

External Factors Affecting Data Acquisition During Corneal Topography Examination

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Purpose. To analyze the factors affecting data acquisition during corneal topography examination with the Medmont E-300 videokeratoscope and to provide strategies to minimize their effects. **Methods.** Sixty eyes from thirty young adults were examined. A second observer registered incidences with the potential to affect data acquisition. Those factors were correlated with the difficulty of measurements as judged subjectively by the practitioner who performed the examination. Measurements of axial curvature were analyzed to evaluate the variability expressed as intrasession and intersession coefficient of variation and the standard error of the mean (SEM). **Results.** The level of difficulty rated by the practitioner was in general low, with 70% of the eyes being easy or very easy to measure. For the remaining 30% of the eyes, corneal topography measurements were considered to be difficult (27%) or very difficult (3%). Of the external parameters investigated, only fixation instability ($P < 0.001$, χ^2) and the need for head repositioning ($P = 0.024$, χ^2) were associated significantly with a higher level of difficulty, as rated subjectively by the practitioner. Further analysis showed that some external factors, including those previously mentioned and others related to tear instability, affect the variability of measurements at certain corneal locations, particularly in the vertical meridian when related to tear instability and in the horizontal meridian when related to the need for head repositioning on the chin rest owing to physiognomy interferences with the keratoscope cone. Intersession SEM improved when three readings from each session were considered. **Conclusions.** The level of subjective difficulty found during videokeratoscopy examination is correlated strongly with fixation instability and the need for head reorientation in the chin rest, whereas tear-related events seem to be

less relevant in the practitioner perception of test ease or difficulty. Those factors have relevance in measurement variability.

Key Words: Corneal topography acquisition—Fixation instability—Medmont E-300—Repeatability—Tear instability.

Repeatability of corneal topography is important in current clinical practice for detecting and evaluating the progression of ectatic corneal conditions¹; for contact lens fitting^{2,3}; for assessing the morphometric changes induced by rigid and soft contact lenses^{4,5}; for following up changes in corneal curvature, refraction, or elevation in corneal refractive therapies, such as refractive surgery or reverse-geometry contact lens fitting for myopia and hyperopia^{6,7}; and for evaluating corneal topography after other surgical procedures, such as penetrating keratoplasty,⁸ particularly when contact lens fitting is needed after surgery.⁹

With the increasing importance of corneal first surface aberrations^{10,11} and tear-induced aberrations during blinking^{12,13} in current vision research, the standards of precision for modern videokeratoscopes have increased as the success of corneal topography-based strategies to improve vision rely entirely on the accuracy and precision of such estimations. However, the higher the sensitivity of the instrument is, the higher the errors that are expected as a consequence of minimal external influences, such as blinking, tear film instability, and buildup after blinking.^{12–16}

Clinicians are aware of the difficulties experienced when trying to take information from corneal topography. When assessing healthy corneas, fixation instability, facial interferences that limit the focus and centration, and tear instability are the main patient-related factors that could adversely affect such an examination. However, the actual role of such factors is not fully known. Of remarkable importance is the influence of tear properties, because they have been shown to affect the aberration structure of the anterior corneal surface when obtained from topographic data and particularly in dry eyes.¹⁷

Current videokeratoscopes can also be used to estimate tear properties, such as tear stability.^{18,19} New developments on high-speed videokeratoscopy are promissory on limiting the intervention of tear factors on videokeratoscopic assessments.²⁰ Also, such approaches have been used to assess tear film buildup immediately after blinking.²¹ Therefore, although videokeratoscopy can be useful for the assessment of the tear film, quantitative measurements obtained with these instruments could also be affected adversely by these and other factors that affect the stability of the smooth front corneal surface needed to obtain a reliable measurement.

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Changes in head position or fixation instability are also a matter of concern, particularly because Mandell et al.²² found important changes in corneal topographic patterns and curvature data with changes in instrument centration.

With this purpose, this study was carried out evaluate which external factors can affect the level of difficulty when performing videokeratography and in the future to evaluate the impact of such factors on data precision.

MATERIALS AND METHODS

Subjects

Sixty eyes from thirty young adults (nine men and 21 women), with a mean age of 21 ± 2.46 years, were examined with the Medmont E-300 Corneal Topographer (Medmont Pty., Ltd., Melbourne, Australia). Exclusion criteria were as follows: known ocular disease, irritation, tear abnormalities, previous surgery, ocular medication use, ocular inflammation, and ocular infection. After the goal and methodology of the study were explained, informed consent was obtained from each subject.

Instrumentation

The Medmont E-300 Corneal Topographer was used to collect topographic data. This instrument has an innovative system of rapid continuous image acquisition, which allows the practitioner to record a set of four images automatically. The Medmont E-300 provides a rating value to guide the clinician regarding the quality of the image that has just been taken. In this study, measurements were made until image scores greater than 98 were obtained. This system has been shown to improve image acquisition because only accurately centered and correctly focused images are used, resulting in a high level of accuracy and precision performance.^{6,23} The ease or difficulty of measurements is related to the presence of external factors as discussed later.

Data Collection

This study was focused on the analysis of the events surrounding data acquisition that could adversely affect data precision. Data of axial curvature in diopters (D) was obtained at the corneal center and at 1.5 and 3.5 mm from the corneal center in the 0°, 90°, 180°, and 270° semimeridians of each repeated examination (three separate examinations on three different days per eye).

External Factors

Although all measurements were taken by the same observer (J.M.G.-M.), a second observer (A.Q.) registered incidences that could potentially affect measurements according to a predefined protocol, as explained later. These events were related to the following: the need to relocate the head in the chin rest to allow proper focusing and centering of the cornea; the lack of fixation or fixation instability; tear instability; and lipid layer dynamics on blinking as seen through the videokeratoscope. Additionally, overall subjective difficulty as reported by the operator was also recorded. Simple classifications were made, as described later.

Physiognomy interferences were registered as yes or no, depending on the need to relocate or reorient the patient's head on the chin rest to avoid upper orbital or nose interference during the centering and focusing processes, respectively. Problems with shadows, usually present with larger keratoscopic rings, were not a problem with this instrument.

Fixation stability was recorded as stable or not stable, depending on the ease for centering and focusing in a few seconds or whether it was more time-consuming and difficult to obtain, because of the subject's inability to keep stable fixation.

Tear stability was recorded as fairly stable, moderately unstable, or severely unstable, according to the absence of irregularities during the measuring procedure, the presence of observable dry spots within 5 to 10 seconds of blinking as areas of irregular keratoscopic projection (Fig. 1A), or the presence of dry spots or more extensive areas within the first 5 seconds of blinking, respectively.

Tear pattern after blinking was recorded as not observable, wave, or fluid amorphous (Fig. 1). The pictures shown correspond to a different videokeratography system, but they are included because they reflect more clearly the criteria used to classify tear pattern.

Overall difficulty was established as a four-level classification for the practitioner to rate the ease of the measuring process subjectively as very easy, easy, difficult, or very difficult.

Statistical Analysis

Data were analyzed by using the statistical package SPSS version 12.0 (SPSS, Inc., Chicago, IL). Descriptive statistics were produced regarding the frequency of each event quoted earlier. The association between external factors and difficulty of measurement was assessed with the chi-square test, used to evaluate differences in the frequency of nominal variables. The level of statistical significance was set at $\mu = 0.05$.

To evaluate the impact of external factors on the variability of topographic data, the coefficient of variation (COV) for axial and tangential curvature, as a percentage of the SD related to the mean value of three repeated measurements taken at the same session (intrasession %COV) and three measurements taken on three different days (intersession %COV).

Also, the standard error of the mean (SEM) for axial curvature was calculated for intersession data as the square root of the SD divided by the number of measurements taken within the same session (intrasession SEM) or among the three sessions (intersession SEM).

Correlations of %COV and SEM with external factors that could potentially affect instrument repeatability were assessed by nonparametric correlation by using the Spearman rho coefficient.

RESULTS

Descriptive statistics for axial and tangential apical curvature and the intrasession and intersession COV are shown in Table 1.

Factors Affecting Measurement Level of Difficulty

The level of difficulty rated by the practitioner was in general low, with 70% of the eyes being easy or very easy to measure. For the remaining 30% of the eyes, corneal topography measurements were considered to be difficult or very difficult, with only 3% being very difficult to perform (Fig. 2A).

The number of events encountered during each measurement session are shown in Figure 2B–E. Of the external parameters that could potentially affect the difficulty of measurement, only fixation instability ($P < 0.001$, χ^2) and the need for head repositioning ($P = 0.024$, χ^2) were associated with a higher level of difficulty, as rated subjectively by the practitioner (Fig. 3). Correlation analysis confirmed these findings (Spearman $\rho = 0.574$, $P < 0.001$; and

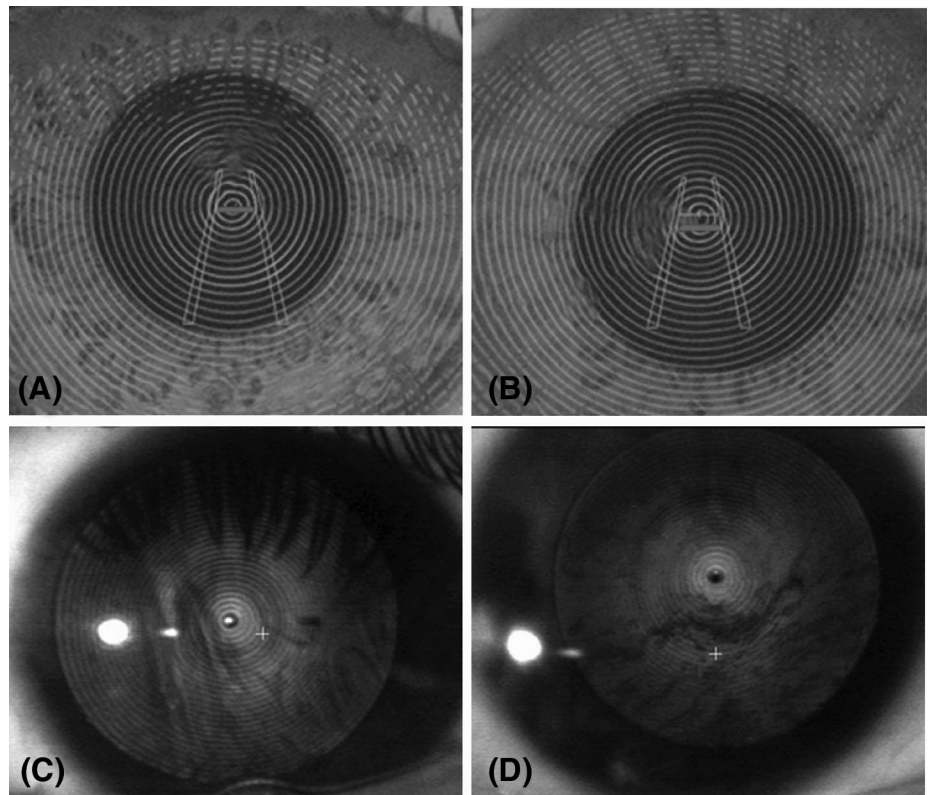


FIG. 1. Examples of tear instability observed through the videokeratoscope camera as central and paracentral distortion (A) or paracentral and peripheral distortion (B) and dynamic tear patterns usually observed with videokeratoscopy during centered and focusing procedure showing a wave pattern (C) and a fluid amorphous pattern (D).

Spearman $\rho = -0.386, P=0.002$ for fixation stability and head repositioning, respectively).

Twelve of 20 eyes that showed unstable fixation were rated as being difficult of very difficult to measure. However, within the group of 26 eyes for which head repositioning in the chin rest was needed, 12 were rated as being difficult or very difficult to measure, whereas another 14 were rated as being easy or very easy to measure. The distinction was clearer when repositioning was not needed, as 28 of 34 eyes were rated as being easy or very easy to measure.

This means that unstable fixation and head repositioning in the chin rest were major factors affecting the practitioner’s appreciation of the difficulty to perform corneal topography with this instrument. Conversely, other factors, such as laterality (left vs. right eye) ($P=1, \chi^2$), observable tear pattern while focusing ($P=0.352, \chi^2$), and even tear instability ($P=0.114, \chi^2$) were not shown to play an important role on subjective difficulty ratings.

TABLE 1. Descriptive Statistics for Axial and Tangential Apical Curvature and Their Respective Intrasession and Intersession Coefficients of Variation

	Axial curvature		Tangential curvature	
	Intrasession	Intersession	Intrasession	Intersession
Mean (D)	43.3	43.3	43.35	43.33
SD (D)	0.16	0.20	0.15	0.18
COV (%)	0.37	0.47	0.35	0.42
SD (%)	0.26	0.30	0.34	0.27

SD, standard deviation; COV coefficient of variation.

Factors Affecting Topographic Data Variability (%COV)

Only the axial intrasession %COV showed a significant correlation with the level of difficulty to perform the measurements (Spearman $\rho = -0.266, P=0.04$). Tangential intrasession %COV also approached significance when correlated with the level of difficulty rated by the practitioner (Spearman $\rho = -0.570, P=0.058$). Therefore, only SEM values for axial curvature were evaluated.

Factors Affecting Topographic Data Variability (SEM)

The four external factors under evaluation affected SEM values, but they did so in a different way.

Tear pattern showed a significant correlation with intrasession SEM, particularly for superior and inferior corneal locations at sessions 2 and 3 (Spearman $\rho = 0.313, P=0.032$ for the most superior location at session 2; and Spearman $\rho = 0.351, P=0.007$ for the most inferior location at session 3). Significant correlations with intersession SEM were also found at the temporal quadrant (Spearman $\rho = 0.350, P=0.007$). This means that the more fluid the tear film, the higher the intrasession and intersession SEM can be at certain measurement sessions.

Tear stability (Non-invasive tear break-up time, NITBUT) also showed significant correlations with intrasession SEM values, predominantly for vertical locations (Spearman $\rho = -0.353, P=0.006$ for superior and mid peripheral location; Spearman $\rho = -0.303, P=0.019$ for inferior and mid peripheral location; and Spearman $\rho = -0.364, P=0.005$ for inferior peripheral location), but also for nasal and temporal quadrants (Spearman $\rho = -0.366, P=0.004$; and Spearman $\rho = -0.332, P=0.009$ for mid peripheral

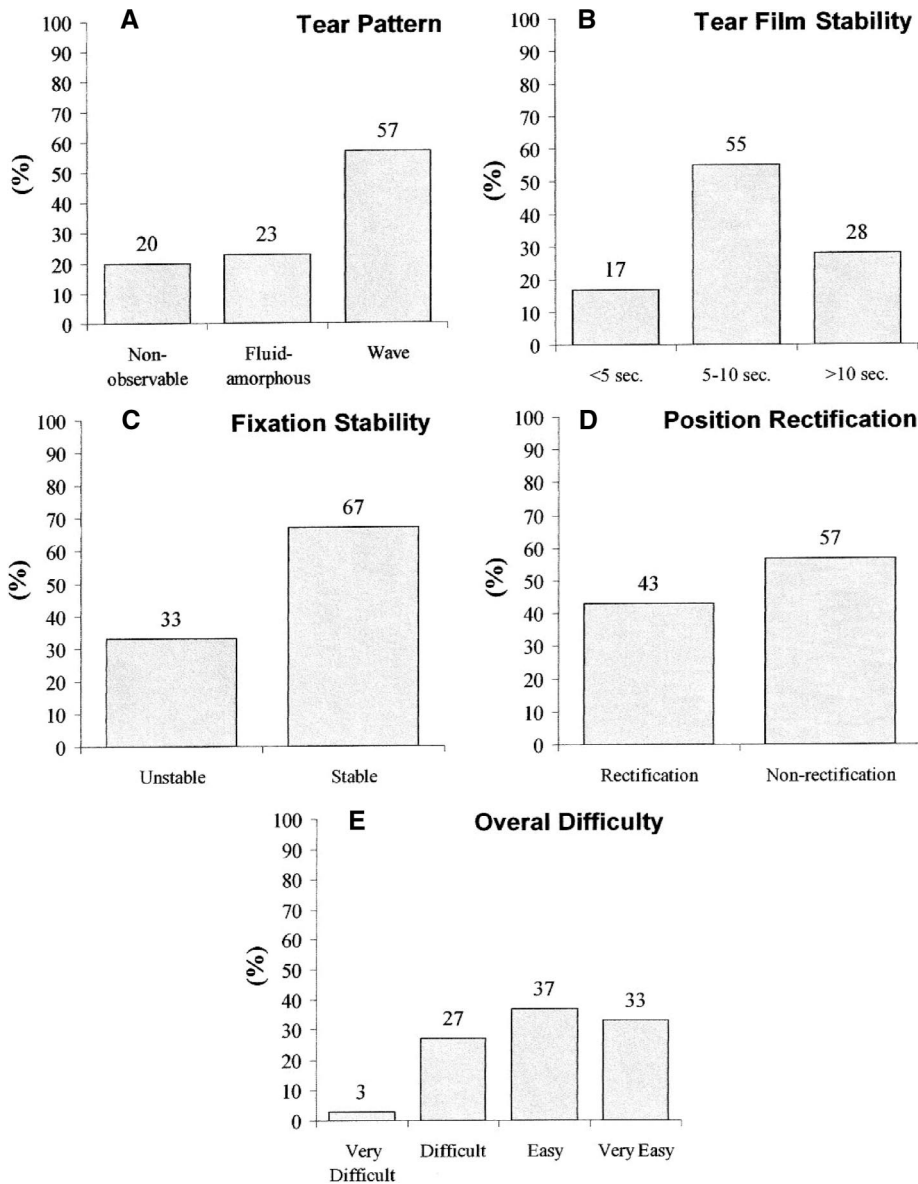


FIG. 2. Prevalence of events associated with the parameters under evaluation and the level of difficulty, as rated subjectively by the operator of the videokeratoscope.

nasal and temporal locations, respectively). In clinical terms, these negative correlations mean that the less stable the tear film is, the higher the intrasession SEM.

Fixation ability seems to play a similar role for intrasession and intersession variability. However, as expected from previous results, the need to relocate the head in the chin rest between subsequent examinations in the same day or on different days is the factor that most significantly affected SEM. A defined corneal area is not affected by these factors, but again, the vertical meridian, and particularly the superior area, seems to be particularly affected by fixation and repositioning interactions. However, there is one exception, as intersession SEM only depends on the need to relocate the head, for the horizontal meridian.

As a result, overall difficulty level as rated by the practitioner was correlated significantly with several intrasession SEM, particularly at session 2 in the temporal and superior quadrants (Spearman $\rho = -0.311$, $P=0.016$; and Spearman $\rho = -0.356$, $P=0.005$, respectively), and with one intersession SEM in the temporal quadrant

(Spearman $\rho = -0.278$, $P=0.031$). This means that the more difficult the measurement is, the higher the SEM value.

Figure 4 shows an analysis of the SEM for intrasession and intersession variability. Intrasession SEM averaged 0.062 D for all positions analyzed, with a maximum for the central and the most peripheral superior locations (Fig. 4A). Intersession SEM averaged 0.076 D when a single measurement from each session was considered and reduced to 0.057 D when the average of three readings was considered for each session. Again, central and peripheral superior readings were the most significantly affected by measurement variability, but they were also those with the most benefit, considering the average of three readings from each session, reducing their SEM indices by 30%.

DISCUSSION

Among the factors that can potentially affect topographic measurement performance, only the need for head repositioning on the

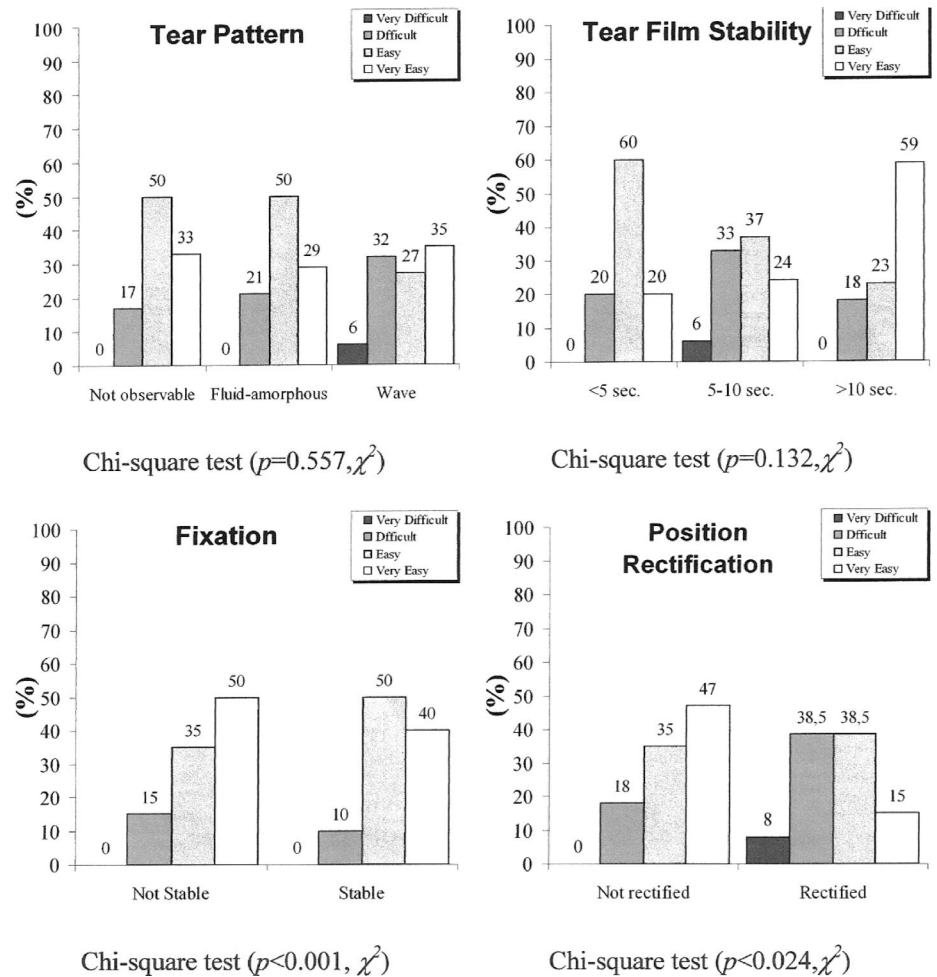


FIG. 3. Associations among different parameters and level of difficulty, as rated subjectively by the practitioner.

chin rest and fixation instability were shown to play an important role on subjective difficulty, as rated by the practitioner. Other tear-related aspects do not seem to affect the subjective difficulty for taking measurements. This could be explained because tear instability-related problems, if not severe, are easily avoidable by having the practitioner instruct the patient to blink again. In addition, the continuous image acquisition of the Medmont E-300 played an important role in this aspect.

Despite the trend toward higher variability expressed by SEM values in the case of wave tear pattern and poorer tear stability (regular ring projection inferior to 10 seconds), the authors were not able to find a correlation between both parameters. Although not statistically significant in most cases, descriptive cross tabulations showed that 28 of 43 eyes with tear instability had a wave pattern during topographic examination. However, 17 cases in which the tear film was considered stable did not follow a consistent pattern and were evenly distributed as having not observable, flow, or wavy patterns of the tear film lipid layer. Although previous studies have shown that a thicker lipid layer could be associated with higher tear film stability,^{24,25} the authors cannot derive conclusions regarding this issue based on the current results because the videokeratographic observation of the lipid layer is not reliable enough to accurately differentiate lipid layer patterns. Furthermore, the tear pattern was not measured with an appropriate method such as the Tearscope (Keeler Ltd, United Kingdom), but

only with videokeratography to see the tear dynamics while focusing ring reflections.

Despite the differences detected among sessions for axial curvature, these differences are not clinically significant because they rarely exceed 0.1 D. The standards of precision and accuracy for videokeratography have evolved since the early instruments. Younes et al.²⁶ considered a variability of 0.375 D as the limit to consider differences to be clinically significant. These results show the higher precision of modern videokeratoscopes regarding the constancy of curvature measurements.²⁷ They are even significantly better than those obtained by Buehren et al.¹⁴ centrally and peripherally for instantaneous power maps. Repeatability of topographic readings are particularly important when aberrometric data are to be obtained, because tear dynamics have been shown to have an important impact on corneal aberrations, even on healthy eyes,^{12,13,28} and Medmont E-300 can achieve that precision^{6,23} with minimal interference of external factors such as those analyzed in this study.

In this study, head repositioning on the chin rest was the main factor affecting variability, followed by fixation instability and, at a lower rate, tear dynamic behavior. Higher variability was found at the center and most superior and inferior locations and what could be related to lid interferences, eyelash shadows, particularly at the upper positions. Missing data at those positions were also a sign of the difficulty of those measurements. Modern videokera-

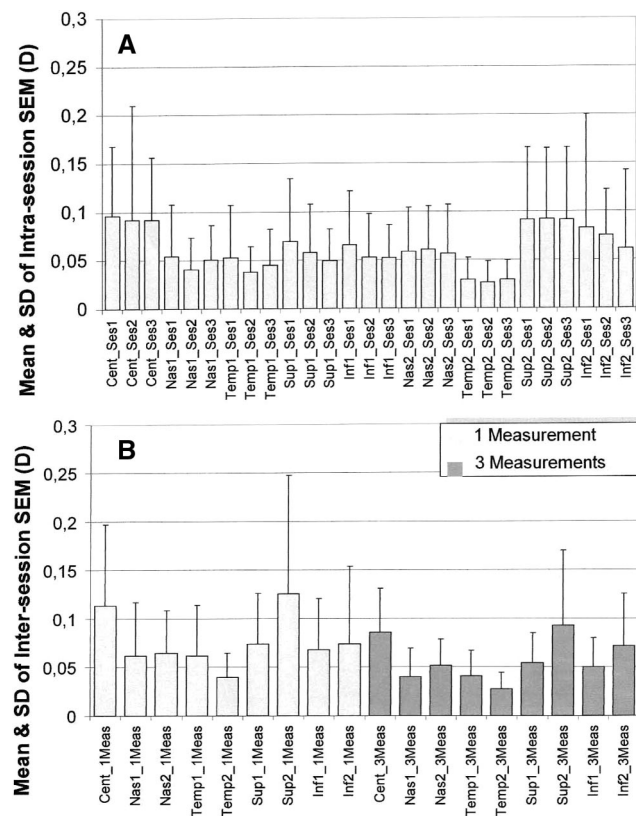


FIG. 4. Intrasession (A) and intersession (B) standard error of the mean (SEM). Intrasession report results from the three sessions. Intersession SEM represents values computed from the first measurement of each session (light gray) and from the average values of the three measurements taken at each session (dark gray). Error bars represent one SD of the SEM calculations.

topography, using smaller ring patterns, avoid nasal interference usually experienced by early instruments, but it is of clinical knowledge that the lower and upper eyelids continue to adversely affect measurements, inducing some limitation when the extreme superior cornea is to be analyzed.

This was the first study considering in vivo videokeratographic difficulties found by practitioners when performing videokeratographic measurements and the potential influence of external factors on such difficulty ratings. However, tear instability, as defined as observable tear breakup immediately after blinking or within the following 5 seconds, has an effect on the lack of consistency of the measurements, particularly at the most peripheral superior location. These are important concerns, because head reorientation was needed in 43% of the eyes because of facial physiognomy interferences in performing the test. Also, severe tear instability (i.e., observable tear breakup within 5 seconds of blinking) was present in 17% of the eyes, and moderate tear instability (i.e., observable tear breakup within 5 to 10 seconds of blinking) was present in 55% of the population.

Although this study failed to find a consistent behavior for data variability with different external factors affecting the difficulty of the topographic capture, it has found some interesting trends that must be addressed. One of these trends is the preference for tear parameters to affect the variability of topographic readings more so in the superior and inferior cornea. This is supported by the higher prevalence of tear instability and frequency of dryness

occurrence near the palpebral tear meniscus.²⁹ That tear factors mainly affect intrasession variability is also of clinical interest.

The higher interference of head reorientation on subsequent data acquisition in the nasal and temporal quadrants was expected, because in such cases, the patient is asked to slightly rotate his or her head to avoid the keratoscopic projection cone's hitting the superior orbital rim and nasal bone. This could induce slight misalignments between the optical system of the keratoscope and the corneal surface between subsequent measurements and thus induce an increase in SEM values. Changes in alignment between the videokeratoscope and corneal surface has been shown to change significantly the peripheral curvature of the cornea.²²

The issues addressed in this study suggest that several factors that are relatively common during topographic data acquisition can affect the variability of consecutive readings taken within the same session. Although the errors induced could be below the limit of clinical significance, new applications using corneal topography could be significantly affected, such as aberration calculation from corneal topography. Further work should be done to investigate how these facts affect the repeatability and accuracy of axial, tangential, and elevation parameters with modern corneal topographers, at central and peripheral locations separately. This work is currently under development by the authors.

REFERENCES

- Chastang PJ, Borderie VM, Carvajal-Gonzalez S, et al. Automated keratoconus detection using the EyeSys videokeratoscope. *J Cataract Refract Surg* 2000;26:675–683.
- Buifidis T, Konstas AG, Mamtziou E. The role of computerized corneal topography in rigid gas permeable contact lens fitting. *CLAO J* 1998;24:206–209.
- Douthwaite WA. Initial selection of soft contact lenses based on corneal characteristics. *CLAO J* 2002;28:202–205.
- Gonzalez-Mejome JM, Gonzalez-Perez J, Cervino A, et al. Changes in corneal structure with continuous wear of high-Dk soft contact lenses: A pilot study. *Optom Vis Sci* 2003;80:440–446.
- Yebra-Pimentel E, Giraldez MJ, Arias FL, et al. Rigid gas permeable contact lens and corneal topography. *Ophthalmic Physiol Opt* 2001; 21:236–242.
- Cho P, Lam AK, Mountford J, et al. The performance of four different corneal topographers on normal human corneas and its impact on orthokeratology lens fitting. *Optom Vis Sci* 2002;79:175–183.
- Srivannaboon S, Reinstein DZ, Sutton HF, et al. Accuracy of Orbscan total optical power maps in detecting refractive change after myopic laser in situ keratomileusis. *J Cataract Refract Surg* 1999;25:1596–1599.
- Borderie VM, Touzeau O, Laroche L. Videokeratography, keratometry, and refraction after penetrating keratoplasty. *J Refract Surg* 1999;15:32–37.
- Alio JL, Belda JL, Artola A, et al. Contact lens fitting to correct irregular astigmatism after corneal refractive surgery. *J Cataract Refract Surg* 2002;28:1750–1757.
- Applegate RA, Hilmantel G, Howland HC, et al. Corneal first surface optical aberrations and visual performance. *J Refract Surg* 2000;16: 507–514.
- De Brabander J, Chateau N, Marin G, et al. Simulated optical performance of custom wavefront soft contact lenses for keratoconus. *Optom Vis Sci* 2003;80:637–643.
- Montes-Mico R, Alio JL, Munoz G, et al. Postblink changes in total and corneal ocular aberrations. *Ophthalmology* 2004;111:758–767.
- Montes-Mico R, Alio JL, Munoz G, et al. Temporal changes in optical quality of air-tear film interface at anterior cornea after blink. *Invest Ophthalmol Vis Sci* 2004;45:1752–1757.
- Buehren T, Collins MJ, Iskander DR, et al. The stability of corneal topography in the post-blink interval. *Cornea* 2001;20:826–833.
- Nemeth J, Erdelyi B, Csakany B. Corneal topography changes after a

- 15 second pause in blinking. *J Cataract Refract Surg* 2001;27:589–592.
16. Owens H, Phillips J. Spreading of the tears after a blink: Velocity and stabilization time in healthy eyes. *Cornea* 2001;20:484–487.
17. Montes-Mico R, Alio JL, Charman WN. Dynamic changes in the tear film in dry eyes. *Invest Ophthalmol Vis Sci* 2005;46:1615–1619.
18. Goto T, Zheng X, Klyce SD, et al. A new method for tear film stability analysis using videokeratography. *Am J Ophthalmol* 2003;135:607–612.
19. Goto T, Zheng X, Okamoto S, et al. Tear film stability analysis system: Introducing a new application for videokeratography. *Cornea* 2004;23:S65–S70.
20. Iskander DR, Collins MJ. Applications of high-speed videokeratoscopy. *Clin Exp Optom* 2005;88:223–231.
21. Nemeth J, Erdelyi B, Csakany B, et al. High-speed videotopographic measurement of tear film build-up time. *Invest Ophthalmol Vis Sci* 2002;43:1783–1790.
22. Mandell RB, Chiang CSA, Yee L. Asymmetric corneal toricity and pseudokeratoconus in videokeratography. *J Am Optom Assoc* 1996;67:540–547.
23. Tang W, Collins MJ, Carney L, et al. The accuracy and precision performance of four videokeratoscopes in measuring test surfaces. *Optom Vis Sci* 2000;77:483–491.
24. Craig JP, Tomlinson A. Importance of the lipid layer in human tear film stability and evaporation. *Optom Vis Sci* 1997;74:8–13.
25. Isenberg SJ, Del Signore M, Chen A, et al. The lipid layer and stability of the precocular tear film in newborns and infants. *Ophthalmology* 2003;110:1408–1411.
26. Younes M, Boltz R, Leach NE, et al. Short- and long-term repeatability of Visioptic Alcon EyeMap (Visioptic EH-270) corneal topographer on normal human corneas. *Optom Vis Sci* 1995;72:838–844.
27. Hannush SB, Crawford SL, Waring GO III, et al. Accuracy and precision of keratometry, photokeratoscopy, and corneal modeling on calibrated steel balls. *Arch Ophthalmol* 1989;107:1235–1239.
28. Montes-Mico R, Alio JL, Charman WN. Postblink changes in the ocular modulation transfer function measured by a double-pass method. *Invest Ophthalmol Vis Sci* 2005;46:4468–4473.
29. Bruce AS, Mainstone JC, Golding TR. Analysis of tear film breakup on etafilcon A hydrogel lenses. *Biomaterials* 2001;22:3249–3256.