Wavefront Aberrations in Subjects Wearing Soft Aspheric Contact Lenses and Those Wearing Spherical Ones

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Abstract

Purpose: To measure the level of higher order aberrations (HOA) when wearing a soft aspheric contact lens (CL), compared to a spherical CL, in myopic subjects. **Method:** Fifteen myopic subjects aged 20-30 years were tested for the presence of dry eye. Aberrometry measurements were done without a contact lens as well as with a spherical CL and an aspheric CL. Root mean square error (RMS) of HOA, spherical aberration (SA) and coma were measured five times in an interval of 15 seconds without blinking for each of the 3 conditions. **Results:** Wearing a spherical CL produced a significant increase of SA and horizontal coma compared to an eye without a contact lens. When wearing an aspheric CL, there was a trend towards a smaller increase of these aberrations. However, the difference between both types of lens was not statistically significant. In terms of total HOA, these were higher when wearing the spherical CL, while they tended to be less with the aspheric CL. As for the variations between blinks, there was a similar increase in total HOA and individual modes with time for the three conditions. **Conclusion :** Wearers of aspheric CL seem to show a tendency towards smaller amounts of SA, horizontal coma and HOA in general in comparison with wearers of SCL. However, total HOA increases during a long interval between blinks, no matter the condition

KEY WORDS:
soft CL, aspheric CL, higher order aberrations, spheric aberrations, coma

Sommaire

Objectif : Mesurer le niveau des aberrations d'ordres supérieurs (AOS) lors du port d'une lentille cornéenne (LC) souple asphérique, par rapport à une LC sphérique, chez des sujets myopes. **Méthode :** Des mesures de sécheresse oculaire et d'aberrométrie ont été effectuées sur un échantillon de 15 sujets myopes âgés de 20 à 30 ans. L'aberrométrie était mesurée dans trois conditions : 1. avec une LC sphérique, 2. asphérique ou 3. sans LC. Pour chacune de ces trois conditions, la racine des moindres carrés (RMC) des AOS, l'aberration sphérique (AS) et la coma ont été mesurées à cinq reprises dans un intervalle de 15 secondes durant lequel le sujet devait s'abstenir de cligner des yeux. **Résultats :** Les AOS augmentent lors du port d'une lentille sphérique. Avec les LC asphériques, l'augmentation des AOS tend à être plus faible. La LC sphérique provoque une augmentation significative de l'AS et de la coma horizontale par rapport à la condition sans LC. Pour la LC asphérique, on note une tendance vers une progression moins importante de ces aberrations, quoique les différences entre ces deux types de lentilles ne soient pas statistiquement significatives. Quant aux variations inter-clignement, il y a une augmentation semblable des AOS et des modes individuels dans le temps pour les trois situations. **Conclusion :** Il y a une tendance vers moins d'AS, de coma horizontale et d'AOS en général lors du port d'une LC asphérique par rapport au port d'une lentille sphérique. Par ailleurs, toutes les aberrations mesurées augmentent lors d'un intervalle prolongé entre les clignements, peu importe la condition testée.

INTRODUCTION

Since the end of the 1990s, interest in improving the optical quality of the eye has grown. In order to improve visual performance, contact lens (CL) companies have developed so-called "high-resolution" CL that are supposed to correct the spherical aberration (SA) in addition to correcting the refractive error (myopia, hyperopia) and astigmatism. A reduction in aberrations ensures better imagefocus. As demonstrated in the past, the SA inherent in the optical system of the eye affects 90% of the population and introduces, on average, 0.15 μm of positive aberration.[1] SA is one of the many forms of wavefront aberration that affects the human eye. It has also been established that, for a person wearing CL, vision quality is affected, not only by the optical system of the eye, but also by the optical properties of the CL, as well as by the interaction of the CL with the eye, particularly with respect to the cornea and the tear film.[2] Thus, it would be pertinent to study the effect of aspheric CL on various types of aberrations.

Using a wavefront analysis, two recent studies demonstrated that certain types of soft spherical CL used to correct myopia increase total HOA, compared to when CL are not worn.[2,3] In 2003, Lu et al. also demonstrated that subjects wearing soft, spherical CL have more HOA on average than those who do not wear CL. However, they also noted a great amount of variability with respect to these aberration changes among CL wearers. These authors are of the opinion that, given the significant individual variations, the correction of aberrations with CL should be done on a personalized basis.[4]

The eye does not have an aberration-free optical system, and the wavefront resulting from the passage of light through the various ocular media undergoes deformations. In optics, the deformations of the sphericity of the light wavefront that reaches the retina are called aberrations. As a result of these aberrations, the image the eye produces of a point object is no longer a point but, rather, an irregularly shaped spot.

The most common method for representing wavefront aberrations is the Zernike polynomial. According to this model, the various types of aberrations are represented by modes that are inserted inside the various orders and are quantified by the coefficient of these modes. The sum of these individual modes forms the polynomial. Orders of three and more are qualified as higher orders. The most notable of these modes are the vertical and horizontal comas, the trefoil, and the SA. One of the most commonly used indicators for total aberration of the eye is the root mean square (RMS). The RMS is defined by the square root of the sum of the square of the Zernike coefficients. A high RMS generates a reduction in optic quality. Naturally the aberrations between the two eyes are generally substantially symmetrical.[10,11]

The tear film is important for protecting the surface of the eye, but also for ensuring a quality optical surface.[5] It represents the most powerful optical surface of all the ocular dioptrics, as a result of the significant difference in the refractive index between the air and the tears.[6] As a result, a slight variation in thickness or regularity will produce significant aberrations. Therefore, maintaining a uniform tear film is essential for providing a high-quality retinal image.[6,7] Montés-Micó et al. demonstrated that, after blinking, the tear film quickly stabilizes, which causes a reduction in higher order aberrations. Following this, they start to increase, following the evaporation of the tears, which results in an irregularity and then the disruption of the tear film.[8] In their study, which was published in 2005, the minimal quantity of aberrations was measured at 6.1 ± 0.5 seconds after blinking, on average, in normal subjects.[8]

Koh et al. demonstrated that it is possible to classify the temporal changes in the total HOAs that occur after blinking in four models: the stable model, small fluctuation model, sawtooth model, and other models.[5] At the same time, if an aspheric CL that includes a correction is poorly centred, it could cause a non-negligible quantity of coma.[9] Since we know that the eyelids close in a lateral progression, moving from the outer canthus to the inner canthus, we know the effect of gravity, and we know that the apex of the cornea is decentred temporally in most individuals, it is to be expected that the CL is not perfectly centred and that its position varies in the interval between blinks.[9]

The HOA degrade the quality of the retinal image. The SA causes a circular halo around the image while the coma gives the image of a point a comet-like tail shape. This results in a trailing blur next to the image, parallel to the symmetry axis of the "tail." The influence of these two aberrations depends significantly on the diameter of the entrance pupil of the optical system. The SA and the coma are generally the two most noted HOA in the human eye.

The purpose of this study is to measure the level of HOA in subjects with myopia when wearing a soft aspheric contact lens (CL), compared to a spherical CL, particularly during the interval between blinks.

The first hypothesis presented in this study is that wearing a spherical CL will cause an increase in the HOA in most subjects. Then, when aspheric CL are worn, the SA will be reduced, as compared to wearing spherical CL. Finally, the HOA present between blinks will also vary in keeping with the capacity of the CL to maintain the regularity of the tear film on its surface and also in keeping with the nature of the optic design.

MATERIALS AND METHODS

SUBJECTS

Fifteen subjects aged 20–30 years were recruited to test the hypotheses. The characteristics of the subjects are provided in Table 1. The subjects had to be CL wearers and have myopia with a spherical equivalent between -1.00 D and -7.50 D. The astigmatism could not exceed one-quarter of the sphere. The subjects did not present any ocular pathology and had not undergone surgery or refractive surgery that could have modified the integrity of the cornea.

With respect to the CL, two ocufilcon D CLs (gr. 1 of the FDA classification) with 55% water content were used. Only the optical design differed: one was spherical and the other was aspheric.

Demographic data for the sample

Data	Age	Myopia	Astigmatism	Meridian K flat	Meridian K steep	Pupil diameter
Average	22.9 yrs	-3.48D	-0.2D	43.38D	44.00D	5.96mm
Standard deviation	±1.44 yr	±2.03D	±0.34D	±1.36D	±1.49D	±1.10mm

Tableau 1. *Demographic data for the 15 subjects that completed the study.*

INSTRUMENTS AND PROCEDURES

During the first visit, each subject was evaluated to confirm that they satisfied the inclusion criteria. This evaluation involved a subjective refraction and a biomicroscopic examination of the anterior and posterior segments of the right eye, since only the right eye was tested. The keratometry and fit of the CL were also verified, only in the right eye, using a biomicroscope.

At the end of this visit a quantitative evaluation of the tear film was made. The volume of tears was measured with cotton threads calibrated for this purpose (Zone-Quick™, Menicon, Japan). Then the tear film break-up time (TBUT) was evaluated with fluorescein by observing the subject's eye with a biomicroscope and a yellow filter.

During the second visit, aberrometric measures were taken with the Nidek OPD-Scan II™ optical path difference scanning system (Nidek Co., Japan). This diagnostic instrument is an auto-refractometer, a corneal topographer, and an aberrometer. This tool was used to make a quantitative analysis of the light wavefront reflected by the retina after passing through the ocular dioptrics and media. These measurements were taken without pupil dilation. The NIDEK OPD-Scan II™ consists of two main systems. The projection system consists of an infrared beam that passes through a wheel equipped with a slit that produces light beams in the direction of a lens and mirrors. The wheel turns constantly at high speed, so as to cover the 360° of the pupil. The light beams enter the eye and are then reflected by the retina to head outside the eye toward the detector system. Finally, these rays cross through another lens and are then captured by an array of photodetectors.

The difference in the amount of time it takes the light to reach the central photo-detectors and the peripheral ones is converted into refractive power. This movement from the centre to the periphery is similar to that of the standard retinoscope used in clinics to objectively measure the ocular refractive error. The projection and detector systems turn in a synchronized manner around the optic axis of the device in order to measure the refraction of each meridian in increments of one degree.[13] This instrument acquires 1,440 data points that describe a refraction map through the pupil.[14] This map is converted into a map of the wavefront error through the pupil. This device was designed for clinical use.

The first step involved qualifying the reliability of this aberrometer. This validation was made with a sub-group of five subjects, given the limited amount of time allocated for this study. For this, three aberration measurements were made, without a CL, over two days.

Then, for each of the subjects, the ocular aberrations were measured without a CL. Then measurements were made with spherical and aspheric CLs, in turn. The CL was inserted in the eye at least five minutes before the measurements were taken. This period of time stabilized the tear film and the CL on the eye. Every time a measurement was taken using the aberrometer, the subject had to blink three times, stare at a target, and keep their eyes open until the measurements were completed (15 seconds). Half the group started with the spherical CL and the other half with the aspheric CL. Measurements for each of the three conditions were repeated three times. The aberrometer isolated the RMS values for the various aberrations that comprise the wavefront. The values for the vertical coma, horizontal coma, SA and total HOA were extracted for the analysis.

Data were analyzed with the SPSS™ 17.0 statistical application for Windows™. General linear models were used to test the possible significant differences in the data collected in keeping with the "aberration type," "correction type," and "time" factors. When applicable, post-hoc comparisons between the various CL conditions were made using paired tests on the estimated marginal averages (with a Bonferroni adjustment for multiple comparisons). If the general linear model revealed no time variation, the estimated marginal averages were only compared at the sixth second (time when the tear film is generally more stable[8]). If that was not the case, these paired tests were made every three seconds during the 15-second interval during which the subject was not to blink. A coefficient value of $p < 0.05$ was considered significant.

RESULTS

RELIABILITY

First, the Nidek OPD-Scan II™ aberrometer produced reliable results. For example, for four of the five subjects tested during two different days, the difference in the numerical values obtained for the SA between the two sessions did not exceed 0.05 μm. This was not clinically significant.

ABERRATION MEASUREMENTS DURING THE INTERVAL BETWEEN BLINKS

The averages and standard deviations of the aberrations studied for the three CL wearing conditions are reported in Figures 1–3. The average pupil dilation during the measurements was 5.96 ± 1.10 mm.

a) Spherical aberration

With respect to the SA, the general linear model analysis revealed that this aberration did not vary more over time for the three conditions during the 15-second interval (*p* = 0.491).

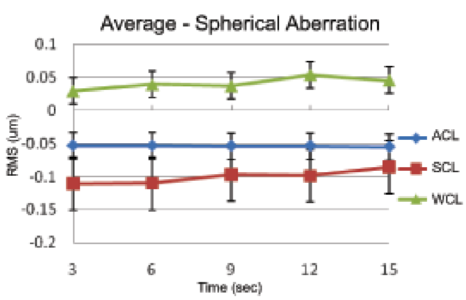

Figure 1. *Evolution of the average (n=15) of the spherical aberration during the 15-second interval during which the patient had to keep their eyes open while wearing no CL (green triangle), wearing a spherical CL (red square) and wearing an aspheric CL (blue diamond). The error bars correspond to the standard deviation.*

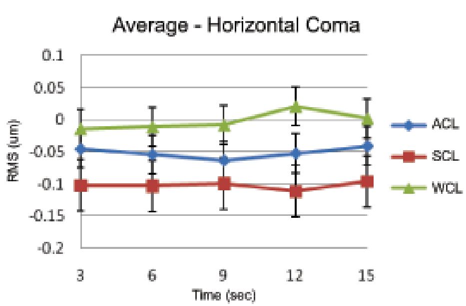

Figure 2. *Evolution of the average (n=15) of the horizontal coma during the 15-second interval during which the patient had to keep their eyes open when wearing no CL (green triangle), wearing a spherical CL (red square) and wearing an aspheric CL (blue diamond). The error bars correspond to the standard deviation.*

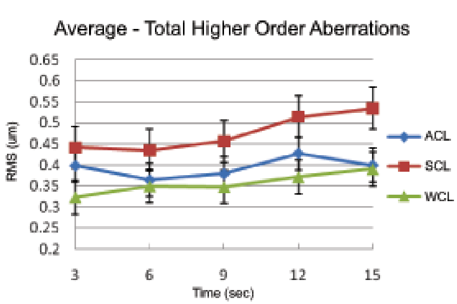

Figure 3. *Evolution of the average (n=15) of the total of the higher order aberrations during the 15-second interval during which the subject had to keep their eyes open when wearing no CL (green triangle), wearing a spherical CL (red square) and wearing an aspheric CL (blue diamond). The error bars correspond to the standard deviation.*

At the sixth second, the estimated marginal averages presented a statistically significant difference ($p < 0.0005$) between the condition without CL and the condition with a spherical CL ($p = 0.008$) or with an aspheric CL ($p = 0.001$) (Figure 1). The average SA measured in the subjects not wearing CL was +0.040 μm, compared to −0.110 μm, after a spherical CL was inserted. However, the comparison of the estimated marginal average pairs revealed no significant difference between wearing a spherical or aspheric CL ($p = 0.486$). Nevertheless, the aspheric CL did show a tendency to reduce the total SA (eye + lens), compared to the spherical lens. However, the average SA was the least when no CL was worn.

b) Coma

No change in terms of time for the three conditions was observed for the horizontal coma (general linear model; $p = 0.649$).

Analysis of the estimated marginal averages, at the sixth second, revealed a significant difference between the result obtained without a CL and that obtained with a spherical CL ($p = 0.025$) (Figure 2). The spherical CL tended to produce a higher amount of horizontal coma, compared to the aspheric CL. However, the horizontal coma with the spheric CL was not significantly different compared to that of the eye without a CL ($p = 0.074$). Moreover, a general linear model revealed no statistically significant differences for the vertical coma for the three CL conditions ($p > 0.05$).

c) Relationship between the spherical aberration and the horizontal coma

Analysis of the Pearson correlation coefficient revealed an association between the SA and the horizontal coma with no CL and with a spherical CL. Table 2 indicates the determination coefficient (r^2) observed in these conditions for each time sampled. For the condition with no CL, all of the correlations in this table were statistically significant, except for the 12th second of the situation without CL. That correlation is, however, in keeping with the other values. All of the corrections with a spherical CL were statistically significant. However, because no correlation was significant in the presence of an aspheric CL.

d) Total higher order aberrations

Finally, with respect to the progression of total HOA over time, a general linear model indicates the existence of a significant variation ($p = 0.013$) for the total average HOA for the three conditions. The pair comparison (estimated marginal averages) served to establish that the change occurs between the sixth second and the fifteenth second ($p = 0.008$) as well as between the ninth and the fifteenth seconds ($p = 0.007$).

Correlation between the Spherical Aberration and the Horizontal COMA (R^2)			
	No contact lens	Spherical contact lens	Aspheric contact lens
3rd second	0.647**	0.694**	0.403
6th second	0.586*	0.736**	0.424
9th second	0.544*	0.772**	0.343
12th second	0.454	0.770**	0.465
15th second	0.519*	0.798**	0.476

***The correlation is significant at 0.05 (bilateral)**
****The correlation is significant at 0.01 (bilateral)**

Tableau 2. *Pearson correlation coefficients for the relationship between the spherical aberration and the horizontal coma every 3 seconds of the 15-second interval during which the subject had to keep their eyes open when wearing no CL, wearing a spherical CL and wearing an aspheric CL. The table indicates the strength of this relationship in the three conditions tested.*

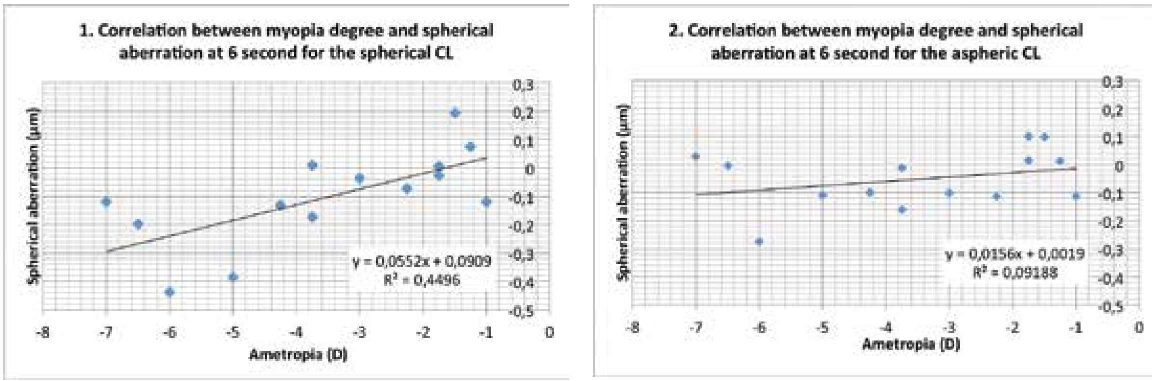

Figure 4. *Relationship between the subjects' ametropia (n=15) and the total spherical aberration (eye plus CL) at the 6th second of the 15-second interval during which the subject had to keep their eyes open when wearing the spherical CL (1) and the aspheric CL (2).*

The general linear model for the total quantity of HOA demonstrated a significant difference between the three CL-wearing conditions (p = 0.021) (Figure 3). However, the paired comparisons (estimated marginal averages) do not reveal significant differences between the CL-wearing conditions ($p > 0.05$). When an aspheric CL is worn, the average HOA seemed to be similar to that when no CL is worn, while there were more aberrations with the spherical CL.

DISCUSSION

The average SA measured in the subjects without CL was +0.040 µm at the sixth second (time when the tear film was the most stable[8]) (Figure 1). This value is below the average SA found in most of the population, namely +0.15 µm positive SA.[1] Therefore, the SA seems to be positive in the mostly myopic subjects who took part in this study. After a spherical CL was installed, the average SA was -0.110 µm. Therefore, this type of CL introduced a statistically significant negative SA in the sample studied, which is in keeping with the predictions of geometric optics. Based on our results (Figure 4), it seems that the more negative a spherical CL is, the more negative the total SA (eye and CL) is (although the correlation is average, with a coefficient of determination of R^2 = 0.4496). This relationship is weak in the case of the aspheric CL with R^2 = 0.09188 and is not significant ($p > 0.05$).

Any spherical minus lens produces a negative SA on its own. However, if we consider only the tendency concerning averages, the aspheric CL produces less negative SA (-0.053 µm), compared to the spherical CL. Therefore, it is possible to suppose that the designers of the spherical CL gave a negative or neutral SA correction value for low myopic corrections, knowing that the SA of the eye (positive) added to that induced by the concave nature of the CL would remain positive. In keeping with the concepts of geometric optics, it is likely that the aspheric CL designers calculated the negative value of the spherical aberration of the CL that corrects the myopia, so that it would complement the generally positive spherical aberration of myopic eyes.

As for the aspheric CL of medium or high minus power, the SA correction of the CL complements the increasingly negative SA produced by the increase in the concave power of the lens. Without this positive correction, the amount of SA produced by the lens would be so high that it would shift the total SA of the eye/lens pair toward the negative. Thus the aspheric lens would be designed to induce the necessary quantity of SA to cancel out the quantity usually produced by the power of the lens on its own.15 For this reason, the inversion of the sign of the SA induced may be observed in the five subjects wearing CL with a power greater than or equal to -5.00 D.

Moreover, according to Figure 1, the SA becomes more negative, on average, for the subjects with spherical CL. When the subject wears an aspheric CL, this aberration decreases in absolute value but is not the same as the values obtained without a CL. This confirms the initial hypothesis resulting from the hypothesis that the total SA could be better controlled with an aspheric lens. Nevertheless, this study does not confirm that the aspheric CL provides statistically significant results.

It should be noted that aspheric CL designers are targeting a theoretical SA. In fact, it is possible that the SA of the eye in certain subjects may be different from the proposed average value. Thus it is possible that, for these subjects, the SA may be worse or may not improve with the aspheric CL, compared to that measured with a spherical CL.

The results for the horizontal coma demonstrated a statistically significant increase for subjects wearing a spherical CL, compared to those wearing no CL (Figure 2). Two main factors seem to influence the amount of horizontal coma: the quantity of SA induced by the CL and lens decentring. As indicated above, high minus powers cause a transfer of the SA toward negative values when the subject wears a spherical SA. Also, the visual axis is generally off axis by 1/4 to 1/2 mm nasal, with respect to the pupillary axis (angle Kappa). A CL would tend to centre itself on the corneal apex, since it is usually temporal with respect to the visual axis. Therefore, when a subject looks through a CL along their visual axis, they are not exactly centred on the optical axis of the CL.

The SA of the CL combined with the decentring of the CL, compared to the optical system of the eye, could produce the horizontal coma. The stronger the spherical lens power is, the more SA it induces and the more the decentring will induce a significant amount of horizontal coma. This relationship accounts for the correlation between the SA and the horizontal coma for subjects wearing spherical CL (Table 2). This same correlation is found, although to a lesser extent, when the subjects do not wear CL.

According to the results, horizontal coma tends to be less when the subject wears an aspheric CL than when wearing a spherical CL. In fact, the SA is lower when the subject wears an aspheric lens than when wearing a spherical lens and, therefore, less horizontal coma is produced by decentering, due to the angle between the corneal apex and the visual axis. When considering only the numerical values obtained, the horizontal coma remains at a minimum when the subject wears no CL.

Since the visual axis and the apex are decentred on a horizontal plane, rather than a vertical one, the same tendency was not observed during the study of the vertical coma. Therefore, no significant trend for this aberration was observed.

During the analysis of the quantity of total HOA, no significant difference was noted following the paired comparison of the three conditions (Figure 3). It is, however, possible to observe a difference at the limit of statistical significance ($p = 0.054$) between the average HOA present when the subject wears a spherical CL compared to when they wear no CL. The spherical CL induces a higher quantity of HOA during the entire interval between two blinks. Nevertheless, neither of the two methods of correction is preferable for slowing the increase in the quantity of HOA, because the time following blinking increases. A significant increase in HOA was demonstrated for all of the conditions by comparing the results for the sixth and the ninth seconds for those observed at the fifteenth second. In keeping with the average TBUT of the subjects (seven seconds after the blink), this increase could be attributable to a thinning of the tear film following the break-up. The quantity of HOA induced certainly helps to reduce visual quality during a task involving a lot of concentration. To sum up, neither of the two CLs tested helps control the HOA.

CONCLUSION

In this study, the two types of CL (spherical and aspheric) increased the quantity of SA, horizontal coma, and total HOA in the subjects. However, wearing an aspheric CL tends to reduce the quantity of all the aberrations studied, compared to wearing a spherical CL. The aspheric CL is particularly beneficial for subjects with myopia of more than 5 D., wearing spherical CL, since these lenses induce an important quantity of negative SA and, possibly, horizontal coma. The SA and the coma do not vary significantly between blinks. However, the total HOA increased significantly during the interval between them. It could be interesting to reproduce this study with a CL made of a material that does not dry so rapidly, so that the HOA remains stable over time. In a future study, it could also be interesting to set up two separate groups, one with dry eyes and one with normal eyes, so as to better define the relationship between eye dryness and wavefront aberrations.

This study was approved by the Comité d'éthique de la recherche des Sciences de la Santé (CERSS) of the Université de Montréal and respected ethical standards with respect to using human subjects for research (principles of the Helsinki protocol). The participants were informed about the nature and details of the project and gave their written consent before taking part.

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