OCT technique for evaluating diurnal variation in corneal thickness

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PURPOSE: To assess the possible changes that may occur in corneal thickness during the course of the day, over a total period of twelve hours, using an optical coherence tomography (OCT) device.

SETTING: Department of Optics, University of Valencia, Spain.

METHODS: Fifty left eyes from fifty young, healthy subjects were examined for this study using a non-invasive OCT technique. Corneal thickness was measured in five different positions (centre and 3 mm towards the nasal, temporal, inferior and superior direction) every 4 hours over a total period of 12 hours each day during a period of 3 days, using the Topcon SL SCAN-1 OCT device.

RESULTS: A slight but significant decrease in corneal thickness was observed during the day. The thinning on corneal thickness was not uniform and depends on the corneal region under consideration. The superior region presented the greatest thinning, whereas inferior corneal region underwent the least thinning.

CONCLUSION: OCT allows for the quick and easy analysis and assessment over time of variations in corneal thickness in different corneal regions or positions. Significant changes occur in corneal thickness during the day. These changes, even if they do not modify visual performance, should be taken into consideration for several clinical and research applications.

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corneal parameters, such as corneal thickness, anterior and posterior curvatures and asphericity, etc. Currently, more and more people undergo refractive surgery and/or use different types of contact lenses, making it essential to determine all possible data on the cornea. Furthermore, it is vital to determine how the different parameters of the cornea behave over time, in order to provide better information or treatment to a subject (i.e. best type of contact lens or the best refractive surgery procedure, etc.).

The purpose of this study was to evaluate and quantify natural diurnal changes that occur in corneal thickness by means of a non-invasive technique: optical coherence tomography (OCT).

**PATIENTS AND METHODS**

**Patients**

Fifty individuals, 22 male and 28 female, aged from 21 to 44 years (mean age 29 years) were included in this study. Spherical refractive errors ranged between −0.75 to +0.50 dioptres (D), with a mean spherical refractive error of −0.22 ± 0.34 D. Only one eye per patient, the left, was included in the study. Intraocular media were clear and the patients had no known ocular disease. All patients were informed about the details of this study, and written informed consent was obtained after verbal and written explanation of the nature and possible consequences of the study, in accordance with the Declaration of Helsinki. No ethics committee approval was required for this study. Subjects with best-corrected visual acuity less than 20/40, ocular or systemic disease, ocular surgery history, intraocular pressure higher than 21 mmHg and retinal or optic disc disease were excluded from taking part in this study. None of the subjects were regularly using contact lenses, or any ocular or systemic medication.

A series of preliminary tests were conducted to ensure that all subjects had normal anterior segment and central corneal thickness.

**Ocular Coherence Tomography**

The Topcon SL SCAN-1 is a spectral domain OCT instrument that provides high-resolution cross-sectional images of the posterior and anterior segments of the eye. The SL SCAN-1 device uses a superluminescent diode (SLC) light source with a wavelength of 840 nm, axial resolution of 8.9 µm, a lateral resolution less than 20 µm and a scanning speed.

![Figure 1. Grid scan pattern used for measuring one eye (left). This pattern provides six B-Scans, where corneal thickness was measured in the centre of each one (corneal centre can be measured using the horizontal or the vertical scan). Measuring positions are marked with red dots.](image1.png)

![Figure 2. Example of an OCT B-Scan showing the cornea of a study subject. CT: Corneal thickness.](image2.png)
of 5,000 A-scans/second. This device has the following options for scan patterns: horizontal line, vertical line, cross, raster, grid, radial and circle.

**Experimental procedure**

Measurements of the cornea were taken four times each day, over a total of three days. To avoid the peak in corneal thickness immediately after waking, the first measurements were taken around 9.00 a.m., at least 2 hours after time of waking reported by subjects. Then, successive measurements were taken every 4 hours, until approximately 9.00 p.m., to record each individual’s natural diurnal variations in corneal thickness. For each subject, a 6 mm width scan using the instrument’s grid pattern mode was acquired. This way, six images are obtained with one simple measurement, as shown in Figure 1. Figure 2 shows an example of a B-scan out of the data set. The instrument has an eye preview camera to assist with the alignment of the subject. External illumination was used to improve the eye preview image quality. All these measurements were determined with an OCT technique, while the subject was looking at an external fixation target. Three sets of measures were taken at the centre of the pupil, using the grid scanning pattern (Figure 1) where corneal thickness was measured at different positions with the OCT device software. Once the set of scans was saved, measurements were taken at the centre of each scan, corresponding to points at 3 mm from the corneal centre in each one of the four cardinal directions (superior, inferior, nasal and temporal) and the corneal centre. These measurements are represented in Figure 1 by red dots.

**Data analysis**

All the data collected was analyzed using SPSS Statistics v.17.0 package (www.ibm.com/software/analytics/spss/). Diurnal changes in corneal thickness were studied using a two-way repeated measures ANOVA, before normality assumption was ensured by means of the Shapiro-Wilk test. Measuring position of the cornea (centre, nasal, temporal, inferior and superior) and time were set as within-subject factors. A post-hoc multiple comparison test using the Bonferroni method was then performed if ANOVA revealed differences. Statistical significance was set at p = 0.05.

**RESULTS**

Figure 3 shows the group mean corneal thickness as a function of time for the five different positions under study. Error bars have not been depicted in order to allow better visualisation. Figure 3 reproduces diurnal variation in corneal thickness values. A general overview of Figure 3 reveals that corneal thickness decreases slightly during the day, and also that some differences exist across different positions. The central position is the thinnest, whereas the superior position displayed the thickest corneal thickness.

Repeated measures ANOVA revealed that both time and corneal position had a significant effect on corneal thickness (p = 0.015 and p < 0.001, respectively). Post-hoc multiple pairwise comparisons using the Bonferroni method showed that inferior and temporal positions were not significantly different (p = 0.187), nor were the superior and nasal positions (p = 0.069).

Besides determining the evolution of corneal thickness over the course of the day, it is also important to have a value indicating the change in corneal thickness. Change in corneal thickness over the 12-hour period was calculated by subtracting the mean value obtained after the 12-hour period from the mean value obtained in the first series of measurements (at approximately 9.00 a.m.). This was done for each corneal position considered in this study. These values are gathered in Table 1. To better illustrate the change shown in Table 1, Figure 4 shows the percentage variation in corneal thickness between the start-of-day measurement and the end-of-day measurement (total period of 12 hours). The superior position showed the highest variation in corneal thickness between the beginning and the end of the measurement period. The smallest variation in corneal thickness was found in the inferior position. All of these variations are, in any case, very small (the largest represents a variation of around 1% of the total corneal thickness).
The small variation in the values could be due to the difference in the times of the measuring periods. The results obtained here are also very similar to those obtained by du Toit et al., although these authors used an optical pachymeter. Read et al. studied the variation in corneal thickness and shape during the day using a Pentacam HR device (Scheimpflug technique). They obtained a corneal thickness variation for the central cornea smaller than \(-5 \mu m\) for a similar period of time to the one used in this study (9.00 a.m.-09.00 p.m. approximately). For the peripheral cornea, the value obtained was slightly larger, and also coincides with our data. The non-uniform diurnal variation observed in corneal thickness between the centre and the peripheral region may relate to differences in the arrangement of stromal collagen fibrils in the different corneal regions. Boteet al. using X-ray diffraction techniques, found that the diameter of stromal collagen fibrils remained constant between the centre and the periphery, but the fibril spacing was greater in the peripheral cornea. The denser packing of fibrils within the central cornea is a possible reason for the slightly smaller amplitude of variation noted in this region compared to the more peripheral cornea.

The information regarding corneal thickness is very important for several applications. If a subject needs contact lenses, for example, knowledge of the behaviour of the cornea during the day, plus the values of the corneal parameters (and the tear film) would allow us to prescribe a particular type of lens with the best fit (material, water content, etc.) for that eye in particular. Also, this set of data would be very useful for obtaining better results in refractive surgery. Lens design and manufacturing could benefit from this information too, making it easier to develop better quality and more comfortable contact lenses. It would be interesting in the future to add more corneal parameters to the study, in order to gather more information that also would be useful for clinical and/or research applications.

### Table 1. Change in corneal thickness (CT) for each one of the five positions studied

<table>
<thead>
<tr>
<th>Corneal position</th>
<th>Change in CT (µm)</th>
<th>Change in CT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre</td>
<td>(-4.0 \pm 3.5)</td>
<td>(0.7 \pm 0.6)</td>
</tr>
<tr>
<td>3 mm nasal</td>
<td>(-5.2 \pm 4.1)</td>
<td>(0.9 \pm 0.7)</td>
</tr>
<tr>
<td>3 mm temporal</td>
<td>(-5.7 \pm 4.0)</td>
<td>(1.0 \pm 0.7)</td>
</tr>
<tr>
<td>3 mm inferior</td>
<td>(-3.5 \pm 3.8)</td>
<td>(0.6 \pm 0.7)</td>
</tr>
<tr>
<td>3 mm superior</td>
<td>(-7.2 \pm 3.7)</td>
<td>(1.2 \pm 0.6)</td>
</tr>
</tbody>
</table>

Values are expressed in microns and by percentage.

**DISCUSSION**

Our results highlight that the cornea undergoes a slight decrease in thickness and this thinning varies depending on the position of the cornea which is under consideration. Also, corneal thickness varies over the entire cornea. The cornea swells during the night, reaching a peak value upon waking. Following sleep, it takes an average two hours for the cornea to deswell. For this reason, the first measurement of each day was obtained at least two hours after the reported time of awakening. In this study, small diurnal changes on corneal thickness were found in all five positions during the 12-hour measuring period. The majority of studies which evaluate diurnal changes in corneal thickness agree that corneal thickness decreases slightly during the day, until it starts swelling overnight. Feng et al. found, also on OCT, that after an 8-hour period during the day, corneal thickness decreased by 2.49 µm, which is very close to the value obtained here for a 12-hour period (4.0 ± 3.5 µm thinning). The small variation in the values could be due to the difference in the times of the measuring periods. The results obtained here are also very similar to those obtained by du Toit et al., although these authors used an optical pachymeter. Read et al. studied the variation in corneal thickness and shape during the day using a Pentacam HR device (Scheimpflug technique). They obtained a corneal thickness variation for the central cornea smaller than \(-5 \mu m\) for a similar period of time to the one used in this study (9.00 a.m.-09.00 p.m. approximately).
In summary, OCT is a good technique for assessing corneal thickness, for both measuring and monitoring. The cornea is a dynamic structure, varying its thickness during the day and presenting different values depending on the corneal position considered. Although the changes in corneal thickness during the day are quite small and do not modify visual acuity or quality of vision, it is important to consider them for different applications. From a clinical point of view, corneal thickness analysis provides useful information for clinicians to bear in mind when prescribing contact lenses, detecting and monitoring diseases and performing refractive surgery, among others.

REFERENCES