Comparison of the Ocular Response Analyzer and the Goldmann Applanation Tonometer for Measuring Intraocular Pressure after Deep Anterior Lamellar Keratoplasty

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PURPOSE. To compare intraocular pressure (IOP) measured using the Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, NY) with that measured using the Goldmann applanation tonometer (GAT) in keratoconic eyes after deep anterior lamellar keratoplasty (DALK) and evaluate the influence of central graft thickness (CGT), corneal astigmatism, corneal hysteresis (CH), and corneal resistance factor (CRF) on the IOP measurements.

METHODS. IOP using the GAT (IOPGAT), CH, CRF, Goldmann-correlated IOP (IOPG), corneal-compensated IOP (IOPc), using the ORA, and CGT were measured in 23 keratoconic eyes undergoing DALK. Bland-Altman plots were used to evaluate agreement between the tonometers. The correlation between refraction, CH, CRF, and CGT with IOP readings was investigated using multivariate regression analysis.

RESULTS. Mean patient age was 27.2 ± 6.5 years. Mean CGT, CH, and CRF were 547.0 ± 42.6 μm, 9.6 ± 2.1 mm Hg, and 9.4 ± 2.1 mm Hg, respectively. Mean IOPGAT, IOPc, and IOPc were 11.3 ± 2.9, 14.1 ± 2.4, and 15.6 ± 2.6 mm Hg, respectively (P < 0.001). The 95% limit of agreement for IOR and IOPGAT was between -2.61 and 8.19 mm Hg and for IOPc and IOPGAT it was between -0.69 and 9.21 mm Hg. CH and CRF were significantly associated with IOPGAT. No significant association was found between CGT and IOP readings obtained using either the ORA or GAT.

CONCLUSIONS. IOP readings by the ORA were significantly greater than those by the GAT, and CH and CRF play a more important role in post-DALK IOP readings by both GAT and ORA than other graft characteristics including curvature and central thickness. (Invest Ophthalmol Vis Sci. 2011;52: 5887–5891) DOI:10.1167/iovs.10-6771

Deep anterior lamellar keratoplasty (DALK) is considered an alternative procedure to penetrating keratoplasty (PK) for corneal pathologies not affecting the endothelium and Descemet’s membrane (DM).1 This technique of transplantation has been found effective to restore visual acuity with refractive outcomes comparable to those of PK in keratoconic eyes, while avoiding complications such as endothelial graft rejection and preserving the eye integrity against blunt trauma.1,2

The main aim of corneal transplantation of any kind is to restore optical properties of the eye. However, it is of particular importance to understand the nature of the change in biomechanical properties of the graft when refractive surgery of the transplanted cornea is anticipated. Further, monitoring intraocular pressure (IOP) after corneal transplantation is very important, as high IOP (>21 mm Hg) is encountered in transplanted eyes at a high incidence, ranging from 10% to 42%.3–6 Although Goldmann applanation tonometry (GAT) is considered the gold standard for measuring IOP, high astigmatism and surface irregularities after corneal transplantation can decrease its accuracy, and therefore other tonometers can alternatively be used.7–9 Further, decreased rigidity of the ocular wall in some conditions such as keratoconus, that may require corneal transplantation, can result in underestimating IOP measured with GAT.

In an attempt to circumvent the aforementioned problems with GAT in grafted eyes, several tonometers have been tried and compared to find an ideal instrument.7–9 Recently, Reichert Ophthalmic Instruments (Buffalo, NY) introduced a new technology noncontact tonometer that measures IOP as well as new metrics called corneal hysteresis (CH) and corneal resistance factor (CRF).12 The Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments) uses an air puff that causes inward and then outward corneal deformation, from which two application pressure measurements are obtained. By taking an average from these two measurements, a Goldmann-correlated IOP (IOPG) is calculated.12 Cornea-compensated IOP (IOPc) determines IOP values, less dependent on corneal properties such as central thickness.12,13 Hysteresis, which is said to be a measure of the viscoelastic properties of the cornea, is the difference between the inward and outward applanation pressures. Hysteresis is influenced by corneal thickness and rigidity.12

The main objective of the present study was to evaluate the agreement between IOP measurements obtained with the ORA and GAT in keratoconic patients who underwent DALK using Anwar’s big-bubble technique1 and investigate the influence of biometric characteristics of the graft, including central graft thickness, mean keratometry, astigmatism, and size, as well as CH and CRF, on these measurements.

MATERIALS AND METHODS

In this cross-sectional comparative study, 23 eyes of 21 (13 male) patients who had undergone DALK using Anwar’s big-bubble technique were included. The underlying pathology was keratoconus in all...
participants. The technique of DALK for keratoconus was previously described in detail.1 and a bared Descemet’s membrane was achieved in all cases. All sutures were removed at least 6 months before participants entered the study. The presence of any ocular diseases other than keratoconus; systemic disorders, such as diabetes mellitus; and a history of additional ocular surgeries such as a previous corneal graft, cataract extraction, and refractive surgery of any kind; and use of topical eye drops or contact lenses led to patient exclusion. This study was approved by the Institutional Ethics Committee according to the Declaration of Helsinki and a written informed consent was signed by all participants after the nature of the study was explained.

An ocular examination including uncorrected visual acuity (UCVA) and best spectacle-corrected visual acuity (BSCVA) using the Snellen acuity chart, slit-lamp biomicroscopy, manifest refraction, and keratometry was performed and preoperative IOPEAT was compiled from medical records. In each eye, IOP was measured twice using a Goldmann applanation tonometer (AT 020; Carl Zeiss Meditec Inc., Dublin, CA) and averaged, after anesthetizing the cornea with a drop of 0.5% topical 0.5% tetracaine. To reduce the effect of corneal astigmatism on the measurements, the tonometer head was rotated 43° to the least-curved meridian.

The ORA was used to measure IOPg, IOPcc, CH, and CRF. Briefly stated, the patients were seated and asked to keep their eyes wide open while fixating on a green target light at the center of red lights. After an air puff was released, the measured parameters were displayed on the monitor. For each patient, four consecutive readings with good quality and two distinct peaks (Fig. 1) were obtained and averaged after the outliers were excluded. Because measuring IOP with one tonometer may influence the after measurement, the tonometers were used in a random order with a 5-minute interval between readings to minimize the effect of IOP fluctuation. To avoid the effect of sleeping and diurnal variation on the measurements of central graft thickness (CGT), CH, CRF, and IOP as well, the measurements were taken in the morning, at least 3 hours after patients awakened, when postawakening decline had already occurred.

The last examination was CGT using an ultrasonic contact probe (A/B scan; Sonomed Inc., Lake Success, NY) after instillation of topical 0.5% tetracaine. The probe was held perpendicular to the center of cornea and five measurements were obtained within a range of ±2 μm and averaged for statistical analysis. All examinations and measurements were performed by a single qualified ophthalmologist (SF).

### Results

The ORA measurements are shown in Table 2. The last examination was CGT using an ultrasonic contact probe (A/B scan; Sonomed Inc., Lake Success, NY) after instillation of topical 0.5% tetracaine. The probe was held perpendicular to the center of cornea and five measurements were obtained within a range of ±2 μm and averaged for statistical analysis. All examinations and measurements were performed by a single qualified ophthalmologist (SF).

### Statistical Analysis

Statistical analysis was performed using commercial software (SPSS version 17; SPSS Inc., Chicago, IL). Data were presented as mean ± SD after their normal distribution was examined. Repeatability (intraobserver variability) of ORA measurements was calculated as 2.77 times the within-subject SD.14 Paired t-test was used to compare pre- and postoperative IOPEAT. Repeated measurement comparison analysis adjusted for multiple comparisons by the Bonferroni method was used to compare mean IOP readings by the ORA and GAT. The agreement between the two tonometers was evaluated with Bland-Altman plots. The correlation of biometric characteristics of grafts (CGT, recipient and donor trephine size, mean keratometry, and astigmatism) as well as the ORA measurements (CH and CRF) with the IOP readings by both tonometers was investigated using multivariate regression analysis. $P < 0.05$ was considered an indication of statistical significance.

#### RESULTS

Mean patient age was 27.2 ± 6.5 years (17–44 years) and mean follow-up period after keratoplasty was 29.2 ± 3.3 months (19–52 months). Mean recipient and donor trephine size was 7.90 ± 0.16 mm (7.50–8.0 mm) and 8.20 ± 0.18 mm (7.75–8.50 mm), respectively, with a trephine disparity of 0.25 mm in 19 and 50 mm in four eyes. Postoperative spherical equivalent refractive error, mean keratometry, and keratometric astigmatism were −4.11 ± 3.46 (−12.25 to +1.15) D, 46.28 ± 2.02 (41.5 to 49.0) D, and 4.49 ± 2.80 (0.50 to 10.0) D, respectively. Table 1 provides further information regarding CGT, pre- and postoperative IOPEAT, IOPg, IOPcc, CH, and CRF. The repeatability of the ORA measurements is presented in Table 2.

As demonstrated in Table 1, preoperative IOPEAT was significantly lower than the postoperative value ($P = 0.02$). Repeated measurement comparison analysis adjusted by the Bonferroni method demonstrated that IOPg was significantly higher than IOPGAT, with a mean difference of 2.8 mm Hg (95% confidence interval [CI], 1.3–4.3 mm Hg; $P < 0.001$), and IOPcc was higher than IOPGAT, with a mean difference of 4.3 mm Hg (95% CI, 2.9–5.6 mm Hg; $P < 0.001$). Similarly, the difference between IOPg and IOPcc reached a significant level ($P = 0.02$), in favor of IOPcc (mean difference, 1.5 mm Hg; 95% CI, 0.2–2.7 mm Hg).

Bland-Altman plots produced a 95% limit of agreement (LOA) for IOPg and IOPGAT between −2.61 and +8.19 mm Hg.

#### Case Study

Case study involving a patient with keratoconus treated with DALK. The patient presented with a steep corneal curvature, visual disturbance due to keratoconus, and a history of previous refractive surgery. Preoperative evaluation included UCVA, BSCVA, manifest refraction, keratometry, and biometry. Preoperative IOP was measured using Goldmann applanation tonometry. Preoperative ORA measurements were obtained, showing increased CH and CRF compared to postoperative values. Postoperative evaluation included UCVA, BSCVA, manifest refraction, keratometry, and biometry. Postoperative IOP was measured using Goldmann applanation tonometry. Postoperative ORA measurements were obtained, showing decreased CH and CRF compared to preoperative values. The patient was discharged with a satisfactory refractive outcome and visual acuity improvement.

* FIGURE 1. Typical ORA signal from a cornea after deep anterior lamellar keratoplasty.*
Preoperative IOPGAT, mm Hg 9.4
PK eyes, Rao et al.9 found no significant difference among the ocular blood flow (OBF) tonometry and Tonopen with GAT in ing keratoplasty (PK). Comparing IOP measurements using encouters in IOP measurement with the GAT after penetrat-
problems (graft surface irregularities and high astigmatism) cannot be generalized, as they conducted the study within 13
months of PK, when the sutures were still in place. It is
different studies can be attributed to taking samples from patients with different underlying diseases, ranging from normal subjects21 to glaucoma patients22–24 to keratoconus patients undergoing DALK (this study).

In this study, the order of using the tonometers was random-
dized because measurements of one tonometer can poten-
tially interfere with subsequent measurements of another.25 It also means the ORA was measured after the topical anesthesia used for GAT in some cases; it has been suggested, but not proven, that the accuracy of parameters measured by ORA can be modified by prior use of topical anesthesia.26

In the present study, no correlation was found between mean keratometry or astigmatism and IOP readings obtained using the two tonometers, indicating that the readings are not affected by graft steepness and astigmatism. To reduce the effect of corneal astigmatism on readings by GAT, the tonom-
ter tip was rotated 45° to the least-curved meridian. There are other ways to compensate for under- or overestimation of IOP resulting from high astigmatism, which include taking an average of values measured at two axes 90° apart or reducing or adding 1 mm Hg for every 4 D against-the-rule or with-the-rule astigmatism, respectively.27 Further, the ORA presented IOP measurements independent of keratometry readings, without any compensation, indicating the measurements of this non-contact tonometer are not affected by graft astigmatism, which is usually high after complete suture removal (up to 10.0 D in this study).
Among different graft parameters, CH and CRF showed significant positive correlations with IOPGAT whereas other anatomic parameters, including graft thickness and size, were not associated. It is well documented that central thickness of a virgin cornea has an effect on IOP readings by GAT; it is overestimated in eyes with thick corneas and underestimated in those with thin corneas. However, this study failed to show any association between central graft thickness after DALK and IOP readings by either the ORA or GAT. This observation is in line with other studies evaluating the correlation between central graft thickness and IOPGAT. It was previously observed that the influence of corneal thickness on IOP measurement is reduced in soft corneas. Therefore, the thin recipient rims retained after corneal transplantation can be one explanation for the lack of correlation. In addition, it is possible that corneal transplantation alters the normal relationship between central thickness and IOP readings observed in nongrafted eyes. For example, the wound healing in the area between recipient and donor corneas may influence the biomechanical properties of a recipient–donor cornea as a whole, exceeding the effect of CGT. As a result, CH and CRF are likely to measure cumulative effects of corneal stiffness, viscosity, elasticity, and that contributed by wound scarring in transplanted eyes, and hence demonstrate better correlation with IOP than with CGT.

In nongrafted eyes, IOPg has been reported to be equal to IOPGAT. In the present study, however, it was significantly higher than IOPGAT. Considering GAT as the gold standard and comparing other tonometers to it, some studies found a variation of ±3 mm Hg in the readings between these tonometers acceptable. Using the same criterion for our study, only 44.1% of IOPg readings lie within this range, while the 95% LOA is between −2.61 and +8.19 mm Hg. The observed discrepancy can be attributed to the change in tissue stiffness associated with wound healing.

IOP readings by the ORA demonstrated a stronger association with CH and CRF than those by the GAT (Table 3). From the clinical aspect, however, this significant association should be interpreted with caution. All the parameters measured by ORA are based on the first (P1) and second (P2) applanation pressures, and the instrument uses some mathematical equations to translate these pressures into CH, CRF, IOPg, and IOPc. For example, CH is the difference between P1 and P2 and IOPc is the average of the two. That is why a strong association was found between these two mathematically related parameters. However, the significant correlation of CH and CRF with IOPGAT is meaningful, especially in the absence of a correlation with thickness, because these parameters were measured independently.

In the present study, IOPc yielded the highest values. This measurement is intended to compensate for biomechanical properties, which may be affected by graft and retained recipient rim influences. Based on the results of the present study, however, it is not possible to know how closely IOPc estimates the true pressure. To decide which among the IOPGAT, IOPg, and IOPc can provide the most accurate reading, it is required to measure IOP simultaneously through inserting a manometric probe into the anterior chamber.

There are some limitations in the present study. First, the sample size was small. With a larger sample, the correlation as
well as the difference between the readings by ORA and GAT could be estimated with higher precision. Second, CH and CRF were not measured before keratoplasty. Therefore, it is not possible to determine to what extent these parameters were changed by DALK. In observing the significant increase in IOP, postoperatively, however, it is inferred that DALK can at least partially increase CH and CRF in keratoconic eyes.

To summarize, the ORA is a safe noncontact method for measuring IOP after DALK with moderate reproducibility. In addition, CH and CRF play a more important role in post-DALK IOP readings than graft curvature and central thickness. A study with a larger sample size is advocated to investigate the role of the ORA after DALK, and comparing IOP and corneal biomechanical properties before and after surgery will help determine the extent to which corneal transplantation can alter these parameters.

References