Measurement of Corneal Swelling Variations without Removal of the Contact Lens during Extended Wear

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PURPOSE. To validate the use of noncontact scanning slit pachymetry and OCT pachymetry measurements without contact lens (CL) removal, to determine corneal swelling variations during extended wear (EW).

METHODS. Central corneal thickness (CCT) was measured with ultrasonic (US) pachymetry, noncontact scanning slit pachymetry (Orbscan II; Bausch & Lomb, Tampa, FL), and optical coherence tomography (OCT) 1 week before the wearing of CLs and during 1 week of EW. High-Dk (lotrafilcon A) and low-Dk (etafilcon A) soft CLs were randomly fitted for EW in the right and left eyes of 20 subjects with normal ocular health. Orbscan and OCT were also performed without CL removal after 3 and 7 days of wear.

RESULTS. CCT measured with Orbscan and OCT showed a high correlation with US pachymetry. There were corneas with edema and without edema. Bland-Altman analysis showed a high level of agreement between Orbscan and OCT, with and without CL removal and with US pachymetry. High repeatability of Orbscan ($r^2 = 0.000$) and OCT ($r^2 = 0.001$) measurements without CL removal was also found. Etafilcon A lenses induced significantly higher corneal swelling than did lotrafilcon A lenses measured with Orbscan and OCT.

CONCLUSIONS. Orbscan and OCT are accurate, noninvasive, and reproducible techniques for evaluation of CCT without CL removal. OCT has more accuracy and repeatability than does Orbscan. Both techniques allowed for measurement throughout the study period of the CCT differences induced by CL wear. (*Invest Ophthalmol Vis Sci.* 2007;48:3043–3050) DOI: 10.1167/iovs.06-1372

C entral corneal thickness (CCT) is a sensitive indicator of corneal health.[1] Techniques for measuring CCT include optical pachymetry (Haag-Streit; Köniz, Switzerland), ultrasound (US) pachymetry, confocal microscopy, US biomicroscopy, optical scanning slit analysis (Orbscan II; Bausch & Lomb, Inc., Tampa, FL), and optical coherence tomography (OCT) with well-correlated measurements.[2–9] Currently, US pachymetry is the gold standard for the measurement of corneal thickness. Its disadvantages include the necessity for physical contact with the cornea and corneal anesthesia and the risk of technician's error.[9]

Extended wear (EW) of contact lenses (CL) is associated with various adverse ocular responses, such as corneal swelling overnight. In experiments, corneal swelling, stromal acidosis, and impaired corneal hydration control occur when the cornea is subjected to hypoxia.[10–12] Corneal swelling is directly related to the oxygen permeability (Dk) of CLs, and it is a quantitative measurement for assessing the impact of corneal hypoxia of CLs during EW.[10] Usually, corneal swelling is measured immediately after CL removal.[12–17]

The purpose of this study was to validate noninvasive techniques (Orbscan and OCT) to measure CCT without CL removal during EW, to determine corneal swelling. These techniques will be useful for prospective longitudinal studies of EW CLs.

MATERIALS AND METHODS

The study was a 2-week, prospective, double-masked, randomized, controlled trial.

Subjects

Twenty subjects were enrolled. There were 14 women and 6 men (mean age, 20.25 ± 2.2 years; range, 18–25). The spherical equivalent refractive error ranged from +2.00 to −4.75 D (−1.60 ± 1.75 D). Eleven subjects were CL wearers (two used rigid gas permeable [RGP] lenses and nine used soft lenses). Subjects were excluded if they had an active ocular surface disease, such as significant dry eye, papillary conjunctivitis, corneal opacities, current medication that could affect ocular physiology, and astigmatism (>2.00 D), or who had previously worn EW lenses. Subjects had vision correctable to 20/20 in each eye. Informed consent was obtained from each subject after approval was granted by the Human Sciences Ethics Committee of the University of Valladolid. All subjects were treated in accordance with the Declaration of Helsinki.

Lenses

Subjects were randomly assigned to a week's EW of a high-Dk CL (lotrafilcon A, Dk = 175; Focus Night & Day; Ciba Vision, Duluth, GA) on one eye and a low-Dk lens (etafilcon A, Dk = 33; Acuvue 2, Johnson & Johnson Vision Care, Jacksonville, FL) on the other eye. The characteristics of the lenses used in this study are listed in Table 1. It was predicted that the difference in oxygen permeability of these lenses would produce various levels of hypoxia and thus various degrees of corneal swelling. Lotrafilcon A is a silicone-hydrogel CL that has been approved in the United States for 30 nights' EW. Etafilcon A is a hydrogel lens with much lower permeability. It has been approved in the United States for 7 days' EW.

An independent investigator composed the randomized schedule. Each subject in the study simultaneously wore both lenses under investigation.

Instrumentation

Corneal thickness was measured with Orbscan II (version 3.12; Bausch & Lomb,), OCT (OCT 3, version 4.0.1; Carl Zeiss Meditec, Inc., Dublin, CA) and an ultrasonic (US) pachymeter (Sonogage, Inc., Cleveland, OH), calibrated by the manufacturer. OCT was performed after Orbscan. US was performed after Orbscan and OCT, to avoid corneal changes resulting from contact with the probe.

TABLE 1. Nominal Parameters for CLs

Lens Type	Base Curve	Lens Diameter	Central Thickness*	Water Content	Dk	Power (D)
Lotrafilcon A	8.60 mm	13.80 mm	0.080 mm	24%	175	+2.00--−4.75
Etafilcon A	8.40–8.80 mm	14.00 mm	0.084 mm	58%	33	+2.00--−4.75

D, diopter.
* Central thickness: −3.00 D.

Orbscan measurement was performed three consecutives times on each cornea during each visit, by using a published method.[9] The Orbscan software automatically analyzes up to 240 data points per slit and calculates central and peripheral corneal thickness from the difference in elevation between the anterior and posterior surfaces. To determine the thickness of the cornea, Orbscan uses an algorithm and multiplies the corneal thickness by an acoustic factor of 0.92. The mean of three measurements of each cornea was used as the final value. The same experimenter and masked operator performed all Orbscan measurements during all visits.

OCT is a noninvasive, no-contact imaging technique that uses infrared light to obtain high-resolution, cross-sectional images in vivo of the cornea, optic nerve, and retina. StratusOCT 3 software (Carl Zeiss Meditec, Inc.) was used to measure the distance between the anterior and posterior boundaries of the corneal tissue. Measurements were obtained using the scan profile protocol, selecting the A-scan for the corneal apex and placing the cursors at the peaks of the anterior and posterior corneal surfaces in the scan profile chart (Fig. 1). The results were measured in micrometers. The mean of the three scans of each cornea was used as the final value. The same experimenter and masked operator performed all OCT scans during all visits.

US measurements were obtained 1 week before the fitting of the CLs and during the last visit, immediately after the removal of the CLs. Five measurements of each cornea were obtained. The cornea was anesthetized with a drop of proparacaine hydrochloride (0.5%). The probe was applied perpendicular to the corneal surface. The same experimenter and masked operator performed US pachymetry during all visits. The mean of five measurements of each cornea was used as the final value.

Procedures

For the study, five visits were scheduled over 2 weeks. During the initial visit (day 0), participants were screened according to inclusion and exclusion criteria. The procedures governing the study were explained, and informed consent was obtained. Best corrected visual acuity, keratometry, and biomicroscopic and baseline pachymetry with the US pachymeter, Orbscan, and OCT were conducted.

During the second visit (on day 3) and the third visit (on day 7), corneal pachymetry was performed with Orbscan and OCT. During the third visit, after corneal pachymetry was performed, both high- and low-Dk CLs were fitted randomly by an independent investigator

lenses. Another independent investigator checked the fit of each lens and examined the postlens tear film to ensure that no debris was present.

During the fourth visit (on day 10, 3 days of CL wear) Orbscan and OCT pachymetry were performed without CL removal. During the fifth visit (day 14, 7 days of CL wear), Orbscan and OCT pachymetry measurements were taken with and without CL removal. US pachymetry was performed immediately after CL removal after the Orbscan and OCT procedures. On the third, fourth, and fifth visits, an independent investigator evaluated the lenses and ocular health. To ensure that corneal edema induced by overnight wear had dissipated, all visits related to the study took place between 4 and 8 PM. This is the time of the day when the eye is most stable physiologically.[1]

Data Analysis

Statistical analysis was performed using a commercial package (SPSS 13.0; statistical package for Windows; SPSS, Chicago, IL). The OCT and Orbscan measurements of each cornea were compared with the measurements by US pachymetry before and after the subject used the CLs. The relationships among OCT, Orbscan, and US pachymetry were evaluated by the Pearson correlation method. $P < 0.05$ was considered statistically significant.

The degree of agreement between OCT, Orbscan, and US pachymetry (before and after EW, with and without CLs removed) was evaluated with the Bland-Altman analysis.[18] The differences between the two measurement techniques were plotted against the averages of the two techniques. Limits of agreement (LoA) were calculated (mean ± 2 SD).

The repeatability of Orbscan and OCT measurements was evaluated with and without CL removal. Repeatability is the condition in which independent test results are obtained by the same method on identical test items in the same laboratory by the same operator using the same equipment, with the shortest time lapse possible between successive sets of readings.[19] We determined repeatability by obtaining three Orbscan and OCT measurements. The coefficient of repeatability (obtained from the repeated administration of the test under identical conditions) was defined as the SD of the difference from the mean of the repeated measurements divided by the average response. Statistical significance was tested with a Student's paired *t*-test. $P < 0.05$ was considered statistically significant.
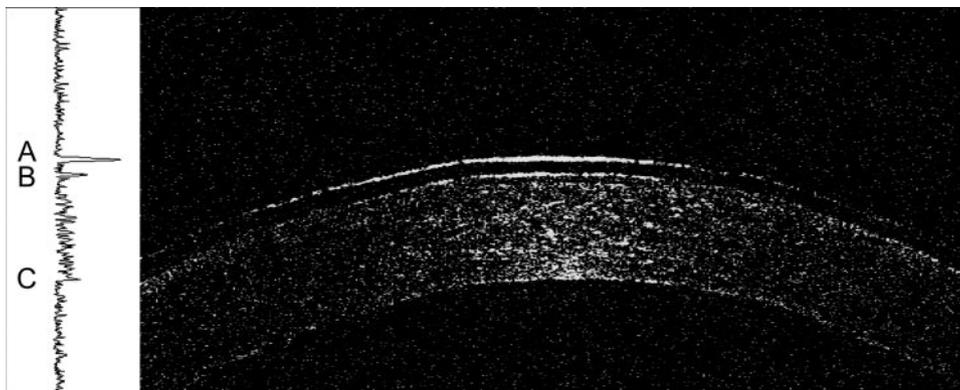

FIGURE 1. OCT corneal scan without CL removal. *Left*: scan profile display: A, peak of CL; B, peak of anterior corneal surface; C, peak of posterior corneal surface. Corneal thickness is the distance between peaks B and peak C. *Right*: Cross-sectional image of cornea without CL removal.

The paired *t*-test was used during each visit to detect differences in corneal thickness between CLs. Repeated-measures analyses of variance (Re-ANOVA with a Bonferroni correction) were used to detect differences in corneal thickness attributable to each type of lens in each patient, with the CLs in and immediately after their removal. $P <$ 0.05 was considered statistically significant.

RESULTS

No subjects had significant biomicroscopic signs (grade $>$ 1, Efron grading scale) of CL complications (corneal staining,
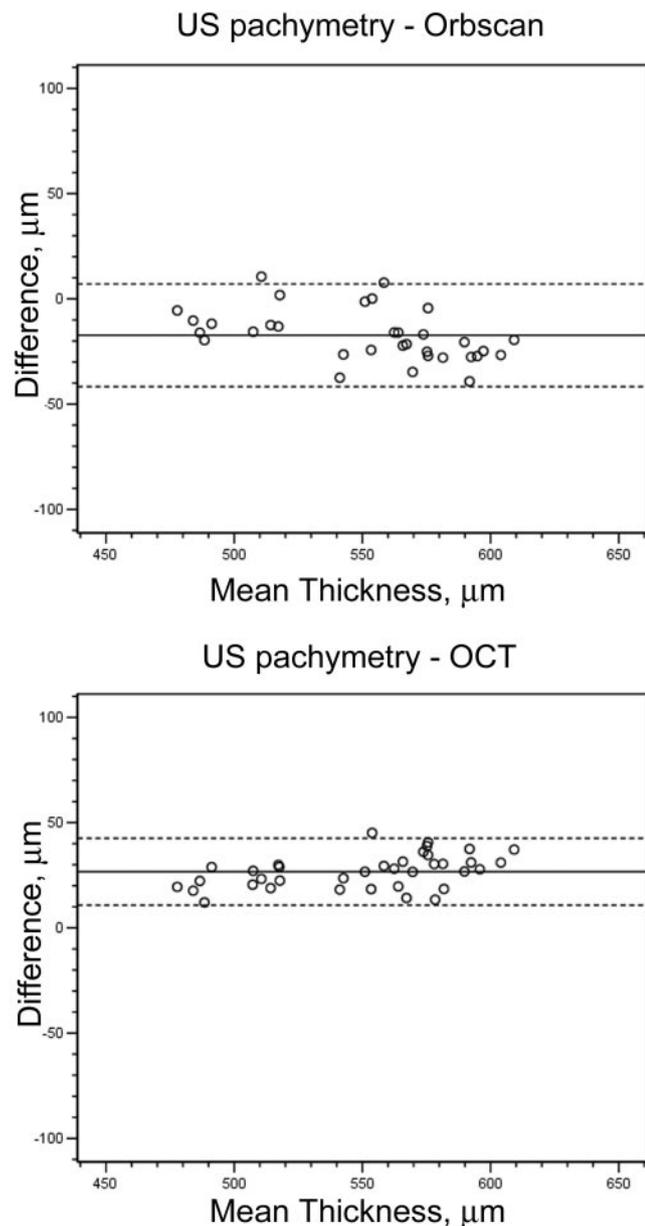

FIGURE 2. Bland-Altman plot comparing the CCT measured by Orbscan, OCT, and US pachymetry (first visit). The mean difference between Orbscan and US pachymetry (*top*) was -16.7 ± 12.4 μm (95% CI, -21.28 to -12.20 μm); the LoA ranged from 8.1 to -41.5 μm (SD $\pm$ 2). Pearson correlation coefficient, 0.927 ($P <$ 0.001). The mean difference between OCT and US pachymetry (*bottom*) measurements was 27.33 ± 8.1 μm (95% CI, 30.30–24.37 μm); LoA ranged from 11.13 to 43.53 μm (SD $\pm$2). Pearson correlation coefficients were 0.919 ($P <$ 0.001).
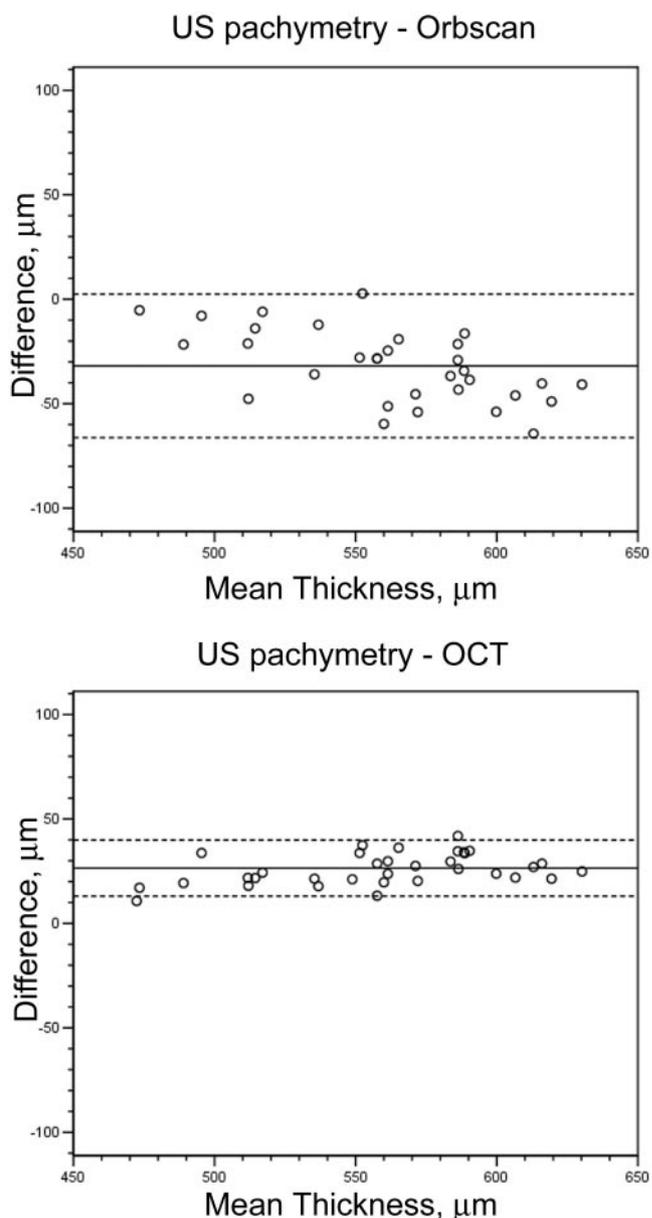

FIGURE 3. Bland-Altman plot comparing the CCT measured by Orbscan OCT and US pachymetry immediately after CL removal (last visit). The mean difference between the CCT measured by Orbscan and US pachymetry (*top*) was -31.94 ± 17.19 μm (95% CI, -25.74 to -38.14 μm); LoA ranging from 2.44 to -66.32 μm (SD $\pm$2). Pearson correlation coefficient, 0.970 ($P <$ 0.001). The mean difference between the CCT measured by OCT and US pachymetry (*bottom*) was 26.48 ± 6.98 μm (95% CI, 23.96–29.00 μm); LoA ranged from 12.52 to 40.44 μm (SD $\pm$ 2). Pearson correlation coefficients were 0.986 ($P <$ 0.001).

limbal injection, striae, folds, or other). Two subjects left the study: One had front surface deposits (lotrafilcon A lens) and the other lost a CL (an etafilcon A lens).

Baseline mean corneal thickness was 555 ± 42 μm when measured with US pachymetry, 573 ± 46 μm with Orbscan, and 528 ± 38 μm with OCT. Orbscan was approximately 16 ± 29 μm higher than US pachymetry. OCT was approximately 27 ± 16 μm lower than US pachymetry.

After 1 week of EW, the mean corneal thickness was 560 ± 42 μm when measured with US pachymetry, 590 ± 53 μm with Orbscan, and 531 ± 39 μm with OCT. Orbscan was

approximately 32 ± 17 μm higher than US pachymetry. OCT was approximately 26 ± 7 μm lower than US pachymetry.

Agreement of corneal thickness before CL wear is summarized in Figure 2 and after CL wear in Figure 3 (Bland-Altman plot analysis).

The Orbscan, before and after CL wear, showed a high correlation with OCT pachymetry. The Bland-Altman plot comparing the CCT measured by Orbscan and OCT is shown in Figure 4.
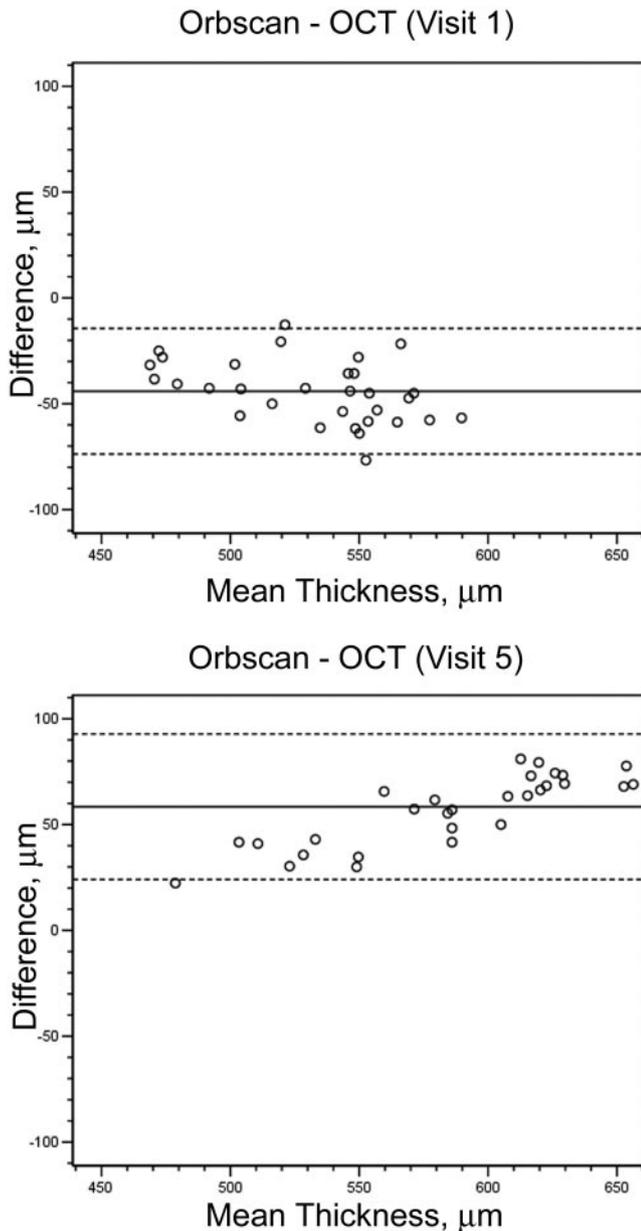

FIGURE 4. Bland-Altman plot comparing the CCT measured by Orbscan and OCT in first visit (without CL wear) and fifth visit (after CL removal). *Top*: The mean difference in the first visit between the CCT measured by Orbscan and OCT pachymetry was −44.08 ± 14.84 μm (95% CI, −49.52 to −38.64 μm), with LoA ranging from 14.40 to −73.75 μm (SD ± 2). Pearson correlation coefficient, 0.962 (*P* < 0.001). *Bottom*: The mean difference in the fifth visit between the CCT measured by OCT and US pachymetry was 58.43 ± 17.18 μm (95% CI, 52.23–64.62 μm); LoA ranged from 24.07 to 92.79 μm (SD ±2). Pearson correlation coefficient, 0.973 (*P* < 0.001).
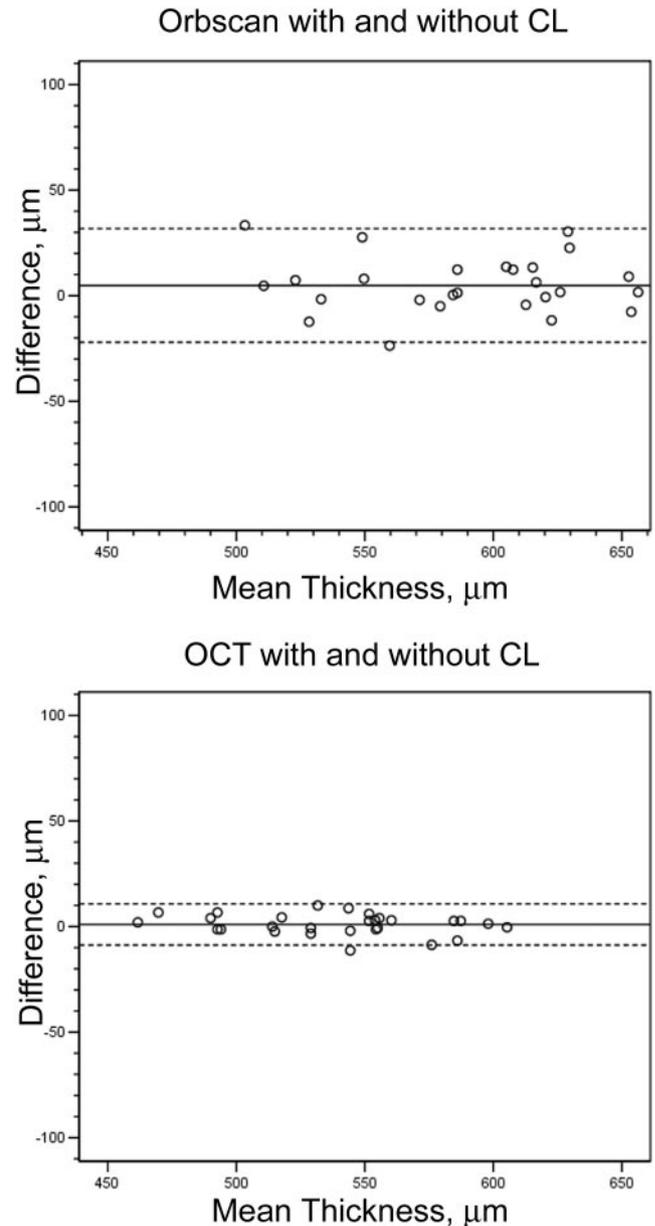

FIGURE 5. Bland-Altman plot comparing the CCT measured by Orbscan (*top*) and OCT (*bottom*), with and without CL removal. The mean difference between Orbscan without CL removal and after CL removal (*top*) was 4.85 ± 13.47 μm (95% CI, −0.27 to 9.97 μm); LoA ranging from 31.79 to −22.09 μm (SD ±2). The mean difference between OCT without CL removal and after CL removal (*bottom*) was 0.98 ± 4.88 μm (95% CI, −0.90 to 2.88 μm); LoA ranged from 10.74 to −8.78 μm (SD ±2).

Agreement of Measurements of Corneal Thickness with and without CL Removal

The Orbscan and OCT, with and without CL removal, showed a high correlation with US pachymetry after CL removal. Orbscan correlation coefficients were *r* = 0.962 without CL removal and *r* = 0.970 after CL removal. OCT were *r* = 0.982 without CL removal and *r* = 0.986 after CL removal (*P* < 0.001). The Orbscan and OCT measurements also showed a high correlation with and without CL removal (*r* = 0.964, *P* < 0.001 [for Orbscan]; *r* = 0.992, *P* < 0.001 [for OCT]). The Bland-Altman plot comparing the CCT measured by Orbscan, OCT, and US pachymetry immediately after CL removal is shown in Figure 3.

TABLE 2. Analysis of Repeatability of Three Measurements in Each Eye

Method	Mean Difference	SD	r^2	P*
Baseline (visit 1) $n = 40$				
Orbscan (CCT)				
Measure 1	−0.92	3.80	0.018	0.726
Measure 2	0.65	4.59	—	—
Measure 3	0.27	4.77	—	—
OCT (CCT)				
Measure 1	−0.58	3.18	0.004	0.934
Measure 2	0.05	3.37	—	—
Measure 3	0.52	3.13	—	—
Without removing CL (visit 5) $n = 36$				
Orbscan (CCT)				
Measure 1	−0.39	9.69	0.000	0.996
Measure 2	0.85	8.68	—	—
Measure 3	−0.46	10.18	—	—
OCT (CCT)				
Measure 1	−0.57	4.15	0.001	0.982
Measure 2	−0.10	3.61	—	—
Measure 3	0.68	3.30	—	—
After removing CL (visit 5) $n = 36$				
Orbscan (CCT)				
Measure 1	−0.97	7.20	0.070	0.123
Measure 2	−1.68	11.63	—	—
Measure 3	2.65	6.34	—	—
OCT (CCT)				
Measure 1	1.10	3.20	0.045	0.785
Measure 2	−0.62	3.04	—	—
Measure 3	−0.48	3.72	—	—

  * Student's paired *t*-test.

The Orbscan mean difference with and without CL removal was 4.85 ± 13.47 μm (95% CI, 9.97 to −0.28; $P = 0.063$, paired *t*-test). The OCT mean difference with and without CL removal was 0.98 ± 4.88 μm (95% CI, 2.87 to −0.91; $P = 0.294$, paired *t*-test). A Bland-Altman plot comparing the CCT measured by Orbscan and OCT, with and without CL removal, shows the difference between the two measurements (Fig. 5).

Repeatability of Measurements of Corneal Thickness with and without CL Removal

The OCT and Orbscan techniques demonstrated good repeatability with and without CL removal (Table 2). Although further analysis indicated that r^2 for Orbscan ($r^2 = 0.000$) and OCT ($r^2 = 0.001$) measurements without CL removal were lower (less variation) than r^2 for measurements before fitting the CLs (Orbscan $r^2 = 0.018$ and OCT $r^2 = 0.004$) and after removal (Orbscan $r^2 = 0.070$ and OCT $r^2 = 0.045$), the differences were not statistically significant.

The Orbscan coefficient of repeatability was 1.57% without CL removal and 0.73% after removal. The OCT coefficient of repeatability was 0.69% without CL removal and 0.64% after removal.

Corneal Swelling Measured with and without CL Removal

We compared Orbscan and OCT measurements with and without CL removal with US pachymetry measurements after CL removal. OCT measurements were not significantly different from US pachymetry readings, with and without CL removal.

TABLE 3. Summary of Measurements of CCT

	Visit 1	Visit 2	Visit 3	Visit 4	Visit 5 CL in†	Visit 5 CL out‡	Re-ANOVA§
Ultrasonic (μm)							
Lotrafilcon A	553 ± 37	—	—	—	—	551 ± 36	0.075
Etafilcon A	557 ± 47	—	—	—	—	567 ± 47	0.032
P*	0.400	—	—	—	—	0.020	
Orbscan (μm)							
Lotrafilcon A	574 ± 43	577 ± 44	577 ± 45	587 ± 45	593 ± 46	586 ± 43	0.001
Etafilcon A	573 ± 49	573 ± 51	574 ± 52	597 ± 56	613 ± 56	605 ± 55	<0.001
P*	0.693	0.265	0.476	0.095	0.009	0.011	
OCT (μm)							
Lotrafilcon A	527 ± 36	525 ± 35	524 ± 34	523 ± 29	529 ± 31	524 ± 33	0.571
Etafilcon A	530 ± 41	526 ± 36	525 ± 36	539 ± 42	551 ± 41	539 ± 44	<0.001
P*	0.287	0.651	0.407	0.004	0.001	0.008	

  * Student's paired *t*-test.
  † Measurements taken without removing CL.
  ‡ Measurements taken immediately after CL removal.
  § Re-ANOVA with Bonferroni correction.

The mean difference after CL removal was 0.73 ± 2.6 μm (95% CI, 0.19 to -1.64; $P = 0.117$, paired t-test) and without CL removal was 0.97 ± 2.8 μm (95% CI, 0.10 to -2.05; $P = 0.076$, paired t-test). Orbscan measurements were significantly different from those of US pachymetry, with and without CL removal. The mean difference after CL removal was -2.70 ± 3.1 μm (95% CI, -1.58 to -3.81; $P < 0.001$, paired t-test). Without CL removal, the mean difference was -3.54 ± 3.5 μm (95% CI, -2.23 to -4.86; $P < 0.001$, paired t-test).

CL Difference

The mean corneal thickness of the lotrafilcon A– and etafilcon A–wearing eyes measured before, during, and after CL wear with US pachymetry, Orbscan, and OCT are shown in Table 3. There were significant differences in corneal swelling (Re-ANOVA Bonferroni correction, $P < 0.05$) induced by 1 week of EW with the etafilcon A CL when measured with US, Orbscan,

FIGURE 6. Corneal thickness with lotrafilcon A and etafilcon A CLs measured with Orbscan (*top*) and OCT (*bottom*). Corneal thickness with etafilcon A CLs increased with time more than that with lotrafilcon A CLs. Both instruments had the same trend in the corneal-swelling measure.

TABLE 4. Corneal Swelling Induced by 1 Week of CL Wear

% Corneal Swelling	Lotrafilcon A (%)	Etafilcon A (%)	*P**
Ultrasonic	-0.89 ± 1.95	1.89 ± 3.20	0.003
Orbscan with CL†	2.50 ± 2.92	6.23 ± 2.50	0.010
Orbscan without CL‡	1.67 ± 2.22	4.98 ± 3.07	0.008
OCT with CL†	0.11 ± 2.36	3.71 ± 2.25	0.002
OCT without CL‡	0.17 ± 2.28	2.41 ± 2.65	0.017

* Student's paired t-test.
† Measurements taken without removing CL.
‡ Measurements taken immediately after CL removal.

and OCT. However, corneal swelling induced with lotrafilcon A was not statistically significant ($P > 0.05$) when measured with US, Orbscan, and OCT (Fig. 6).

The Etafilcon A CL caused greater corneal swelling than did the lotrafilcon A lens, as measured by US pachymetry, Orbscan, and OCT, with and without CL removal after 1 week of EW. Table 4 shows corneal swelling with lotrafilcon A and etafilcon A CLs measured with US pachymetry, Orbscan, and OCT. All differences in corneal swelling induced by both types of CLs were statistically significant (paired t-test).

There were no statistically significant differences in corneal swelling measured with OCT with and without CL removal, as measured with US pachymetry after CL removal ($P = 0.246$ without CL removal and $P = 0.131$ after CL removal, paired t-test) for lotrafilcon A and ($P = 0.197$ without CL removal and $P = 0.472$ after CL removal) for etafilcon A eyes. In contrast, there were statistically significant differences in corneal swelling as measured with Orbscan with US pachymetry, for lotrafilcon A ($P = 0.003$ after CL removal and $P = 0.002$ without CL removal) and for etafilcon A ($P = 0.004$ after CL removal and $P = 0.002$ without CL removal).

DISCUSSION

The precision and repeatability of optical and US pachymeters, slit scanning topography (Orbscan), optical coherence tomography (OCT), and other techniques have been determined. Measurements have been taken in healthy subjects,[1,8,19,20] patients undergoing corneal refractive surgery procedures,[21,22] and CL wearers, to determine corneal swelling induced by CL hypoxia.[14,15,23]

In a randomized, double-masked study, we fitted low-Dk (etafilcon A) and high-Dk (lotrafilcon A) soft CLs in volunteers to find out whether OCT and Orbscan measured without CL removal can detect differences in corneal swelling. In the first week, no CL wear and no statistically significant differences were found (paired t-test). After the CLs were fitted, Orbscan and OCT were performed without CL removal, to detect differences in corneal thickness. We found statistically significant differences after only 3 days of EW with OCT and after 6 days of wear with Orbscan. These differences were verified after CL removal with US pachymetry, Orbscan, and OCT. For Orbscan and OCT procedures, we found similar accuracy and repeatability before fitting the CLs, immediately after CL removal, and without CL removal. Our findings were in accord with previous results.[1,8,14,15,19–23]

We found similar correlations between US pachymetry with Orbscan and OCT before fitting CL, after CL removal, and without CL removal.[1,9,24] Bland-Altman analysis[18] showed less agreement between US pachymetry with Orbscan than between US pachymetry with OCT immediately after CL removal, which is in agreement with the results in Fishman et al.[9]
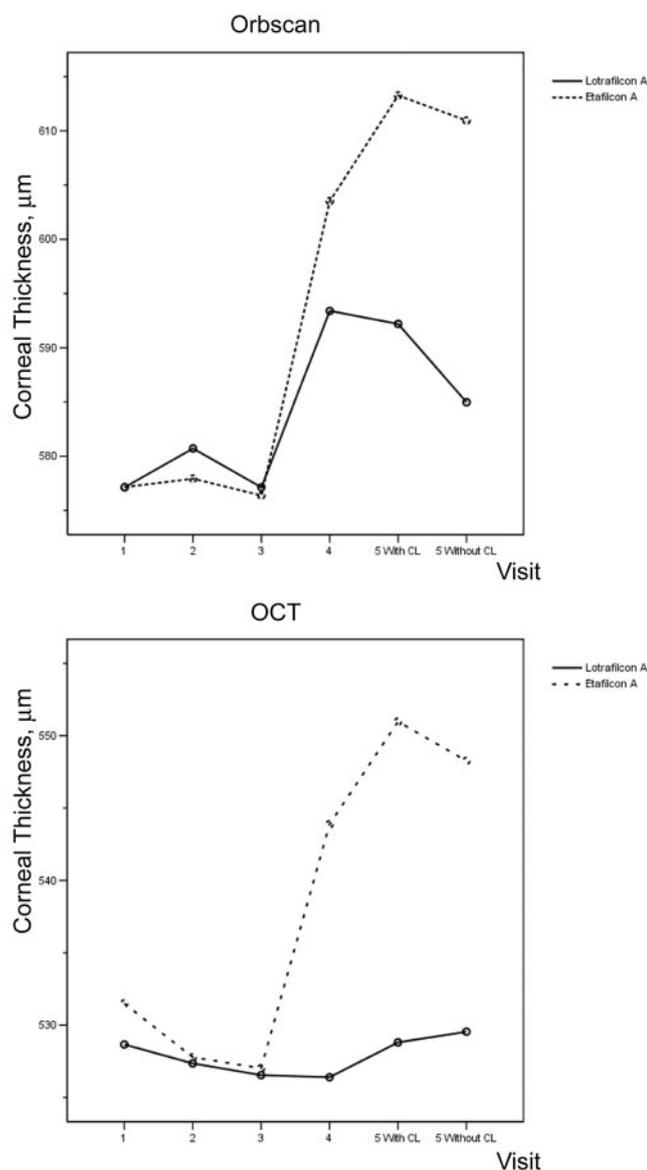
OCT measurements were lower than US pachymetry before (normal corneas) and after (swelling corneas) EW (~ 27 μm), which is in agreement with previous results.[14,25] OCT measurements (with and without CL removal) had no statistically significant differences with US pachymetry after CL removal. This indicates that OCT measurements with and without CL removal are similar.

Orbscan measurements were higher than US pachymetry in normal and swelling corneas (~ 20-32 μm). Measurements obtained by Orbscan have a high degree of variability. Orbscan overestimates corneal thickness in normal eyes and underestimates it after LASIK,[24,26–28] in peripheral locations,[1] or in keratoconus.[29] A definitive reason for the differences between corneal thicknesses measured with Orbscan has not been found.[24] There are different hypotheses explaining the cause: the thickness of the tear film[1]; changes in the stromal refractive index; different degrees of corneal hydration; and changes in corneal shape and corneal density and structure. These causes may override the effect of US pachymetry (overestimation of corneal thickness).[24,30] Boscia et al.[31] concluded that the cause of the error lies in the optical acquisition process, because the repeatability of the measures was good. Various authors have recommended using Orbscan in conjunction with US pachymetry.[24,31] Lack of agreement of Orbscan without CL removal may arise because the thickness of the CL is included in the measurement.

The coefficients of repeatability of Orbscan ($<2\%$) and OCT ($<1\%$), with and without CL removal were inferior to the previous report[19] for the OCT measurements ($<3\%$) and similar to Orbscan (~ 10 μm).[24,32] This indicates that during the same session, corneal thickness measurements are repeatable, and there is therefore no need to acquire a large number of readings for a reliable estimate of corneal thickness.[19]

Orbscan and OCT can measure corneal thickness without CL removal with reproducibility and accuracy. OCT has a high level of agreement and coefficient of repeatability and fewer differences and than Orbscan measurements.

Fonn et al.[13] found 2.7% overnight swelling after 8 hours of sleep with lotrafilcon A and 8.66% with etafilcon A, as measured with an optical pachymeter. These results are higher than the corneal swelling that we found measuring with US pachymetry and OCT, yet are similar to the Orbscan measurements (Table 4) after CL removal. Optical pachymeters have less accuracy (10–100 μm)[24] than does OCT. Fonn et al. compared the corneal thickness baseline (measured at 4 PM) with overnight swelling (measured at 7 AM after CL removal) after 8 hours of sleep with a CL and eye closure in one eye. In contrast, we compared corneal thickness at the same time during the first and last visit (between 4 and 7 PM), to ensure that corneal edema induced overnight had dissipated and that differences were mainly related to CL wear. Diurnal variations suggest that corneas are thinnest between the hours of 7 and 10 PM.[1,33]

Wang et al.[15] found 13.4% to 13.8% and 12.1%[14] of corneal swelling after three hours with soft CL and PMMA lens wear with eye closure, respectively, as measured by OCT. Measurements were taken in the morning (after 10 AM), 20 minutes after CL removal. Lin et al.[12] found 4.6% and 2.6% corneal swelling after 6 nights of EW with medium- and high-Dk RGP, respectively. Measurements were taken in the afternoon during the baseline visit and in the morning (after 8 hours of overnight wear with eye closure) after lens removal. Haque et al.[16] found 4.9% corneal swelling with RGP CLs after 4 weeks of overnight wear. Moezzi et al.[17] found corneal edema when measured with Orbscan before and after wearing soft (15%) and PMMA (13%) CLs with near-zero oxygen transmissibility in an eye patched for 3 hours.

In our study, corneal swelling was lower than reported by Wang et al.,[14,15] Lin et al.,[12] Haque et al.,[16] and Moezzi et al.[17] We recorded all measurements in the afternoon, between 4 and 8 PM, because this is the time of the day when the eye is most physiologically stable.[1] We did not occlude any eye, because we wanted to make the measurements in the conditions most similar to the normal use of the lenses and to ensure that corneal edema induced overnight had dissipated.

These results indicate that Orbscan and OCT can measure corneal swelling without CL removal with reproducibility and accuracy. OCT corneal swelling measured with and without CL removal was similar. However, Orbscan showed more differences between measurements.

Re-ANOVA analysis found that CCT with the etafilcon A CL was higher than with the lotrafilcon A CL ($P < 0.05$) after 1 week of EW. The lotrafilcon A lens has higher Dk than the etafilcon A. Corneal swelling in lotrafilcon A has been explained in two ways. It has been described as a possible sympathetic swelling effect of the contralateral eye, and it has been said that the permeability of the CL has to be higher than 175 for no lens-induced edema.[13]

The use of OCT or Orbscan (or both) without CL removal can make it possible to observe differences in corneal swelling throughout the time of CL wear. Both techniques are noninvasive, repeatable, and accurate. The results for both instruments showed the same trend in corneal swelling after EW of CLs. The method can be useful in long clinical trials, to permit more measurement without CL removal; it can help researchers avoid corneal anesthesia (US pachymetry); it provides more precision than the optical pachymeter; the training requirements are minimal; and it has high repeatability.[14,24]

In conclusion, corneal swelling induced by CL hypoxia could be measured without CL removal with OCT and Orbscan. OCT has more accuracy and repeatability than does Orbscan without CL removal. Both instruments had the same trend in the corneal swelling measure. Corneal thickness measurements without CL removal with OCT or Orbscan (or both) are a noninvasive technique to measure the differences over time in corneal thickness induced by EW CLs.

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