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Optical quality and intraocular scattering assessed with a double-pass system in eyes with contact lens induced corneal swelling

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ABSTRACT

Purpose: To evaluate the impact of contact lens (CL)-induced corneal swelling on the optical quality of the eye by means of the double-pass technique.
Methods: Measurements of 6 healthy subjects were obtained in 5 visits over 1 week, at baseline and after sleeping with 4 different CLs of +0.50 D, +2.00 D, +5.00 D and +8.00 D (Acuvue2), randomly fitted on 4 different days. The control eye wore no CL. Corneal pachymetry and optical quality of the eye (OQAS, Visiometrics) were measured once at baseline and at three interval times in the follow-up visits: immediately after CL removal, and 1 and 2 h after CL removal. Optical quality was evaluated by means of the Strehl ratio and OQAS values at 100%, 20% and 9% contrasts. Intraocular scattering was evaluated with the objective scatter index (OSI).
Results: Mean overnight swelling was 5.98 ± 4.29% in CL-eyes *versus* 0.30 ± 0.78% in control eyes ($p < 0.01$). Corneal swelling was maximal immediately after CL removal and decreased with time ($p < 0.01$). A significant worsening in all optical quality parameters and a significant increase of the OSI were found in eyes with corneal swelling ($p < 0.05$). Two hours after CL removal there were no statistically significant differences ($p > 0.05$) between CL-eyes and control eyes in any of the measured parameters.
Conclusions: Corneal swelling has a significant impact on the optical quality of the eye and on intraocular scattering as assessed with the double-pass technique.

1. Introduction

Contact lenses (CL) wear is associated with adverse ocular responses such as corneal swelling due to hypoxia [1,2]. This swelling is directly related to the oxygen transmissibility (Dk/t) of the CL [2,3] and can be measured by precise methods of detecting corneal thickness changes, such as optical coherence tomography (OCT) [3–5]. OCT is a non-invasive, non-contact imaging technique that uses infrared light to obtain high-resolution, cross-sectional *in vivo* images of the cornea [6].

Vision impairment, mainly manifested as a noticeable decrease in contrast sensitivity with corneal swelling, has been reported after CL removal [7]. The increase in scattering caused by corneal swelling [8–11] is one of the causes of optical quality (OQ) worsening. However, the role of wave-front aberrations changes after CL removal, the other possible cause of optical quality worsening, is still controversial. Whereas short-term use of PMMA CLs [12] reduced the optical quality of the cornea, no changes have been described after the use of RGP or soft lenses.

The double-pass technique [13] has proven to be a useful tool for the comprehensive evaluation of the optical quality of the eye in daily clinical practice [14–16]. In contrast with wave-front aberrometers, the double-pass technique contains all the information about the optical quality of the eye, including the contribution of all higher order aberrations and intraocular scattering (IS) (forward and backward scattering as measured by the OSI) that are generally missed by aberrometric techniques. As suggested by a previous study [17] and in comparison with double-pass systems, wave-front aberrometers cannot easily evaluate the impact of ocular transparency loss and they may overestimate retinal image quality in eyes with prominent scattered light.

To our knowledge, no comprehensive data on changes in the optical quality of the eye caused by overnight CL wear using

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objective techniques that take into account all the aberrations and scattering have been reported. As reviewed in the introduction, the overnight CL wear causes corneal oedema, which is related to optical quality worsening mainly due to the increase of scattering. Thus having objective measurements of these changes is important for its gradation and for a better knowledge of overnight CL wear impact on vision. The purpose of this study was to evaluate the impact of CL induced corneal swelling in the optical quality of the eye by means of the double-pass technique.

2. Materials and methods

2.1. Subjects

Six healthy subjects, three women and three men (mean age, 27.17 ± 4.1 years; range, 23–34), participated in this prospective, randomized, masked study. The refractive error in terms of spherical equivalent ranged from +0.50 to −3.00 D (-1.58 ± 1.49 D). Subjects were excluded if they had a history of ocular surgery, an active ocular surface disease such as a significant dry eye, papillary conjunctivitis, corneal opacities, current medication that could affect ocular physiology, astigmatism >0.50 D or if they had used CL for long periods. Subjects reported monocular best spectacle-corrected visual acuity of 20/20 or better. Informed consent was obtained from each participant 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.

2.2. Instrumentation

Corneal thickness was measured by means of an OCT instrument (3D OCT-2000, Topcon, Japan). Three consecutive measurements were obtained from each cornea on each visit. The mean of the three scans of each cornea was used as the final result. The same masked researcher performed all OCT scans during the study visits.

Retinal image quality was measured by means of the *Optical Quality Analysis System* (OQAS, Visiometrics S.L., Spain), a double-pass based instrument for measuring the optical quality of the eye clinically [18]. The device includes a motorized optometer within the −8.00 to +6.00 D range to correct the patient's defocus [13]. No trial frame was introduced during the measurements to correct astigmatism because it was smaller than 0.50 D in all cases. Data were referred to a pupil size of 4 mm for all patients and were obtained without pupil dilation. Room illumination was kept low during testing to ensure a natural pupil diameter larger than 4 mm. Three consecutive measurements were obtained for each eye and their mean was used as the final value.

Retinal image quality was assessed by means of several parameters closely related to the modulation transfer function (MTF): the Strehl ratio and the OQAS values (OV). The Strehl ratio is computed as the ratio between the areas under the MTF curve of the measured eye and the aberration-free eye [19]. The higher the Strehl ratio, the better the optical quality, with a maximum value of 1 and mean values in young populations close to 0.25 [19]. The OVs are related to the MTF values corresponding to three different spatial frequencies that describe the optical quality for three contrast conditions commonly used in ophthalmological practice: 100% (OV100%), 20% (OV20%), and 9% (OV9%). OV values higher than 1.00 are normally associated with good optical quality.

The system also quantifies intraocular scattered light from the acquired double-pass image by means of the OSI parameter. This parameter is defined as the ratio between the integrated light in a peripheral annular area (from 12 to 20 min of arc) and the central peak (1 min of arc). As the scattering increases more light is spread to the periphery (high OSI index), whereas in absence of scattering the light concentrates in the centre (low OSI index). Values of OSI below 1 are usually linked to eyes with low intraocular scattering [20].

2.3. Procedures

This study included 5 visits over 1 week: at baseline and after one night of sleeping with one of the four different CL of +0.50 D, +2.00 D, +5.00 D and +8.00 D (Acuvue 2, Etafilcon-A material, Johnson & Johnson Vision Care, USA). Each CL was randomly fitted in one eye and the fellow eye was used as a control. An independent investigator scheduled the random fittings.

Etafilcon-A is a type of hydrogel lens that has been approved in the United States for 7 days extended wear (EW). The hypothesis was that the difference in power and crucially, the difference in thickness of the CL would produce various levels of hypoxia and thus various degrees of corneal swelling.

During the baseline visit (day 0), inclusion criteria were verified on all participants. Pachymetry with OCT, and OQ and IS with the OQAS system were performed. All baseline measurements were performed between 4 p.m. and 8 p.m. since some authors have suggested that this is the time of day when the eye is physiologically more stable [21]. All follow-up visits were in the morning (between 8 a.m. and 10 a.m.) and the eye with the CL was firmly occluded with gauze and taped to ensure that induced overnight corneal oedema was present at the time of measurement. In the four follow-up visits, the same measurements were obtained at three different interval times: immediately after CL removal, and 1 and 2 h after CL removal.

2.4. Data analysis

Statistical analysis was performed using a commercial package (SPSS 19.0 statistical package for Windows; SPSS, Chicago, IL). The results were expressed as the mean ± standard deviation.

A multivariate analysis of variance (ANOVA) was used to detect statistically significant differences between the control and study eyes in different time periods (before and after CL wear). Repeated-measures analysis of variance (Re-ANOVA with Bonferroni correction) was used to detect statistically significant differences in corneal thickness attributable to the time period after CL removal or CL power. A p value less than 0.05 was considered statistically significant. Correlations between the OQ, IS and corneal swelling were analyzed by means of the Pearson coefficient.

3. Results

None of the subjects had significant biomicroscopic signs (grade > 1, Efron grading scale [22]) of CL complications (corneal staining, limbal injection, striae, folds, or others).

3.1. Corneal swelling

We found an increase in corneal thickness (Table 1) in the eyes wearing CL compared with the control eyes. Mean corneal pachymetry for all CL was higher immediately after removal ($p < 0.01$ ANOVA with Bonferroni correction) and decreased 1 and 2 h after CL removal, without significant statistical differences in relation to the baseline pachymetry ($p = 0.45$ and $p = 1.00$ respectively, ANOVA with Bonferroni correction).

Corneal swelling was higher in eyes with CL, with significant statistical differences between both groups ($p < 0.01$ ANOVA) (Table 1 and Fig. 1). Corneal swelling was maximal immediately after CL removal ($p < 0.01$ Re-ANOVA) in all eyes, and decreased 1 and 2 h after CL removal. Eyes with lower Dk/t lenses, due to more positive