Optical aberrations associated with the use of soft hydrophilic contact lenses
Clinical study

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ABSTRACT: Purpose. The aim of this clinical study was to determine how the wavefront's and the retinal image's qualities, of eyes with extraocular contact lenses, are modified as the time of use of the lenses increases. Method. The aberrations of the eyes of 8 volunteers were measured, with and without lenses and for different time of use of the lenses, with a Hartmann-Shack Aberrometer. The collected data was then analyzed with the use of pupil plane and image plane metrics. Results. The results show a trend for the wavefront map's and the retinal image's qualities to decrease when comparing data obtained with less used and more used lenses, even if the amount of the eye's natural aberrations does not increase. Additionally, it was analyzed the presence of ocular aberrations' variation between cases without and with lenses and it was verified a trend to higher order aberrations, specially the anti-rotational ones, increase when placing the lenses. Conclusions. Despite the verified decrease of the wavefront map's and the retinal image's qualities to decrease when comparing data obtained with less used and more used lenses, even if the amount of the eye's natural aberrations does not increase. Additionally, it was analyzed the presence of ocular aberrations' variation between cases without and with lenses and it was verified a trend to higher order aberrations, specially the anti-rotational ones, increase when placing the lenses. Despite the verified decrease of the wavefront map’s and the retinal image’s qualities, as the lenses are more used, such does not justify not using the contact lenses to correct refractive errors. Such decrease suggests a need to find out why the lenses' optical performance decreases and a need to quantify that decrease. Thus, the several studies concerning this issue, and other related, will allow the increasing number of contact lenses' users to become more satisfied, as the quality of their vision increases throughout the lenses lifespan.

Key-concepts: Ocular aberrations, contact lenses, metrics, pupil diameter, variations.

INTRODUCTION

Due to the several advantages offered by extraocular contact lenses - they are less affected by wet environments, do not get fogged, supply a widened field of vision and are particularly indicated for the sports practice -, their use has become extremely popular in the last few decades, essentially among teenagers and adults and mainly as spectacles’ substitutes, for correction of refractive errors. Because of this increasing success, specialists have been paying more and more attention to these devices and its characteristics, always showing interest to the way the use of (different types of) contact lenses influences the presence and variation of different optical aberrations.

One question that was raised and not answered to throughout the reading of several references, refers to the presence and variation of different optical aberrations throughout the time of use of the contact lenses. Such question stemmed from the fact that contact lenses’ users usually complain that the quality of the vision gets worse as the lenses became more used, something that is not supposed to happen during the lenses’ lifespan. This issue was the starting point for the definition of the main aim of this work: to objectively determine how the quality of the image seen by the users of contact lenses varies throughout the lenses’ lifespan.

It was set out to base this type of study in measurements made to the eyes of users of different types of contact lenses, in order to be able to compare and/or generalize the results, but such
was not possible due to the limited number of volunteers. Consequently, this work was centered in determining the variation of the quality of the image seen by users - without taking in account neural processing - of monthly hydrophilic contact lenses (“soft” lenses).

Besides this particular study the measurements made without and with contact lenses were analyzed and compared, in order to verify how the use of lenses influences the variation of some aberrations.

**METHODS**

In order to reach the aim defined for this work, the ocular aberrations of volunteers’ eyes were measured, with a Hartmann-Shack aberrometer. The measurements, carried throughout the months between May and September of 2007, to the eyes of 8 volunteers (with and without placed lenses) took place at ALM OFTALMOLASER - Serviços de Ofalmologia Médica e Cirúrgica, S.A., a ophthalmologic clinic situated in Lisbon, and were all carried out by the same optometrist.

All measurements were performed under normal conditions of accommodation and it was paid special attention to the eye’s lacrimal film: it was made sure that the measurements were not held to very dry eyes, because that would introduce errors into the obtained data.

**Initial parameters’ definition**

Before initiating the collecting of data, it was necessary to focus at and define two parameters that can significantly influence the results: the number of measurements by volunteer and the pupil diameter.

In what concerns the number of measurements by volunteer, the ideal would have been to carry them throughout one complete month: taking the first measurement within the first days of use of a lens and, then, taking others throughout the 30 following days, with constant intervals between them and among the different cases. However, due to the fact that the volunteers were not paid and due to the clinic’s schedule, such was not possible.

The pupil diameter has a major role in this type of studies, since variations of the pupil diameter throughout the measurements have a great influence over the results, especially for eyes with significant amounts of aberrations. What happens is that, when the pupils are wider, the increase of the amount of rays that enter trough the periphery of the pupil increases, what results in a decline of the vision quality\(^1\), whereas reduced pupil diameters may result in an upgrading of the vision quality, even in eyes with optical aberrations\(^2\). Therefore, it is not suitable to compare and to correlate measurements taken with different pupil sizes, since these measurements do not reflect, in an absolute way, the amount of aberrations (especially the superior order’s ones) present in these optical systems. Another important aspect concerning the pupil diameter is the fact that it is advisable for the measurements to be carried out on pupils with a diameter equal to or greater than 6 mm, which ensures greater accuracy of the data measured with a Hartmann-Shack Aberrometer.

Unfortunately, it was not possible to assure that the measurements were always taken for the same pupil diameter, because that would require the use of pupil dilators that blur the vision for a considerable period of time, what would lower the already small number of volunteers.

**Population’s characteristics**

Two of the 8 study’ volunteers were males and the other 6 females, with ages ranging from 22 to 24 years (average of 23 years). They all use monthly contact lenses to correct myopia - low order aberration characterized by the focusing of the light rays of distant images in spots anterior to the retina, what results in a poor long distance vision - and, in some cases, also astigmatism - low order aberration that, due to the irregularities of the cornea’s surface, is characterized by the focusing of images in different points, both anterior and posterior to the retina. One of the volunteers (MS) changed lenses during the study period, what sums up a total of 18 lenses target of study, 5 of them being thoric - lenses used with the purpose of correcting astigmatism, in addition to myopia. The following table summarizes the lenses’ specifications.

<table>
<thead>
<tr>
<th>Contact lenses’ characteristics</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of contact lenses for spherical correction (myopia’s compensation)</td>
<td>18</td>
</tr>
<tr>
<td>Spherical power</td>
<td>-2 &lt;-&gt; -7</td>
</tr>
<tr>
<td>Number of contact lenses for both spherical and cylindrical correction - thoric lenses (both myopia and astigmatism’s compensation)</td>
<td>5 (31.25%)</td>
</tr>
<tr>
<td>Cylindrical power</td>
<td>-1.25 and -1.75</td>
</tr>
<tr>
<td>Curvature axis</td>
<td>8.4 &lt;-&gt; 8.9</td>
</tr>
</tbody>
</table>

Table 1. Specifications of the contact lenses used by the different volunteers.
The variations of the Zernike coefficients were, then, analyzed for 38 cases: the presence and magnitude of different aberrations in all of the 38 pairs (one measurement taken to an eye without lens and another taken to the same eye with the lenses), were compared. In 18 of these 38 cases (47.37%), the radius increased when placing the lens, while in the 20 remaining cases (52.63%) the radius decreased. The mean value of these variations was -0.032%.

**Analysis of the measurements taken throughout the lenses’ lifespan**

The analysis of the measurements taken throughout the lenses’ lifespan was based on a total of 38 measurements taken to eyes with lenses. 16 (42.11%) of that 38 cases, were taken with pupil diameters of 6 mm or more. In general, the pupil diameters had varied from 4.28 to 8.64 mm, with a mean value of 2.97 mm. From the 38 measurements considered, 26 cases were eligible for analysis. These 26 cases can be divided in two distinct groups:

**Group 1**: 16 cases (pair of measurements taken to the same eye, with the same lens placed, but for different lenses’ time of use) to which the variations of different parameters, throughout the lenses’ lifespan, were determined;

**Group 2**: 10 cases (pair of measurements taken to the same eye with lenses placed: one measurement taken with a very used lens and the other with another lens, a less used one) to which the variations of the same parameters were determined.

The second group was considered in order to verify if increases of certain aberrations, or decreases of the retinal image’s quality, that may be observed as the usage of lenses increases, were not due to a natural increase of the eye’s aberrations. Seven (43.75%) of the 16 cases that belong to the first group are characterized by a positive variation of the pupil diameter and 9 (56.25%) by a negative variation of that diameter. The mean value of these variations was 0.307%.

Seven (70%) of the 10 cases that belong to the second group are characterized by a positive variation of the pupil diameter, while 3 (30%) are characterized by a negative variation of this diameter. The mean value of these variations was 3.39%.

**Material**

The eyes’ monochromatic aberrations, with and without lenses, were measured with a Hartmann-Shack aberrometer. These aberrometers measure...
the wavefront error (difference between the shapes of the real wavefront and a reference one – plain wavefront) that leaves the eye’s pupil. For such, a fine ray of light (0.1 mm) is projected, by a laser or SLD, into the fovea, and the image is reflected by the retinal surface. The reflected light emerges from the pupil as an aberrated wavefront and travels from the eye to a set of microlenses, uniformly displayed in an external grating, in an eye’s conjugated plan - this way, the shape of the wavefront in the set of lenses’ plan is similar to its shape in the eye’s pupil - , being captured through all the pupil’s diameter. Each microlens focus a portion of the wavefront on a point of its focal plan, forming a pattern that is registerd by a CCD detector\(^{[3,4]}\).

The images collected in the CCD’s matrix are processed: the total number of points is counted, since there should be a point for each microlens, and the points’ deviations are determined. From these deviations - distance between the different points and the corresponding ideal ones - it is possible to determine the local wavefront’s slopes and, based on that, to determine the total wavefront error’s shape.

An ideal wavefront, totally plain, will produce a perfectly regular pattern. On the other hand, a deformed wavefront will produce a pattern with deviations and even some absent points.

![Perfect eye (with no aberrations)](image)

![Eye with aberrations](image)

**Figure 2. Schematic representation of the points’ pattern captured by the CCD detector, in an ideal case (eye with no aberrations) and for a aberrated wavefront\(^{[6]}\). (Adapted)**

In most cases, being this study such an example, the reconstruction of the wavefront, from the pattern registered in the CCD’s matrix, is achieved with the use of Zernike polynomials. Each of these polynomials represents a typical isolated aberration, becoming more complex as its order (level) increases. Thus, the total optical aberration that exists in one’s eye can be seen as the result of all its components’ sum\(^{[1,4,5]}\).

A way to survey how the “relative amount” of isolated aberrations contributes for the total aberration, is based in the analysis of the several polynomials’ Zernike coefficients (ZC): the coefficients related to the aberrations with larger contributions will have greater values.

In this particular study, the measurements were taken with a ZYWAVE\(^{TM}\)’s Hartmann-Shack aberrometer, manufactured by Technolas GmbH Ophthalmologische Systeme, a Bausch&Lomb’s company.

This instrument’s diagnosis table had forehead and chin rests - with adjustable height - that helped keep the central portion of the pupil lined up with the aberrometer’s camera. This limits the movements and minimizes the introduction of errors and variations into the acquired data.

This aberrometer’s laser diode works in the infrared zone, emitting rays with wavelengths of 785 nm. Other specifications of this instrument are listed at the following table:

<table>
<thead>
<tr>
<th>Range</th>
<th>Spherical</th>
<th>Cylindrical</th>
<th>Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+6.00 D</td>
<td>-12.00 D</td>
<td>0º – 180º</td>
</tr>
<tr>
<td>Pupil diameter</td>
<td>2.5 mm</td>
<td>8.5 mm</td>
<td></td>
</tr>
<tr>
<td>Laser protection’s class</td>
<td>1 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure time/measurement</td>
<td>0,1 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating mode</td>
<td>Continuous wave (cw)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power in the cornea</td>
<td>≤ 3,5 μW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ray’s minimum diameter</td>
<td>15 μm on focusing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. Specifications of the aberrometer used in this study\(^{[6]}\). D stands for dioptres.**

The measured data was analyzed with a computational tool, developed in MATLAB\(^{®}\) by Filipa Viola - Visual Acuity Simulation Program -, Master in Biomedical Engineering\(^{[7]}\). This program receives, as an input in an interactive menu, the name of the file containing the data measured with the aberrometer, and returns the graphic representations of several metrics of the retinal image and the wavefront’s quality - Zernike coefficients, wavefront aberration maps (two and three dimensional), PSF and MTF - and images that give an idea of how the volunteers see different shapes and images - Snellen Chart, gratings (of low and high frequency) and a cross air.

**Metrics used**

Before starting the data analysis, it was necessary to determine what metrics to use, with the goal to
verify if the image’s quality really decreases, throughout the contact lenses’ lifespan. To do that, an exhaustive research work, centered on studies that aimed - central or complementary - to determine the best metric(s) in determining the retinal image’s quality and visual performance, in different situations (with the use of spectacles, the use of different types of contact lenses, etc.) and for different visual tasks, was carried through [8,9,10,11,12]. Unfortunately, from all the articles read, no conclusions could be made about a single ideal metric - a metric that predicts well the impact of different aberrations in the vision, for different situations and visual tasks -, or even a small group of ideal metrics. Then, the metrics chosen were ones that had presented general good behaviors, in different conditions, and that were of relatively easy application.

The metrics used in this study’s analysis are presented next. The first two are examples of pupil plan metrics, since they describe the wavefront’s error in the pupil plan. The other two are image plane metrics, given that they describe the retinal image of a point of light (Point Spread Function - PSF - metrics) and sinusoidal gratings (Modular Transfer Function - MTF - metrics).

1. Analysis of the Zernike coefficients:

The first metric used analyzes the Zernike coefficients associated with different aberrations. The calculus of the CZ’s variations between different measurements uses the following equation:

$$\Delta(\text{parameter})_{i-f} = \frac{\text{parameter}_f - \text{parameter}_i}{\text{parameter}_i} \times 100$$

in which the indexes $i$ and $f$ are referred to the different parameter’s absolute values, in the initial (reference) and final (other than the reference) instants, respectively.

This equation is also applied afterwards, in order to determine the different metrics’ variations.

2. Critical pupil method (pupil fraction method):

The critical pupil method is a metric of the wavefront’s quality, based on the concept of pupil fraction:

$$\text{pupil fraction} = \frac{\text{area of good pupil}}{\text{total area of pupil}}$$

This method, developed using MATLAB®, continuously examines the quality of the wavefront, inside a sub-aperture that is concentric with the pupil. The analysis starts with a small sub-aperture (sub-aperture’s radius = 5% (pupil’s radius)), that expands until a certain criteria equals a pre-defined critical value. The sub-aperture’s radius, at which the critical value is reached, is known as ‘critical radius’ and the pupil fraction can be determined as follows:

$$\text{pupil fraction} = \frac{\text{critical radius}}{\text{pupil radius}}$$

A large pupil fraction is desirable because that means that most of the light entering the pupil will contribute to a good-quality retinal image [12].

Despite this metric being biased in favor of the central portion of the pupil, this is a reasonable approach, since this portion makes a larger contribution to vision - Stiles Crawford effect [13].

In what concerns the criteria used to determine the wavefront’s quality, several metrics can be taken into consideration [13]. Here, we chose to use the root-mean-squared wavefront error (RMS), which was determined for the several sub-apertures:

$$\text{RMS} = \left( \frac{1}{A} \int_{\text{sub-aperture}} (w(x,y) - \bar{w})^2 dx dy \right)^{0.5}$$

[micrometers]

On the previous equation, $w(x,y)$ represents the aberrated wavefront inside the sub-aperture, $\bar{w}$ represents the average of the same wavefront, $A$ is the sub-aperture’s area and the integral is determined over the entire sub-aperture. Computationally, the RMS is just the standard deviation of the values of the wavefront specified at various pupil locations [12].

The value determined as critical, for this criteria, was 0,1963 nm (laser’s wavelength/4 = 0,785nm/4) [11,12].

Although the two previous metrics provide information concerning the quality of the wavefront, the reality is that they do not allow to predict the quality of the retinal image: besides not knowing, exactly, in what way the superior order’s aberrations contribute to the total aberration, the combinations of the different coefficients, of both inferior and superior orders, also have a significant impact in the visual quality, in a way that is not predictable just by examining the individual components.

Thus, it is important to use other metrics that allow determining the quality of what someone really sees, throughout the lenses’ lifespan. These metrics are known as image plane metrics and measure the quality of the retinal image, of which the following two are examples.
3. Square-root of the second moment of light distribution (PSF’s compactness metric):

Metrics of the retinal image’s quality can be based in one of the two following parameters: compactness or contrast. As more compact and with a higher contrast a PSF is, the better its quality.

![Figure 3. Representation of two PSF’s of different qualities: the one in the left, more compact and with high contrast, is of better quality than the one in the right, less compact and with low contrast][12].

This metric was developed using MATLAB® and measures the spatial compactness of the PSF, and is computed as follows:

\[ SM = \left( \frac{\int_{pupil} (x^2 + y^2) \text{PSF}(x,y) dx dy}{\int_{pupil} \text{PSF}(x,y) dx dy} \right)^{0.5} \]  

As this metric’s value lowers, the more compact the associated PSF is.

4. MTF’s area:

The forth metric used in this study calculates the area of the MTF associated with the different measurements. This function measures the ability of an optical system to transfer contrast to an image, at different frequencies. So, it is desirable for this metric’s value to be as high (under and near one) as possible, which means that the area under the line defined by this function should be as large as possible.

**RESULTS**

**Analysis of the measurements taken with and without lenses**

Given that the purpose of using contact lenses is to correct lower order aberrations, significantly improving the vision’s quality, the last three metrics presented were not used in this first analysis, since that are no doubts that the quality of the wavefront’s map and of the retinal image increase when placing the lenses. So, the only parameters analyzed in this point were variations’ averages, within distinct intervals of pupil radius’ variation, of some superior order’s Zernike coefficients - comas and spherical aberrations -, and some related sums - sum of the absolute values of all the superior order’s coefficients and the same sum but without considering the comas and the spherical aberrations, to examine eventual compensations.

In general, although some of the positive variations’ averages may be explained as a result of positive pupil radius’ variations, others suggest that the lens placing, although compensating the lower order’s aberrations, induce an increase of the higher order aberrations, particularly the anti-rotational ones (namely comas), what can be explained by a poor fitting of the lenses to the cornea’s surface.\(^{[14]}\) If, without lenses, the higher order aberrations may not be considered, since the lower order aberrations are much larger, with lenses the magnitude of the higher order aberrations is, in many cases, as large as the magnitude of the lower order ones, largely contributing and influencing the total visual quality.

**Analysis of the measurements taken throughout the lenses’ life span**

**Group 1**

For the first metric considered (ZC’s variations), the results were grouped within defined intervals of pupil radius’ variations and for different intervals between measurements (number of days), and the averages of those variations, within the different intervals, were determined. For both analysis, most of the variations’ averages seem to be a result of the associated pupil radius’ variations or to be due to compensations among the different aberrations, especially to what concerns the higher order ones. However, and mainly for lower order aberrations, some of the variation’s averages, of intervals in which the pupil radius’ decreases, are positive, what suggests that, as the lenses become more used, their performance and effectiveness may decrease.

The analysis related with the Critical Pupil Method metric was carried out in a similar way to the one before – the results were also grouped as described above. In this case, when grouping the results within defined intervals of pupil radius’ variations, the results may, in general, be explained by the pupil size variations. However, when we group the results for the different intervals between measurements, it is clear that there really exists a trend for the vision’s quality to decrease as the lenses become more used (these metric’s values decrease as the lenses become more and more used).

For all what was said above, there are no doubts that it was very difficult to extract any conclusions...
from the analysis based on the pupil plane metrics, due to pupil radius’ variations. Even so, some results are contrary to what the pupil radius’ variations would lead to expect and suggest that there really must be some decrease in the vision’s quality, as the lenses’ wearing time increases. Thanks to the Visual Acuity Simulation Program, it was possible to determine the two lastly presented metrics’ values for pre-determined pupil radius. This way, the analyses concerning these two metrics could be done with no radius’ variations influences.

When analyzing the measured data with the first image plane metric (that measures the PSF’s compactness), these metric’s values increased as the lenses’ time of use also increased or, in other words: as the lenses’ wearing time increased, the associated PSF’s became less compact, what implies a decreasing in the vision’s quality.

However, for the second image plane metric (measurement of the MTF’s area), results’ averages did not present any dominating trend, neither to increase or decrease, as the lenses become more used.

**Group 2**

For the first metric considered (ZC’s variations), the results were grouped within defined intervals of pupil radius’ variations and for different intervals between measurements (the measurements referring to the new lenses were taken right after stopping using the old ones, or with one or two months’ gaps). The results can, once again, be mostly explained as consequences of the pupil radius’ variations. Nonetheless, some of the variations’ averages are negative, even when the pupil radius’ increases, what suggests that the wavefront map’s quality may improve when changing old lenses for new ones or, at least, some of the aberrations that most tend to affect the retinal image quality - defocus, coma, spherical, etc - decrease.\(^{(1)}\)

To what concerns the results obtained with the second pupil plane metric (Critical Pupil Method), the metric variations’ averages clearly reveal an improvement of the quality of the wavefront’s map (associated with an increase of the pupil fraction), when changing old lenses for new ones. However, when measurements taken with one or two months’ gaps were compared, there was a decrease of the pupil fraction’s values, what can be due to a natural increase of the eye’s aberrations.

Once again, the results obtained with the first two metrics were very pupil radius’ dependent and it was difficult to objectively analyze them. Fortunately, with the Visual Acuity Simulation Program, it was once more possible to determine the two lastly presented metrics’ values for pre-determined pupil radius. This way, the analysis concerning these two metrics could be done with no radius’ variations influences.

For the first image plane metric (measure of the PSF’s compactness), there was a clear improvement of the retinal image’s quality when changing old lenses for new ones, even when there were one and two months’ gaps between the several measurements’ pairs considered.

Finally, the results obtained when applying the second image plane metric (measurement of the MTF’s area) to the data were more concordant with the results obtained with the others metrics than what happened for the first group.

Summarizing, although not being able to correlate the different results, among them and with the pupil radius’ variations, most of the obtained results suggest that both the quality of the wavefront’s map and the quality of the retinal image tend to decrease as the lenses’ use time increases, increasing when changing old lens by new ones, if no gap between the pair of measurements exists.

**CONCLUSIONS**

The clinical study carried out helped achieve the aims set at the beginning of this work: although it have not been possible to establish a correlation between the lenses’ time of use and their performance, it was shown that there is a decrease in the vision quality (non neural component) as the lenses become more used, which indicates a less effective correction of aberrations. So that it was possible to reach these conclusions, we measured the eyes’ aberrations of several volunteers, with the contact lenses placed, with a Hartmann–Shack Aberrometer. The data obtained was analyzed using 4 different metrics: analysis of the Zernike coefficients, critical pupil method, square-root of the second moment of light distribution (PSF’s compactness metric) and MTF’s area.

It was expected for the first two metrics - examples of pupil plan metrics - to present the worst behavior or to present the most difficult to analyze results due to the pupil variations’ radius associated. Such was mainly verified for the first metric, what did not allowed us to examine how the presence of several individual aberrations varies as the lenses’ time of use increases. The metric Critical Pupil Method has allowed us to obtain very satisfactory results when grouping the data for different interval between measurements; there is a trend for the wavefront map’s quality to decrease as the lenses become more used.
For the two image plan metrics - the last two presented - the results were expected to be more significant than the ones obtained with the first two, since they do not have associated pupil radius’ variations.

Similarly to what happened with the first two metrics, the results obtained with the last two were more expressive when grouping the data for different intervals between measurements: in most cases it was shown that the retinal image’s quality was higher for less used lenses than for more used lenses, within the lenses lifespan, but only with the results obtained with the metric that measures the PSF’s compactness was shown a trend for this quality’s decrease to be more accentuated as lenses’ time of use increased.

Besides this particular analysis, it were also examined the variations of different Zernike coefficients (and related sums), measured in eyes without and with placed contact lenses. Although some of the observed variations may be explained as a result of associated pupil radius variations, others suggest that, although compensating the inferior order aberrations present in the eye, the placing of a contact lens may induce the increase of some superior order’s aberrations, specially the anti-rotational ones.

Taking into account that had not been found any references to other studies in which different metrics are used to measure the wavefront map’s and retinal image’s qualities, throughout the lifespan of contact lenses, the study presented here stands out since it raises some questions not asked until now and tries to answer them. It fails, however, for not concentrating its analysis in a greater and more heterogeneous population of eyes and types of lenses, where different parameters - such as the pupil diameter, the intervals between measurements, and the time spent without lenses before the measurements, etc - are controlled, what made the obtained results very difficult to analyze and compare.

So, it is suggested the accomplishment of an in depth study, that uses a wider number of metrics, especially polychromatic ones - considered to be better predictors of the optical quality and performance -, tested under different conditions in which the different parameters referred, that may influence the results in a non desired way, are well controlled. The accomplishment of studies with a strong statistical power is also recommended.

Another analysis that would be interesting to carry out, given that the use of lenses aims to correct only the lower order aberrations, deals with a simulation of the ideal correction those aberrations and, afterwards, conducting a more detailed analysis focused on the variation of higher order aberrations, throughout the lenses lifespan and without the lower order aberrations’ influence.

Although it have been verified a trend for the wavefront map’s and the retinal image’s qualities to decrease as the lenses’ time of use increases, this decrease does not justify not using contact lenses to correct refractive errors. Rather, it suggests a need to find out why the lenses’ optical performance decreases, as the lenses become more used, and a need to quantify that decrease. Thus, the several studies concerning this issue, and other related, will allow the increasing number of contact lenses’ users to become more satisfied, as the quality of their vision increases throughout the lenses lifespan.

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REFERENCES


