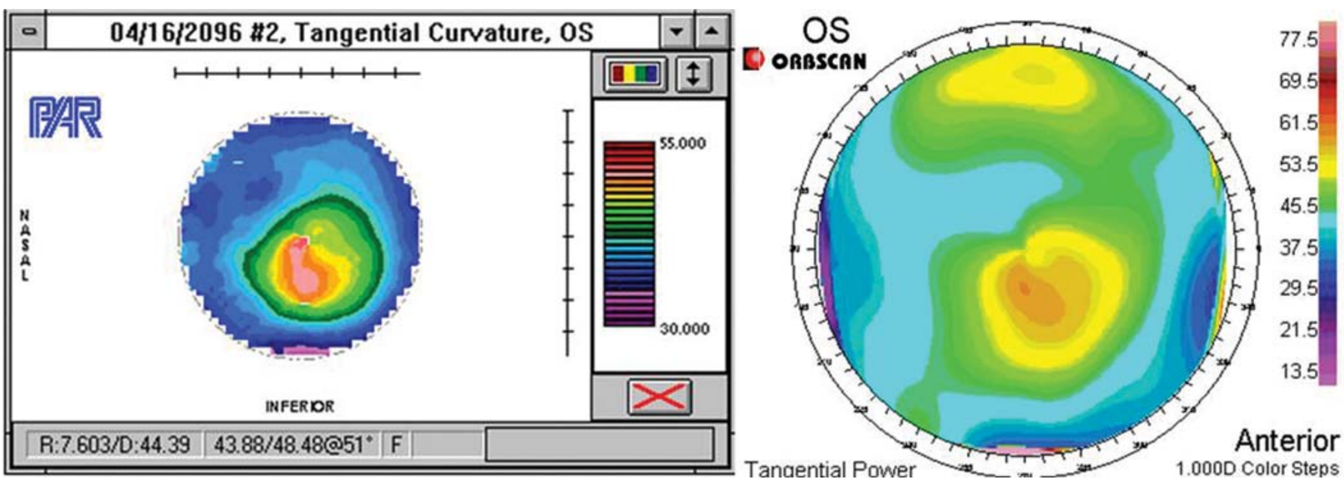

Fig. 3: Examples of IROC (or Tangential) displays on rasterstereographic corneal topography on the left and scanning slit technology on the right, both have curvature calculated based on acquired elevation data

Scheimpflug/Placido system which used a large mire Placido, was in between the other two. This is consistent with the results of the current study in which the large mire Placido devices represented maximum curvature at a lower value than the small mire Placido devices.

CONCLUSION

The results of this study indicate that representations of cone severity can vary significantly between topographers that employ different technologies (Placido *vs* scanning slit *vs* rasterstereography), and well as those that employ the same technology but utilize different hardware (large *vs* small mire Placido). Small mire Placido devices represent the maximum curvature in keratoconus at greater magnitude than large mire devices. In monitoring keratoconus, evaluation of change overtime is fundamental to treatment decisions. Therefore, it is important to keep these differences in mind, if multiple technologies are involved when following the progression of keratoconus, pellucid marginal degeneration, keratoglobus and postsurgical eyes as well as after corneal collagen cross-linking.

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