Is Topography-guided Ablation Profile Centered on the Corneal Vertex Better Than Wavefront-guided Ablation Profile Centered on the Entrance Pupil?

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ABSTRACT

PURPOSE: To illustrate the hypothesis that corneal vertex centration is superior to entrance pupil centration when guiding an ablation by wavefront.

METHODS: In one case example of therapeutic retreatment for treatment zone decentration after primary radial keratotomy (RK) centered on the entrance pupil (line of sight), both a whole-eye wavefront-guided ablation profile (WASCA data) and a topography-guided ablation profile (Atlas data) were generated using the CRS-Master (Carl Zeiss Meditec) and compared. The patient had a large vertical angle kappa. Corneal topography demonstrated that the zone of flattening was decentered superiorly with reference to the corneal vertex and the patient reported severe night vision disturbances.

RESULTS: The wavefront-guided profile, centered on the line of sight, was symmetrical because the wavefront was dominated by spherical aberration induced by the primary RK treatment. On the other hand, the topography-guided profile, centered on the corneal vertex, was asymmetric with an inferior region of ablation, which would logically improve the topographic decentration. The topography-guided profile was chosen for photorefractive keratectomy using the MEL 80 excimer laser (Carl Zeiss). Ten months after the procedure, the treatment zone was topographically well centered on the corneal vertex. Whole-eye higher order root-mean-square (RMS) was reduced by 43% and corneal higher order RMS was reduced by 61%. The patient reported large subjective improvement in the quality of vision and marked reduction in night vision disturbances.

CONCLUSIONS: This case provides evidence that wavefront data centered on the entrance pupil center may not represent the patient’s view and the treatment zone should preferably be centered on the corneal vertex rather than the entrance pupil center. [J Refract Surg. 2012;28(2):139-143.]

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Custom ablation to repair postoperative corneal refractive surgery complications is currently available in two forms, wavefront-guided and topography-guided custom ablation. As the name indicates, wavefront-guided custom ablation uses whole-eye wavefront data to generate an ablation profile with the aim of correcting higher order aberrations. On the other hand, topography-guided custom ablation uses front-surface corneal topography data to generate an ablation profile with the aim of regularizing the front-surface corneal topography. In theory, both methods are doing the same thing in different ways, therefore, wavefront- and topography-guided ablations should be similar for each case, although differences may occur because wavefront-guided ablation profiles also include internal aberrations whereas topography-guided ablation is calculated using corneal data only.

The other major difference between these two techniques is the point about which the ablation calculation is centered. By convention, the Zernike expansion has been used to describe the wavefront calculated from the entrance pupil center (line of sight) (Fig 1), and most commercial wavefront-guided excimer laser ablations are recommended to be centered on the entrance pupil center. On the other hand, the corneal topography measurement is obtained centered on the corneal vertex, and the corneal vertex provides the best approximation of the visual axis, defined as the line joining the fixation point of the pupil.
point and the fovea, passing through the nodal points (see Fig 1). The line of sight and visual axis may intersect the cornea at two separate points, ie, wavefront- and topography-guided ablations will be centered at different locations if the angle kappa is not zero.

We describe an example where a large angle kappa leads to two markedly different ablation profiles for treating a patient complaining of severe night vision disturbances 18 months after radial keratotomy (RK) centered on the line of sight where the outcome obtained using the topography-guided ablation was superior to that of the wavefront-guided treatment.

**CLINICAL EXAMPLE**

A 21-year-old man was referred to the London Vision Clinic, London, United Kingdom, in January 2006 complaining of significant halos and starbursts in his right eye following RK in August 2004 (the left eye was not treated); a simulation of his night vision is shown in Figure 2. Preoperative manifest refraction was −5.75 diopters sphere with corrected distance visual acuity (CDVA) of 20/32. Eight incisions had been placed with an intended treatment zone of 3 mm centered on the line of sight. Nine months after the procedure, uncorrected distance visual acuity (UDVA) was 20/25 with a manifest refraction of −0.75 −0.50 × 120 (20/25). Two further incisions were created at 30° and 210° in May 2005, apparently to correct astigmatism.

The ophthalmic examination performed during his initial consultation at the London Vision Clinic found UDVA of 20/40 with a manifest refraction of +1.50 −1.50 × 111 and CDVA of 20/20. Further testing included topography with Orbscan II (Bausch & Lomb, Salt Lake City, Utah); Pentacam (Oculus Optikgeräte, Wetzlar, Germany) and Atlas (Carl Zeiss Meditec, Jena, Germany); whole-eye wavefront using the WASCA aberrometer (Carl Zeiss Meditec), undilated and after cyclopia using tropicamide 1%; Procyon pupillometry (Haag Streit, Koeniz, Switzerland); corneal analysis using the Ocular Response Analyzer (Reichert, Depew, New York); handheld ultrasonic pachymetry (Corneogage Plus, Sonogage, Cleveland, Ohio); and Goldmann applanation tonometry. Vertical sinusoidal grid contrast sensitivity testing was obtained at 3, 6, 12, and 18 cycles per degree (cpd) using the CSV-1000 (VectorVision Inc, Greenville, Ohio). Corneal wavefront was calculated from the Atlas topography data using VOL-Pro (Sarver & Associates Inc, Carbondale, Illinois). Corneal wavefront and whole-eye wavefront were reported using Optical Society of America notation in a 6-mm zone. Night vision quality was assessed using the Surgical Eyes Visual

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**Figure 1.** Definition of the axes of the eye. The line of sight is the line joining the fixation point and the center of the entrance pupil (E). It intersects the cornea at point P. The visual axis is the line joining the fixation point and the fovea, passing through the nodal points. It intersects the cornea at point (V). Angle kappa (K) is the angle between the pupillary axis (line perpendicular to the cornea and passing through the center of the entrance pupil) and the visual axis. The insert above diagrammatically illustrates the obliquity and centration differences between a visual axis centered ablation (red) and an entrance pupil centered ablation (blue).

**Figure 2.** Subjective simulation of the patient’s night vision before and 10 months after topography-guided photorefractive keratectomy. Postoperatively, the starbursts remained, but the halos had completely disappeared. The residual starbursts could be explained by the radial keratotomy incisions.
Effects Simulator (Adam Bogart, Toronto, Canada). The Artemis 1 very high-frequency digital ultrasound arc-scanner (ArcScan Inc, Morrison, Colorado) was used to determine the thickness profile of each corneal layer. Pachymetric profiles were calculated based on data from four meridional B-scans, comprising eight semi-meridians. This is our standard scanning protocol as it provides a sufficiently high density of information in the central cornea with a lower density of information in the periphery, where it is less needed.

Contrast sensitivity was below the normal range; the patient could see 4 patches at 3 cpd, 4 patches at 6 cpd, 3 patches at 12 cpd, and 4 patches at 18 cpd (the low end of the normal range for the CSV-1000 is 5, 4, 5, and 5, respectively). Analysis of front surface topography showed that the treatment zone was decentered superiorly relative to the corneal vertex; the Atlas axial map is presented in Figure 3. The eye image obtained by the Atlas topographer showed the presence of a large superior angle kappa. Slit-lamp examination of the patient revealed that the treatment zone described by the RK incisions was located slightly superior to the entrance pupil center. Whole-eye wavefront analysis (see Fig 3), calculated centered on the entrance pupil center, showed a symmetrical wavefront error with significant higher order aberrations—spherical aberration of 0.88 μm, coma of 0.24 μm, and higher order RMS of 0.96 μm. Corneal wavefront analysis (see Fig 3), calculated centered on the corneal vertex, showed an asymmetric wavefront error also with significant higher order aberrations—spherical aberration of 1.27 μm, coma of 2.06 μm, and higher order RMS of 2.52 μm. The Artemis epithelial thickness profile (see Fig 3) showed that the epithelium was up to 77-μm thick centrally surrounded by thinner epithelium (down to 44 μm inferotemporally). The epithelial thickness profile was thinner over the area of corresponding increased curvature inferiorly.

The CRS-Master ablation profile planning software (Carl Zeiss Meditec) was used to generate both a wavefront-guided custom ablation profile and a topography-guided custom ablation profile, and both profiles are shown in Figure 4. With the CRS-Master, wavefront-guided profiles are always calculated centered on the entrance pupil center. However, the CRS-Master allows the user to select the location of the center of the ablation profile calculation for topography-guided profiles. Our protocol is to use the corneal vertex as the center of the ablation profile algorithm, identified as the origin of the Atlas topography mires rings.

The topography-guided ablation profile showed an asymmetric ablation with greater ablation depth inferiorly. Therefore, the ablation was targeted to flatten the inferior region of steepening to correct the topographic decentration and move the treatment zone to be centered on the corneal vertex, which should theoretically result in reducing coma on the corneal wavefront. Conversely, the wavefront-guided ablation profile showed a symmetrical ablation as the whole-eye wavefront was dominated by high spherical aberration. If the wavefront-guided ablation profile was used, centered on the line of sight, there would be approximately equal ablation superiorly and inferiorly, which may make the topographic decentration worse. Given that the topography-guided ablation profile seemed to be
a more logical approach to correcting the topographic decentration, a topography-guided repair was the chosen procedure.

Topography-guided photorefractive keratectomy (PRK) centered on the corneal vertex was performed on March 7, 2006, using the MEL 80 excimer laser (Carl Zeiss Meditec). The Atlas examination used for treatment was selected by the surgeon (D.Z.R.), after ensuring that the examination was in focus, had smooth, regular mires rings, and had continuous data within sufficient diameter. The Atlas topographic data were imported into the CRS-Master. During surgery, the corneal vertex was approximated by the first Purkinje reflex, seen as the patient fixated coaxially with the aiming beam and the view of the surgeon’s contralateral eye through the operating microscope. A 7.0-mm treatment zone was used with a transition zone out to 9.0 mm. The ablation profile included a preablation of 6-μm phototherapeutic keratectomy (PTK), which was programmed into the same treatment profile (using the PTK option in the CRS-Master topography-guided ablation planning module), to homogenize the hydration of the corneal surface in advance of the asymmetric ablation being performed.

A bandage contact lens (Acuvue Oasys [Johnson & Johnson, New Brunswick, New Jersey]; 8.8 mm, diameter: 14.0 mm, power: +0.50 D) was inserted and kept in place for several days until the epithelial defect had healed. The patient was instructed to wear plastic shields when sleeping for 7 nights. Tobradex (tobramycin/dexamethasone; Alcon Laboratories Inc, Ft Worth, Texas) and Exocin (ofloxacin; Allergan Ltd, Marlow, United Kingdom) were applied four times daily for the first week. The patient was also given oral morphine sulphate tablets (10 mg, twice daily) and diclofenac (50 mg, three times daily) during the period of re-epithelialization. Following re-epithelialization, the patient received a 3-week course of dexamethasone 0.1% four times daily, followed by fluoromethalone 0.1% drops four times daily for an additional 2 months.

Ten months after the procedure, UDVA in the right eye was 20/20 with a manifest refraction of +0.75 -1.00 × 110 with CDVA of 20/16 -1. The slit-lamp examination showed no haze. The patient reported that the starbursts were still present, but the halos had completely disappeared; a postoperative simulation of his night vision is shown in Figure 2. Figure 3 presents the Atlas topography, whole-eye wavefront, corneal wavefront, and Artemis epithelial thickness, before and after surgery as well as difference maps for each. Corneal front surface topography showed that the treatment zone was centered on the corneal vertex. The Atlas difference map demonstrated an area of flattening inferiorly, which was the location of maximum ablation. Whole-eye wavefront analysis showed that a significant reduction in higher order aberrations had been achieved when the calculation was centered on the entrance pupil center; spherical aberration was reduced by 46% from 0.88 μm to 0.48 μm, coma was reduced by 31% from 0.24 μm to 0.17 μm, and higher order RMS was reduced by 43% from 0.96 μm to 0.55 μm. Corneal wavefront analysis also showed that a significant reduction in higher order aberrations had been achieved with the calculation centered on the corneal vertex; spherical aberration was reduced by 30% from 1.27 μm to 0.88 μm, coma was reduced by 86% from 2.06 μm to 0.29 μm, and higher order RMS was reduced by 61% from 2.52 μm to 0.98 μm. The contrast
sensitivity improved to within the normal range for 3, 6, 12, and 18 cpd with the patient able to correctly identify 5 patches for each spatial frequency.

The Artemis epithelial thickness profile showed that the epithelium had remodeled according to the new stromal surface; the epithelium had thinned centrally and thickened inferiorly where the deepest ablation had been performed, which regularized the epithelial thickness profile. The Artemis stromal thickness change map (see Fig 4) represented the profile of stromal tissue removed by the irregular topography-guided ablation; there was an area of maximum tissue removal inferiorly, which matched the intended ablation profile.

**DISCUSSION**

This case example demonstrates a successful topography-guided repair procedure centered on the corneal vertex in an eye with large topographic decentration and a large superior angle kappa. The topographic decentration was successfully regularized, which resulted in a significant reduction in higher order aberrations as well as a subjective improvement in night vision quality reported by the patient; the halos had completely disappeared. The starburst effect remained, although this could probably be explained by the optical effect of the RK incisions.

This case also demonstrates a large difference in the shape of the ablation profiles between a wavefront-guided profile and topography-guided profile. The difference resulted from the location of the ablation algorithm center—the line of sight for the wavefront-guided profile and the corneal vertex for the topography-guided profile. The wavefront-guided profile would have ablated tissue equally superiorly and inferiorly and therefore would not have corrected the topographic decentration. Given the patient’s subjective asymmetric night vision simulation and the improvement once the treatment zone had been recentered on the corneal vertex by the topography-guided ablation, this suggests that the wavefront-guided profile would not have improved the quality of vision and might even have had a detrimental effect. This implies that a wavefront measurement centered on the entrance pupil in an eye with a large angle kappa does not represent the patient’s vision, as the patient is actually looking along the visual axis and not the line of sight. Therefore, calculating the wavefront centered on the corneal vertex may provide a more representative measurement in eyes with a large angle kappa. Wavefront-guided ablations have previously been used to successfully correct decentrations; however, this case report suggests that the angle kappa must be considered before using a wavefront-guided treatment in a decentration case.

This case report also provides further evidence that the treatment zone in corneal refractive surgery would be better centered on the corneal vertex rather than on the line of sight, as has been reported previously.

**AUTHOR CONTRIBUTIONS**

Study concept and design (D.Z.R., T.J.A.); data collection (T.J.A., M.G.); analysis and interpretation of data (D.Z.R., T.J.A., M.G.); drafting of the manuscript (T.J.A., M.G.); critical revision of the manuscript (D.Z.R., M.G.)

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