Comparison of Posterior Corneal Imaging Before and After LASIK Using Dual Rotating Scheimpflug and Scanning Slit-Beam Corneal Tomography Systems

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ABSTRACT

PURPOSE: To compare the maximum posterior elevation (MPE) measurements before and after LASIK using a dual rotating Scheimpflug (DRS) imaging system (Galilei, Ziemer Ophthalmic Systems, Port, Switzerland) and a scanning slit-beam (SSB) imaging system (Orbscan IIz, Bausch & Lomb, Rochester, NY).

METHODS: This retrospective study included 78 eyes from 78 patients who underwent myopic LASIK. Preoperative and postoperative data collected included anterior and posterior best-fit sphere radius and axial curvature readings, posterior central elevation (PCE), and MPE relative to a best-fit sphere using a 7.8-mm region of interest. Data were compared using paired *t* test analysis.

RESULTS: Mean preoperative PCE (5.06 ± 2.29 µm with the DRS system and 12.78 ± 6.90 µm with the SSB system) and MPE (4.87 ± 4 µm with the DRS system and 15.44 ± 9.78 µm with the SSB system) were statistically different ($P < .001$). Mean postoperative PCE (4.55 ± 2.34 µm with the DRS system and 20.59 ± 8.11 µm with the SSB system) and MPE (4.90 ± 3.35 µm with the DRS system and 24.95 ± 10.15 µm with the SSB system) were statistically different ($P < .001$). The difference between preoperative and postoperative MPE measurements by DRS was not statistically significant ($P = .953$), whereas the difference measured by SSB was statistically significant ($P < .001$).

CONCLUSIONS: The consistency of DRS measurements suggests that the posterior surface of the cornea does not change appreciably after keratorefractive surgery and is imaged more accurately using DRS compared with SSB. The DRS system affords confidence in interpreting data that are useful for discerning morphologic abnormalities of the cornea, both before and after keratorefractive surgery.

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Accurate imaging of the anterior and posterior cornea is essential for the refractive surgeon to screen patients effectively for surgery.[1] Tomography systems currently available in the United States include the Orbscan IIz (Bausch & Lomb, Rochester, NY) (scanning slit-beam [SSB] technology, and Placido imaging); Pentacam (Oculus Optikgeraete GmbH, Wetzlar, Germany) (single rotating Scheimpflug [SRS] system); Galilei (Ziemer Ophthalmic Systems, Port, Switzerland) (dual rotating Scheimpflug [DRS] system and Placido imaging); and Visante Omni (Carl Zeiss Meditec, Dublin, CA) (anterior segment optical coherence tomography and Placido imaging). Abnormal posterior corneal elevation has been shown to aid in the identification of forme fruste keratoconus and early detection of postrefractive keratectasia.[2,3] However, most of the studies that evaluated posterior corneal elevation changes after refractive surgery were based on SSB measurements.[4-10] The SSB system uses both slit scanning and a Placido system to measure anterior and posterior elevation as well as anterior curvature.[11] Several studies conducted with SSB technology suggested that the posterior corneal surface moves forward after LASIK,[4,6,9] although these findings may be artifactual.[12] Studies using the Pentacam, an SRS system, showed no difference in posterior corneal elevation after refractive surgery.[13-16] The DRS sys-

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tem may provide more accurate corneal measurements in eyes after refractive surgery.[17] This study compared maximum posterior elevation (MPE) measurements obtained preoperatively and after myopic LASIK surgery with SSB and DRS technologies.

PATIENTS AND METHODS

Patient Selection

A retrospective chart review was performed after institutional review board approval was obtained at the University of California, Los Angeles (UCLA), on patients who underwent LASIK surgery at the UCLA Laser Refractive Center, Jules Stein Eye Institute, David Geffen School of Medicine at UCLA. Seventy-eight eyes of 78 patients who underwent myopic LASIK from September 2009 to July 2010 were included in the study. No patient had ocular morbidity other than refractive error. For inclusion in the study, patients must have had tomographic analysis by the SSB and DRS systems on the same day preoperatively and on the same day at least 6 weeks postoperatively. An experienced technician performed all measurements. All patients underwent uneventful myopic LASIK surgery performed by a single surgeon (DRH).

Orbscan IIz: SSB

The Orbscan IIz uses a slit-scanning tomographic imaging system for analysis of anterior and posterior corneal elevations from which pachymetric data are derived and integrated with a Placido topographer. The video imaging system performs 40 scans through light slits projected at a 45-degree angle. In two 0.75-second periods, 20 slits are projected sequentially on the eye from the right and left sides of the video axis. An additional image is captured using Placido rings before the slit scans are acquired. The system measures 9,600 points, and these point measurements are used to construct mathematical representations of the true topographic surfaces of the anterior segment that are used to calculate slope and curvature.[18] The system digitally recreates the posterior cornea, anterior iris, and lens from the collected data using triangulation of previously generated anterior elevation and curvature using a proprietary algorithm.[11,19]

Galilei Dual Rotating Scheimpflug Analyzer: DRS

The Galilei analyzer uses the DRS system with two cameras 180 degrees apart integrated with a Placido topographer. It measures more than 122,000 data points per scan. The dual Scheimpflug cameras are located 180 degrees apart to compensate for error associated with scans obtained at an oblique angle. The system takes images of all anterior segment structures (cornea, iris, pupil, anterior chamber, and lens). Posterior corneal surface data are measured using edge detection in images provided by the dual Scheimpflug system. The software has enhanced the posterior edge location and uses ray tracing with the Snell law of refraction through the anterior surface to locate and help in reliably reconstructing the posterior surface.[20] Two snapshot Placido images are acquired and used for anterior curvature, one each with the Scheimpflug camera system at zero degrees and rotated 90 degrees.

Measured variables included preoperative and postoperative anterior chamber depth (ACD), anterior and posterior best-fit sphere (BFS) radius, anterior and posterior axial curvature readings at the 1- to 4-mm zone, and posterior central elevation (PCE) measured at the center of the scan. The main measured variable was the MPE above the BFS. The BFS was defined with a 7.8-mm region of interest for both systems preoperatively and postoperatively. The MPE is the absolute magnitude in micrometers of the most elevated central posterior corneal surface above a BFS. When an area of isolated elevation was surrounded in all directions by a depression, the highest point within this area of elevation was used as the MPE. In the case of an astigmatic posterior corneal surface, the center of the posterior elevation scan was used as the MPE if the elevation in that meridian increased monotonically in both directions. Additionally, the DRS system preoperative and postoperative posterior BFS values were used as the posterior corneal reference surface to determine PCE and MPE with the SSB system.

Statistical Analysis

Statistical analysis was performed with Stata 8.0 software (StataCorp LP, College Station, TX) and Microsoft Excel software (Microsoft Corp, Redmond, WA). Paired *t* test analysis was used to identify differences between preoperative and postoperative values and between devices. The Bland-Altman plot was used to assess the difference between preoperative and postoperative MPE values plotted against the means of the values measured with each device and the agreement between devices in measuring MPE. A *P* value less than .05 was considered significant.

RESULTS

The mean age of the 40 men and 38 women in the study was 34 ± 9.28 years (range: 21 to 67 years). The 78 eyes had a preoperative mean spherical equivalent refraction error of -4.17 ± 2.02 diopters (D) (-1.00 to -9.25 D). **Table 1** summarizes intrasystem preoperative and postoperative parameter comparisons. **Table 2** summarizes intersystem parameter comparisons.

TABLE 1

Mean Dual Rotating Scheimpflug and Scanning Slit-Beam Intrasystem Preoperative and Postoperative Tomography Readings for Anterior and Posterior Corneal Measurements and Anterior Chamber Depth

	Dual Rotating Scheimpflug System			Scanning Slit-Beam System		
Variable	**Preoperative**	**Postoperative**	***P***	**Preoperative**	**Postoperative**	***P***
ACD (mm)	3.39 ± 0.29	3.38 ± 0.31	.175	3.12 ± 0.30	3.12 ± 0.32	.836
BFS (mm)						
Anterior	7.51 ± 0.26	7.94 ± 0.34	< .001	7.87 ± 0.27	8.11 ± 0.30	< .001
Posterior	6.27 ± 0.23	6.22 ± 0.22	< .001	6.45 ± 0.24	6.41 ± 0.24	< .001
Average K (D)						
Anterior	43.96 ± 1.51	40.66 ± 1.98	< .001	44.06 ± 1.60	40.86 ± 1.95	< .001
Posterior	-6.58 ± 0.25	-6.61 ± 0.24	.009	-6.61 ± 0.24	-6.87 ± 0.31	< .001
Anterior K (D)						
Flat	43.40 ± 1.56	40.21 ± 1.99	< .001	43.52 ± 1.65	40.48 ± 1.92	< .001
Steep	44.52 ± 1.55	41.11 ± 2.00	< .001	44.60 ± 1.64	41.24 ± 2.00	< .001
Posterior K (D)						
Flat	-6.41 ± 0.25	-6.42 ± 0.27	.199	-6.02 ± 0.35	-6.22 ± 0.31	< .001
Steep	-6.76 ± 0.27	-6.80 ± 0.25	.003	-7.20 ± 0.38	-7.65 ± 1.00	< .001
PCE (μm)	5.06 ± 2.29	4.55 ± 2.34	.017	12.78 ± 6.90	20.59 ± 8.11	< .001
MPE (μm)	4.87 ± 4.00	4.90 ± 3.35	.953	15.44 ± 9.78	24.95 ± 10.15	< .001
PCE with DRS posterior BFS (μm)				7.49 ± 9.72	18.37 ± 13.41	< .001
MPE with DRS posterior BFS (μm)				9.68 ± 11.78	22.63 ± 15.16	< .001

ACD = anterior chamber depth; BFS = best-fit sphere; K = keratometric power; D = diopters; PCE = posterior central elevation; MPE = maximum posterior elevation, DRS = dual rotating Scheimpflug

The intrasystem changes in ACD were not significant for both systems. Statistically significant differences were found for keratometric power readings before and after surgery except for flat posterior keratometric power readings. There was a greater increase in postoperative posterior axial curvature readings with the SSB system than with the DRS system (**Table 1**).

Mean postoperative PCE was slightly lower than preoperative PCE using the DRS system but was significantly higher postoperatively using the SSB system. Paired *t* test analysis showed that the difference between the DRS system preoperative and postoperative MPE values was not statistically significant. However, the difference between the SSB system preoperative and postoperative MPE values was statistically significant (**Table 1**).

The intersystem differences between ACD readings were significant, with the DRS system yielding higher readings. The SSB system showed slightly higher anterior keratometric power readings and lower flat and higher steep posterior curvature readings compared with the DRS system. The differences were significant except for preoperative average posterior keratometric power and steep anterior keratometric power readings (**Table 2**).

Both preoperative and postoperative PCE readings were higher with the SSB system compared with the DRS system. Mean preoperative MPE measured with the DRS system was significantly lower compared with SSB system measurements. Mean postoperative MPE was also significantly lower with the DRS system than with the SSB system (**Table 2**).

The Bland-Altman plots showed greater bias (9.51 μm) between preoperative and postoperative MPE measurements by the SSB system (**Figure 1B**) compared with the bias (0.03 μm) between DRS system measurements (**Figure 1A**). The range of fluctuation of values was also smaller with the DRS system (**Figure 1A**). **Figures 2A** and **2B** show an increasing bias between SSB and DRS systems measurements of MPE as the MPE magnitude increases. This bias is greater postoperatively (20.05 μm) than preoperatively (10.56 μm).

Taking the BFS used on the DRS system and using it for the BFS on the SSB system, PCE and MPE were

TABLE 2

Mean Dual Rotating Scheimpflug and Scanning Slit-Beam Intersystem Preoperative and Postoperative Tomography Readings for Anterior and Posterior Corneal Measurements and Anterior Chamber Depth

	Preoperative			Postoperative		
	DRS	SSB	*P*	DRS	SSB	*P*
ACD (mm)	3.39 ± 0.29	3.12 ± 0.30	< .001	3.38 ± 0.31	3.12 ± 0.32	< .001
BFS (mm)						
Anterior	7.51 ± 0.26	7.87 ± 0.27	< .001	7.94 ± 0.34	8.11 ± 0.30	< .001
Posterior	6.27 ± 0.23	6.45 ± 0.24	< .001	6.22 ± 0.22	6.41 ± 0.24	< .001
Average K (D)						
Anterior	43.96 ± 1.51	44.06 ± 1.60	.032	40.66 ± 1.98	40.86 ± 1.95	< .001
Posterior	-6.58 ± 0.25	-6.61 ± 0.24	.051	-6.61 ± 0.24	-6.87 ± 0.31	< .001
Anterior K (D)						
Flat	43.40 ± 1.56	43.52 ± 1.65	.033	40.21 ± 1.99	40.48 ± 1.92	< .001
Steep	44.52 ± 1.55	44.60 ± 1.64	.117	41.11 ± 2.00	41.24 ± 2.00	.024
Posterior K (D)						
Flat	-6.41 ± 0.25	-6.02 ± 0.35	< .001	-6.42 ± 0.27	-6.22 ± 0.31	< .001
Steep	-6.76 ± 0.27	-7.20 ± 0.38	< .001	-6.80 ± 0.25	-7.65 ± 1.00	< .001
PCE (μm)	5.06 ± 2.29	12.78 ± 6.90	< .001	4.55 ± 2.34	20.59 ± 8.11	< .001
MPE (μm)	4.87 ± 4.00	15.44 ± 9.78	< .001	4.90 ± 3.35	24.95 ± 10.15	< .001
PCE with DRS posterior BFS (μm)	5.06 ± 2.29	7.49 ± 9.72	.026	4.55 ± 2.34	18.37 ± 13.41	< .001
MPE with DRS posterior BFS (μm)	4.87 ± 4.00	9.68 ± 11.78	< .001	4.90 ± 3.35	22.63 ± 15.16	< .001

DRS = dual rotating Scheimpflug; SSB = scanning slit beam; ACD = anterior chamber depth; BFS = best-fit sphere; K = keratometric power; D = diopters; PCE = posterior central elevation; MPE = maximum posterior elevation

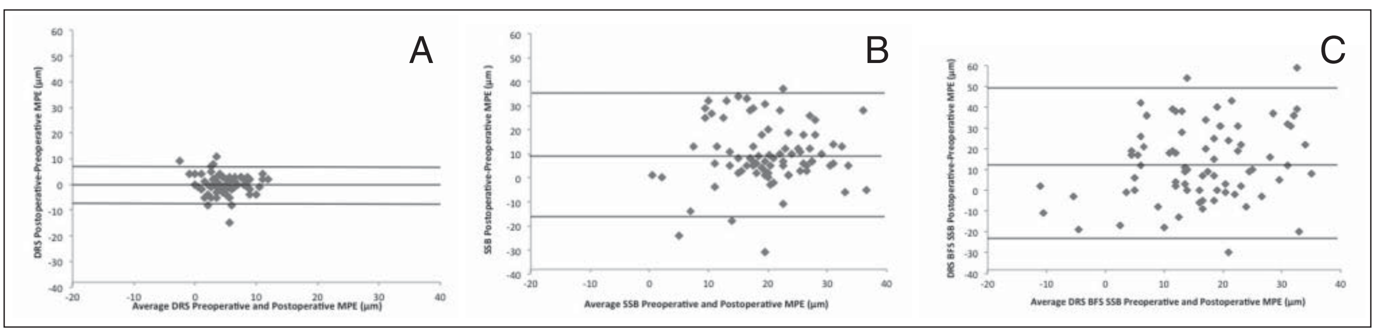

Figure 1. Bland-Altman plots of the maximum posterior elevation (MPE) readings for (A) the dual rotating Scheimpflug (DRS) imaging system, (B) the scanning slit beam (SSB) imaging system, and (C) the SSB system using the DRS posterior best-fit sphere (BFS). The middle line represents the mean. The lines above and below represent the upper and lower 95% confidence intervals of agreement, respectively.

both lower compared with values with the SSB-chosen BFS. The PCE and MPE values measured using SSB were still significantly higher compared with those obtained with DRS, even with the same BFS reference ($P < .001$). The Bland-Altman plot showed greater bias (13 μm) between preoperative and postoperative MPE measurements when using the DRS-derived BFS for SSB measurements (**Figure 1C**).

DISCUSSION

In this study, both systems provided significantly different values for ACD, anterior and posterior BFS radius, and anterior and posterior corneal curvature readings before and after surgery. These findings are comparable to the results of a study by Hashemi and Mehravaran[21] that compared the Pentacam with the Orbscan II. Mean anterior keratometric power values showed flatter read-

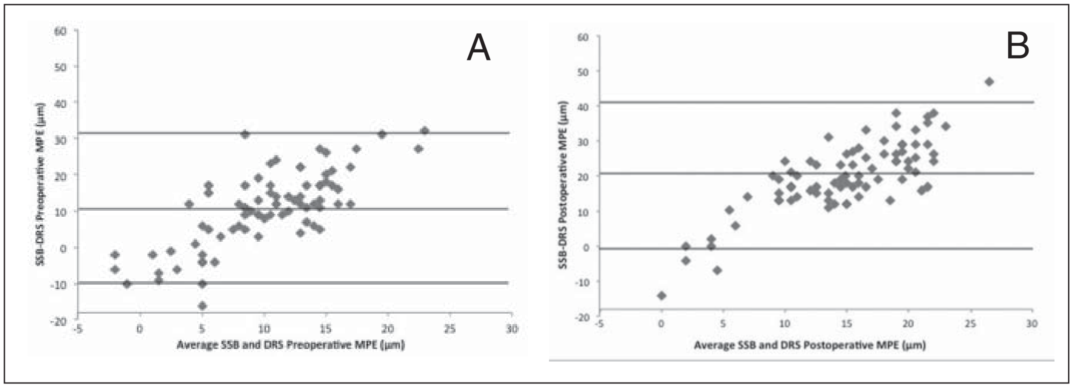

Figure 2. Bland-Altman plots of the (A) preoperative and (B) postoperative maximum posterior elevation (MPE) readings for the dual rotating Scheimpflug (DRS) imaging system and the scanning slit beam (SSB) imaging system. The middle line represents the mean. The lines above and below represent the upper and lower 95% confidence intervals of agreement, respectively.

ings with the DRS system compared with the SSB system, results similar to those reported in a study by Menassa et al.[22] that also compared these two systems.

This study did not find a statistically significant difference in MPE measured before and after LASIK using the DRS system. Smadja et al.[20] found mild posterior steepening early after myopic LASIK, with a shift to the preoperative level between 1 and 3 months using the Galilei. This finding is consistent with our results that show minimal change in MPE at least 6 weeks after surgery. Studies using a single rotating Scheimpflug system also showed no significant posterior corneal displacement after LASIK,[13-14] photorefractive keratectomy,[13,15] and LASIK enhancement.[16] However, a study by Salouti et al.[23] showed significantly higher central, inferior, and temporal anterior and posterior elevation measurements with the Pentacam compared with the Galilei.

A significant increase in posterior corneal elevation was seen with the SSB system. This is consistent with findings from several studies using the SSB system that have postulated an increase in posterior corneal elevation after LASIK and photorefractive keratectomy. Changes in posterior elevation have been correlated with thinner residual bed thickness, higher ablations, high intraocular pressure, and a decrease in anterior chamber depth after refractive surgery.[5,7-10] Currently, these changes are believed to be a result of the SSB method of inferring the posterior elevation based on the anterior elevation measurements. Nawa et al.[24] showed that the apparent posterior corneal steepening may be explained by the change in corneal magnification after LASIK. The Orbscan may calculate the magnification ratio inaccurately because the apparent image of the posterior surface of the cornea becomes smaller postoperatively. Roberts et al.[12] found that the posterior surface edge tracker in version 3.0 of the Orbscan software is not tuned to the higher scatter conditions often found when imaging corneas after LASIK. This causes the edge tracker to generate artificially low corneal thickness values and artificially high central elevation in the posterior cornea, which might be misinterpreted as ectasia.

In the current study, posterior elevation measurements by the SSB system were significantly higher than those by the DRS system. Several studies comparing the posterior elevation values using the Orbscan II and the Pentacam after refractive surgery also showed higher values using the Orbscan II.[21,25-27] A study by Quisling et al.[28] also showed higher posterior elevation measurements with the Orbscan IIz compared with the Pentacam in keratoconic eyes. This difference can be explained by the measurement techniques used by each tomographer. The improved posterior edge detection for the DRS system may enhance the accuracy of measurement of posterior corneal elevation. However, studies by Salouti et al.[23] and Karimian et al.[26] questioned whether there might be underestimation of elevation measurements by the DRS system or overestimation by the SSB system.

No statistically significant difference was found between the MPE values measured by the DRS system preoperatively and postoperatively after LASIK, a finding in stark contrast to those obtained with the SSB system. Bland-Altman analysis showed better agreement between preoperative and postoperative measurements with the DRS system than with the SSB system. In addition, paired *t* test analysis showed that the difference between mean preoperative and postoperative SSB system measurements was statistically significant. Given these findings, the reproducibility of the posterior elevation measurements preoperatively and postoperatively with the DRS system suggest that it is unlikely that the posterior corneal surface moves forward after myopic LASIK in normal eyes when keratectasia does not develop.

Precise and accurate readings of the posterior elevation are essential in screening patients for subtle forme fruste keratoconus that may place them at risk for iatrogenic keratectasia after excimer ablation. However, this study has limitations similar to those in previous comparative studies.[21,23] With the absence of a gold standard reference for corneal tomographers, we cannot state categorically whether there is underestimation or overestimation of measurements between instruments. Further studies are required to determine whether these results are repeatable in patients with corneal pathology, such as ectatic disorders. The DRS system appears to be a useful device for screening candidates for refractive surgery and for investigating corneal pathology after refractive surgery.

AUTHOR CONTRIBUTIONS

Study concept and design (JD, DRH); data collection (JD, JE, AR-M, SZ-G); analysis and interpretation of data (JD, DRH, MES); drafting of the manuscript (JD, AR-M, MES); critical revision of the manuscript (JE, DRH, MES, SZ-G); supervision (DRH)

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