CHAPTER VI

On-Eye Measurement of Optical Performance of Rigid Gas Permeable Contact Lenses Based on Ocular and Corneal Aberrometry

This chapter is partly based on the article by Dorronsoro, C., et al., *Detailed on-eye measurement of optical performance of rigid gas permeable contact lenses based on ocular and corneal aberrometry.* Opt Vis Sci, 2003. 80(2): p. 115-125. Coauthors of the study are: Sergio Barbero, Lourdes Llorente and Susana Marcos.

The contribution of Sergio Barbero to the study was the adaptation of the corneal aberrometry to measurements on eyes with RGP lenses and participation in data collection.

RESUMEN

OBJETIVOS: Obtener una descripción completa de las interacciones ópticas de las lentes de contacto permeables (RGP) en ojos normales.

MÉTODOS: Medimos las aberraciones totales y de superficie anterior en cuatro sujetos; todos ellos eran usuarios de lentes RGP desde hacía bastante tiempo. La aberración de onda de la superficie anterior se obtiene a partir de los datos de elevación de un topógrafo corneal y las medidas oculares de aberración de onda se midieron con una técnica de trazado de rayos laser. Las medidas se realizaron sobre los sujetos con y sin las lentes de contacto.

RESULTADOS: En 3 de los 4 sujetos encontramos mejoras significativas de la óptica de ojos con lentes de contacto comparada con la óptica natural del ojo. En el sujeto de mayor dominancia de aberraciones corneales la RMS (2^{nd} orden y superior) con lente de contacto decrece de 1.36 μm a 0.46 μm. Las aberraciones de 3^{rd} y superior decrecen desde 0.77 μm a 0.39 μm. La óptica de las superficies internas y la flexión de la lente imponen límites a la compensación de aberraciones por parte de las lentes.

CONCLUSIONES: La medida de aberraciones es útil para entender la adaptación de las lentes de contacto y la interacción con las superficies internas del ojo. La aberrometría puede ayudar a elegir los mejores parámetros estándar de las lentes RGP para mejorar la óptica de los ojos individuales.

ABSTRACT

PURPOSE: Our aim was to obtain a complete description of the interactions of rigid gas permeable (RGP) contact lenses with the optics of normal eyes.

METHODS: We measured total and anterior surface aberrations in four subjects, who were all long term RGP contact lens wearers. The anterior surface wave aberration was obtained from videokeratographic elevation maps and ocular wave aberration was measured with a Laser Ray Tracing technique. Measurements were performed with and without their own spherical contact lenses.

RESULTS: We found that in 3 of 4 subjects the contact lens significantly improved the natural optics of the eye. For the subject with higher dominance of corneal aberrations, RMS (2^{nd} order and higher) decreased from 1.36 µm to 0.46 µm. 3^{rd} and higher order aberrations decreased from 0.77 µm to 0.39 µm. The internal optics and lens flexure imposed limits on aberration compensation. Spherical RGP contact lenses did not produce spherical aberration due to a compensatory role of the tear lens.

CONCLUSIONS: Aberration measurements are useful to understand the fitting of contact lenses, and the interaction with internal optics of the eye. Aberrometry can help to choose the best standard RGP lens parameters to improve the optics of individual eyes.

1. Introduction

In this chapter we will show the use of ocular aberrometry and corneal topography to assess optical performance of rigid gas permeable Contact lenses (RGP CL), and the potential of this type of lenses to significantly reduce ocular aberrations (not only defocus and astigmatism, but also high order aberrations). The combination of total and anterior surface aberrations measurements in the same subjects with their natural optics and RGP lens will allow us to assess aspects related to contact lens fitting.

It is widely accepted in the clinical practice that RGP CLs provide the best ophthalmic correction, at least from a purely optical viewpoint[1]. RGP CL are expected to mask the anterior corneal surface with a perfectly regular surface, and fill in with tear all the corneal irregularities. The refractive index similarity between the tear film and the anterior corneal surface reduces the impact of corneal aberrations[2]. However, a direct comparison of the optical changes produced by RGP CLs on the anterior surface of the cornea and total optical system has not previously been reported.

The better visual response of RGP CLs, compared to soft CLs (which would produce the same magnification) or spectacles, is well documented in the optometry literature [1, 2]. Most of these studies are based on psychophysical measurements of visual performance and conclude that RGP CLs provide higher visual acuity and contrast sensitivity. Several studies perform computer simulations to understand the optical performance of the contact lens [3]. Using computer modeling, they study the interaction of the lens with a model corneal surface and the optical contribution of the tear lens between the cornea and contact lens. Validating those simulations is difficult, as they tend to simplify the problem: They do not take into account corneal irregularities, contact lens decentration and flexing, and the influence of the internal optics. Other studies[4] have measured the topography of the CL on the eye to study flexure on eye, but the analysis is based on corneal elevation data rather than on corneal wave aberrations. To our knowledge, only Hong et al. (2001)[5] have measured aberrations in subjects wearing RGP CLs, finding that in 3 out of 4 subjects, RGP CL provided lower aberrations than soft CLs and spectacle lenses.

In this chapter we have measured total aberrations and anterior surface aberrations in four young healthy subjects, long term RGP CL wearers. We have measured aberrations with and without the CL. The combination of these four types of measurements allows a complete description of the interactions of the CL with the subject's natural optics, and to study the optical implications of the RGP CL fitting. In this paper we show the capability of RGP CLs to greatly reduce ocular aberrations beyond defocus, particularly in optically degraded eyes.

2. Subjects and methods

Subjects

Four volunteers (two males and two females) participated in the study. RGP CLs were not fit for this particular study, but rather the subjects were selected because they were long term and satisfied RGP CL wearers. Subjects wore their own CLs, which all were RGP with anterior spherical surfaces. Ages ranged from 18 to 33, and spherical refractions from –4.5 to –8 D. Individual autorefractometer refractions, ages, axial lengths, anterior chamber depths and corneal curvatures are reported in Table VI.1. Parameters of each CL provided by the manufacturers are also included Table 1.

Apart from their ametropia, all eyes were normal, and BCVA was 1.00 or better. Only one eye was tested per subject, right eye for S1, S2 and S4, and left eye for S3. RGP lens stabilization and repositioning after blinking was checked by pupil video monitoring (with respect to the pupil center). While there was not inter-eye differences in the rest of the subjects, in subject S3 centration was significantly better for the left than for the right eye, and therefore the left eye was chosen for measurements. Table VI.1 reports the coordinates of the center of the CL (in its stable position) relative to the pupil center.

All subjects had an eye examination before participating in the experiment. All subjects were informed about the nature of the study and signed an informed consent form, following the tenets of the Declaration of Helsinki. All the protocols and consent forms have been approved by Institutional Review Boards.

	Subjects			
	S1	S2	S3	S4
Eye	OD	OD	OD	OD
Age (yr)	27	33	18	24
Refraction (D)	-8.00 -2.00 x 8	-4.50 -1.25 x 92	-8.00 -0.75 x168	-6.75 -0.50 x159
Axial length (mm)	25.25	26.14	26.78	27.02
Anterior chamber depth (mm)	3.75	3.83	3.67	4.38
Corneal radius (mm)	7.62	8.21	8.19	8.02
Corneal asphericity	0.15	0.1	0.18	0.12
Contact lens type	Permiflex	Permiflex Air	Conflex Air 100 UV	Boston E.S.
Manufacter	Eurolent	Eurolent	Zeiss	Bausch & Lomb
Front optical zone radius. Videokeratoscope (mm)	8.41	9.22	9.62	9.05
Back optical zone radius(mm)	7.70	8.25	7.90	7.95
Front surface asphericity-nominal	0	0	0	0
Back surface asphericity-nominal	0	0	-0.16	0
Front optical zone diameter (mm)	--	--	8.5	8.5
Back optical zone diameter (mm)	8.5	8.1	--	8.4
Back vertex power (D)	-3.50	-3.25	-7.00	-5.00
Central thickness (mm)	0.18	0.18	0.15	0.18
Material	PMMA +CAB	Silicone Fluorcarbonate	Fluor silicone metacrilate	Enflufocon A
N	1.469	1.467	1.467	1.443
Lens center (x,y) mm[a]	(1.1,0)	(-1.66,1.27)	(-1.91,-0.25)	(1.33,0.47)

[a] Relative to pupil center. Positive horizontal coordinates stand for nasal in right eyes and temporal in left eyes. Negative horizontal coordinates stand for temporal in right eyes and nasal in left eyes. Positive vertical coordinates stand for superior, and negative stand for inferior.

Table VI.1: Individual ages, autorefractor refractions, axial lengths, anterior chamber depths, corneal curvatures and contact lens parameters provided by the manufacter.

General experimental procedure

All measurements were conducted in the same experimental session, which lasted about an hour. Initial routine measurements included slit lamp examination, autorrefraction (Automatic Refractor Model 597, Humphrey-Zeiss), and axial length and anterior chamber depth by optical biometry (IOLmaster, Humphrey-Zeiss). These measurements, as well as videokeratography (Atlas Mastervue Corneal Topography System Model 990, Humphrey-Zeiss) were obtained without the CL. A second videokeratography was obtained with the subject wearing his/her CL. Videokeratographic images were taken when the CL had reached a stable position after blinking. Images distorted by tear fluid irregularities (more frequent when the eye was wearing the CL) were rejected. Pupils were dilated by means of one drop of tropicamide

1% prior to Laser Ray Tracing measurements of ocular aberrations. The first set of measurements was taken without the CL, and the last set of measurements with the CL on.

Total aberration and anterior surface aberration measurements

A detailed description can be found in chapter II.

Set up and procedures

Typical pupil diameters for LRT measurements in previous studies were 6.5 mm (with a sample step of 1 mm). In this study we reduced maximum pupil size (6 mm for subject S1, 5.5 mm for subjects S3 and S4, and 5 mm for subject S2). We found that for larger pupil diameters several images (corresponding to the most eccentric entry pupils) were affected by diffraction at the edge of the CL. Sampling step was varied, so that in all cases the pupil was sampled by 37 rays. For comparison purposes, all data were recomputed for 5-mm pupils.

The largest contribution to the displacement of retinal aerial images in measurements without CLs was caused by spherical errors. For the pupil diameters used, all the aerial images fitted within the CCD chip, except for one subject (S3), for whom spherical errors moved the aerial image outside the CCD. For this subject, we compensated for the refractive error with a trial lens (-7D), in measurements performed without the CL. For one subject (S4), we conducted measurements with and without trial lens, to assess any possible contribution of the trial lens correction (see below).

Control and trial experiments.

Pupil monitoring: Similarly to videokeratographic images capture with CLs some training was required to optimize image capture with CLs in LRT, and to ensure that measurements were taken with the lens in its stable position. Initial measurements were performed in one subject wearing RGP CL (S1), using green light (543 nm). The pupil was illuminated by IR (780 nm) light using a ring optical fiber illuminator. A filter (543 nm) was placed in front of the CCD camera that captured the aerial images to eliminate spurious light from the pupil illumination. A frame grabber captured the video signal from the pupil monitoring camera, while the test beam scanned the pupil and the second camera captured the aerial images. Pupil images also show the position of the CL, and the 1st Purkinje images of the sampling beam (actually the reflection comes from the CL, rather than from the anterior corneal surface) as it moves across the pupil. With this configuration, we were able to assess the exact entry pupil location for each captured aerial image. In all cases, aerial images showing a diffraction pattern and elongated in a direction perpendicular to the CL edge, corresponded to rays that hit the edge of the optical zone of the CL. We also were able to assess CL motion dynamics in all subjects by pupil monitoring. All of the CLs moved downwards significantly when the subject raised his/her upper lid more than normal. After some feedback, the subject was able to keep a good CL stability.

We performed measurements in S1 in both visible (543 nm) and IR (786 nm) light. Except for exceptional runs for which the CL was clearly displaced (as assessed by the pupil video image during the measurements in green), results in both wavelengths were within the measurement variability (average standard deviation across Zernike coefficients less than 0.1 µm). For the sake of subject's comfort, only IR light was used for the rest of the subjects. Dynamics of the CL was assessed with the described system prior to the measurement, and when stability was achieved, pupil illumination was turned off during aerial image capture in IR light.

Effect of trial lenses: Trial lenses, or in general any correction system (i.e. Badal optometer) that changes ray convergence to optimize retinal focus, may have an effect on the measured spherical aberration. We measured one subject (S4) with his uncorrected eye and with a trial lens (-5 D) in front of the eye. The converging effect of the lens introduces a scaling in the sampling pattern, which was corrected by the software controlling the scanner. We could not find significant differences in the aberrations measured with and without the trial lens.

Data handling and selection

Special care was taken in the processing of data from eyes wearing CLs, since they were subject to problems not present in the natural eyes (lens movement or partial pupil covering by the eyelid). We rejected aerial images with CL edge effects patterns. The presence of more than three diffraction-like patterns of adjacent rays was a cause to reject the whole series, as we suspected the lens or the subject had moved. More than four images rejected for any reason caused the rejection of the whole series, which was not used in further processing. This happened in 17 out of a total 45 number of series. In very exceptional cases (3 out of 28) we found that the wave aberration corresponding to an apparently normal series of images, was very different from the rest of consecutive runs. These abnormal patterns were rarely or never repeated, and we interpreted that they corresponded to unstable positions of the CL or CL shift during the measurement. These abnormal modes usually had also an abnormally high amount of coma and/or astigmatism. All of the aberration estimates presented here were calculated at least from the mean of three series.

3. Results

Figure VI.1 shows wave aberration maps for all four subjects. For each subject we show the four measurements performed: total and anterior surface aberrations, with and without CL, respectively. Anterior surface aberrations stand for aberrations of the anterior corneal surface for the eye without CL, and aberrations of the anterior surface of the lens when the eye is wearing the CL. Defocus has been removed in all cases. For each subject, the four upper maps include all aberrations except tilt and defocus, and in the four lower maps astigmatism has also been removed. To show the effect of CL wear, we have used the same gray scale for anterior surface and total aberration maps for the same subject. Contours have been plotted at 1 μm intervals. Pupil size is 5-mm in all cases.

For each subject, the four upper maps include all aberrations except tilt and defocus, and in the four lower maps astigmatism has also been removed. Contours have been plotted at 1 μm interval. Pupil diameter is 5 mm in all cases. The RMS (in microns) is indicated for each wavefront. In many cases, and most obviously for S1, the number of contour lines is lower with the CL, indicating a correction of the natural aberrations by the CL. Not only astigmatism decreases (see upper maps), but also higher order aberrations. We found an increase of aberrations with CL only for S4, whose natural aberrations were very low. While the amount of aberrations decreases in most cases, the aberration pattern with CL follows a pattern similar to the natural wave aberration. This is indicative of some degree of conformity. There is a strong similarity between total and anterior surface wave aberration maps in all subjects and conditions.

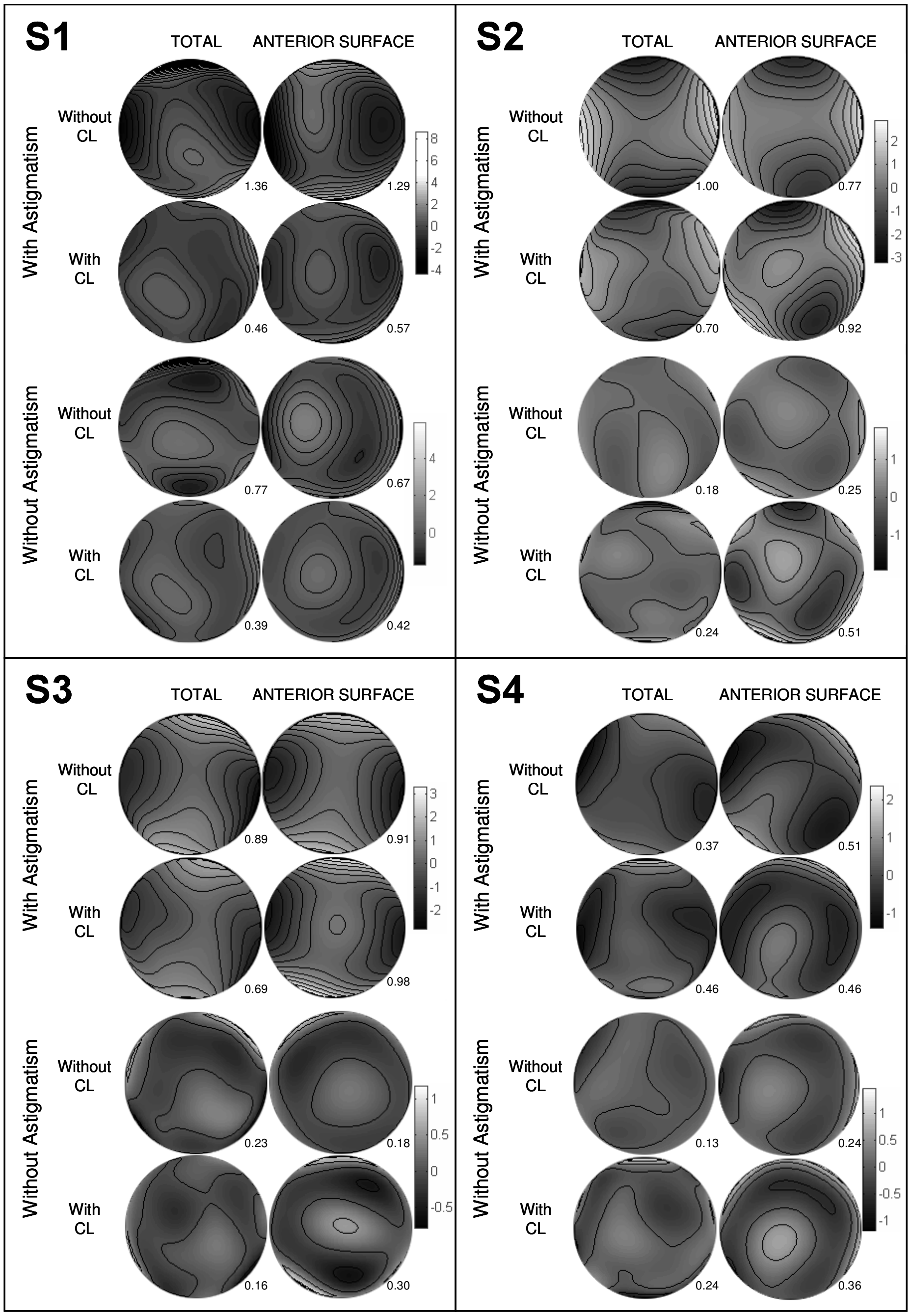

Figure VI.1: Wave aberration maps for all subjects. For each subject we show the four wavefronts measured: total (left panel) and anterior surface (right panel), with and without rigid gas permeable contact lens (RGP CL). Anterior surface aberrations stand for aberrations of the anterior corneal surface for the natural eye, and aberrations of the anterior surface of the CL when the eye is wearing the CL.

Figure VI.2 compares Zernike coefficients for two representative subjects (S1 and S3). S1 (Figures VI.2a and VI.2b) is the subject with the highest amount of aberrations without CLs, and highest degree of compensation with RGP CLs. S3 (Figures VI.2c and VI.2d) has high astigmatism but low high order aberrations. The ordering and notation of the Zernike coefficients follows the recommendations of the Optical Society of America Standard Committee[6]. For subject S1, total astigmatism (terms 3 and 5) is well corrected, but there is also a large reduction of 3rd and higher order aberrations –see for example coefficient 12 (Z_4^0) and 13 (Z_4^{-2}) in Figure VI.2a–. All the most significant anterior surface aberration coefficients are also largely reduced, with the exception of spherical aberration (Z_4^0): astigmatism, terms 3 (Z_2^2) and 5 (Z_2^{-2}) and comatic term 8 (Z_2^{-1}) in Figure VI.2b. There is a good correspondence between total and anterior surface aberrations (Figures VI.2a and VI.2b). S3 shows an aberration pattern dominated by astigmatism (almost as high as S1), practically all corneal in origin, as indicated by the great correspondence of total and corneal aberrations (Figures VI.2c and VI.2d). Spherical aberration is the predominant high order aberration of the cornea, but not of the whole eye. In this subject we found only a small correction of aberrations by the RGP CL.

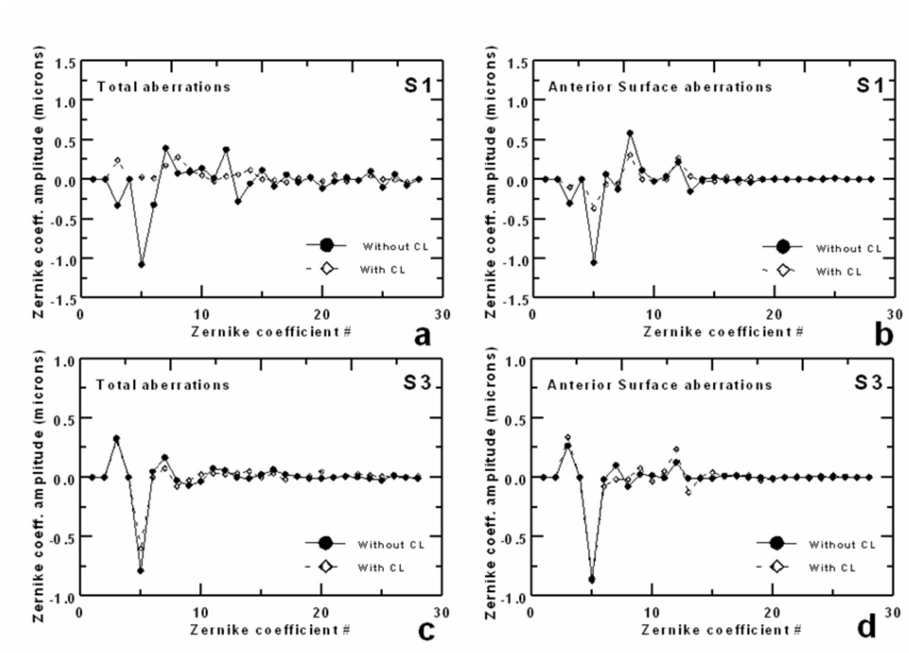

Figure VI.2: Zernike coefficients for subjects S1 and S3. (a) Total aberrations with and without CL for S1; (b) Anterior surface aberrations with and without CL for S1;(c) Total aberrations with and without CL for S3; (d) Anterior surface aberrations with and without CL for S3.

Figure VI.3 summarizes the effect of RGP CLs on total aberrations (RMS) for different orders of the Zernike polynomial expansion, for all subjects. Figure VI.3a shows RMS for all terms, excluding tilt and defocus.

The CL significantly corrects part of the ocular aberrations in three of our four subjects. RMS decrements range from 0.9 μm in S1 to 0.2 μm in S3. For subject S4 there is a slight increase in RMS (0.09 μm). This value is of the order of the RMS variability (0.11 μm for this subject), and therefore it is not statistically significant. This subject has a low amount of aberrations, and internal optics RMS (0.37 μm) is comparable to corneal RMS (0.51 μm). Anterior surface aberrations decrease however (RMS 0.51 to 0.46) with CL wear.

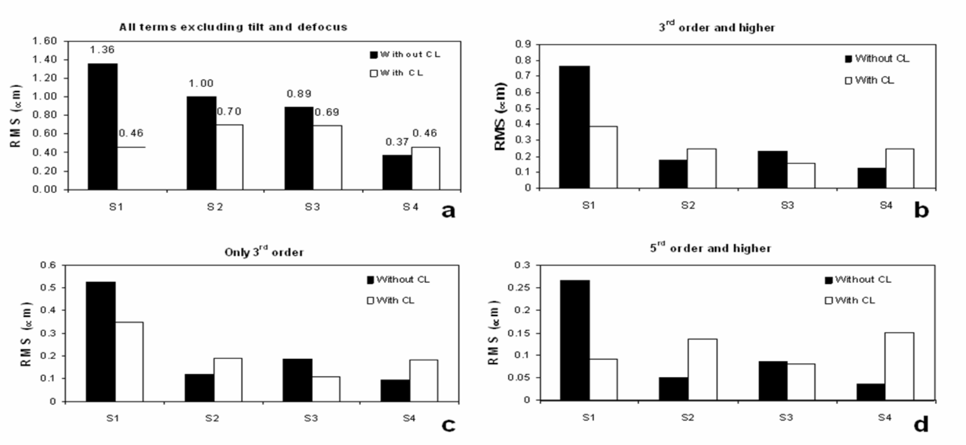

Figure VI.3: Effect of RGP CLs on total RMS for all subjects. (a): RMS for all terms, excluding tilt and defocus; (b) RMS for 3rd and higher order.terms (c): RMS for 3rd order terms; (d) RMS for 5th and higher order terms.

Figure VI.3b shows RMS for all terms of 3rd and higher order. These terms account for all aberrations that cannot be corrected with conventional ophthalmic lenses.

Figure VI.3c shows RMS for Zernike coefficients of 3rd order only, i.e. coma-like aberrations. Figure VI.3d shows 5th and higher order aberrations. Subject S1's natural optics shows high amount of aberrations in all orders, and there is a reduction of aberrations in all orders with RGP CL wear.

All other subjects have a low amount of aberrations without CL, other than astigmatism, and the use of CLs does not change them significantly. The effect of RGP wear on 5th and higher order terms (Figure VI.3d) shows different trends across subjects: a decrease for S1, no difference for S3, and an increase for S2 and S4. Increase in the 5th and higher order terms is curiously found in the same subjects who experienced an increase in 3rd order terms and more systematic decentrations of the RGP lens. A possible increase of 3rd and higher order terms due to decentrations had been predicted[3, 7] although this effect has proved more relevant for aspheric lenses.

Figure VI.4 shows total and anterior surface 4th order spherical aberration coefficient (Z^0_4) for the different subjects, with and without CL.

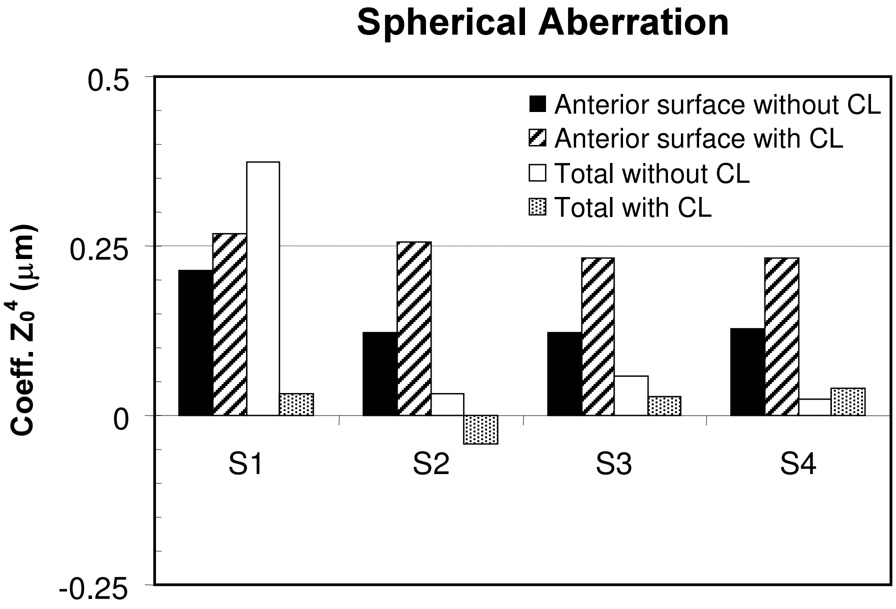

Figure VI.4: Total and anterior surface 4th order spherical aberration coefficient (Z^0_4) for the four subjects, with and without CL.

As expected, despite intersubject differences in the amount of spherical aberration in the natural corneas, we obtained the same amount of spherical aberration for all lenses (increased with respect to natural values because the lenses were spherical). However, the total spherical aberration with CL is close to zero for all subjects.

4. Discussion

Aberration correction

The principle of correction of corneal irregularities (and hence corneal aberrations) by RGP CLs has been explained by several authors[2, 3]. The CL substitutes the anterior surface of the cornea with a polished regular surface. The main refraction is now produced at the anterior surface of the CL. Tear between lens and cornea fills in corneal irregularities. The power of the anterior surface of the cornea decreases to 11 %, as refraction indexes are almost the same (n_{tear} = 1.336, n_{cornea}=1.376). Therefore, the CL correction acts on corneal aberrations. We have found that RGP CLs are able to correct to some extent ocular aberrations. For the most aberrated eye, we found a decrease of RMS (excluding tilt and defocus) by a factor of 3 (or RMS decrement of 0.9 µm). The improvement is not only due to astigmatism corrections. Non conventional aberrations were also significantly reduced: 3rd and higher order RMS decreased by a factor of 2 (a decrement of 0.38 µm). Interestingly, total spherical aberration was close to zero, despite the spherical surfaces of the CL.

These results are comparable to the best case reported by Hong et al.[5] (RMS decreasing from 0.5 to 0.14 µm), who compared the impact of RGP CLs, soft CL and spectacles on the ocular aberrations. This degree of compensation is close to that achieved by some custom correction methods, which aim at correcting not only corneal but the whole optical system aberrations. Navarro et al.[8] reported an increase by a factor of 5 (RMS decrease from 1.25 to 0.25, for 6.5-mm pupils) using static correction by custom phase-plates. Preliminary results with custom CLs show a decrease in RMS from 0.83 to 0.35, for 5 mm pupils[9]. In addition, the first outcomes of custom refractive surgery show variable results[10, 11]. A decrease of the RMS from 1.5 to 0.2 µm for 6.8-mm pupils have been reported using dynamic corrections with adaptive optics[12, 13]. These findings may have some implications in myopia management and control. Several clinical trials[14, 15] have found that children wearing RGP CL had a slower myopia progression than other age- and refraction-matched groups wearing glasses or soft CLs. The differences could not be explained by corneal flattening in RGP CL wearers. Degraded vision with occluding diffusers (and conceivably with an increased amount of aberrations) has been linked to myopia development both in animal models and humans. A better optical quality with RGP CLs may be one of the causes for this apparent slow in myopia progression.

The major limitation of aberration correction with standard RGP CLs is that it is restricted to anterior corneal surfaces aberrations, while the previous methods aim at canceling all aberrations. We have found that the amount of aberration corrected depends on the subject initial aberrations, and in particular, whether the ocular aberration pattern was dominated by corneal aberration, or rather the internal aberrations played a significant role.

Measuring anterior surface and total aberration allows, by subtraction, to account for the contribution of internal aberrations to the ocular optics. Previous studies have applied these comparisons to study the interaction of the aberrations of the different ocular components as a function of age[16], refractive error[17] or in refractive surgery[18]. It appears that in young, normal eyes, there is an important degree of balance between corneal and internal aberrations. The measure of anterior surface and total aberrations in patients with and without RGP CLs allowed us for the first time to evaluate the interactions of the ocular components (including the internal optics) with RGP CLs and understand the performance of this type of lenses individually.

From our subjects (see Figures VI.1 to VI.3), S1 had the greatest amount of corneal aberrations (RMS=1.29 μm, including astigmatism) and the ocular aberration pattern was dominated by corneal aberrations. This is the most favorable case to achieve a good aberration correction with CLs and explains the excellent outcomes for this subject. Subjects S2 and S3 have low internal aberrations (RMS= 0.42 μm, 0.3 μm, respectively) but only moderate corneal aberrations (RMS=0.77 μm and 0.91 μm), and therefore the correction is not so remarkable. Subject S4 had very low corneal aberration (RMS= 0.51 μm), which are partially compensated by internal aberrations (RMS=0.37 μm), producing very low total aberrations (RMS=0.36 μm). In this case, aberration correction was not achieved despite the fact that anterior surface aberrations decreased by the RGP lens (from 0.51 μm to 0.46 μm).

Our study demonstrates that internal optics limits the aberration correction by the use of RGP CLs. However, in those subjects with predominant corneal aberrations, corrections can be of the same order as those achieved by custom devices. This is particularly relevant in those cases where increased aberrations limit visual performance, such as pathological or surgical corneas. All previous studies of aberration compensation made use of customized optical elements, subjects with increased aberrations by corneal pathology, or specially manufactured CLs, while we have studied normal subjects wearing their own standard spherical RPG CLs.

It may be argued that the subjects in our study may not be considered normal, since it is well known that long term RGP lens wear can alter corneal shape and induce corneal warpage and distortion[19]. If that was the case, the potential benefits of RGP CLs to improve the optical quality may be overestimated. We compared 3rd and higher order corneal aberrations in our four subjects with a population of other 38 normal young (31 ± 7 years) myopes (–4 ± 2.2 D), measured using the same procedures. For this control group, 3rd and higher order corneal RMS was 0.57 ± 0.2 μm. This value was close to the RMS (0.67 μm) for the most aberrated subject S1 in our study, which had been wearing

RGP CLs for more than 10 years. Corneal aberrations in the other three subjects were lower than 0.25µm as seen in Figure VI.1. Therefore, the results found in the study are not necessarily unique to this particular set of subjects, and most subjects from the control group could potentially benefit from a reduction of aberrations by RGP CLs.

In this study we have shown the application of combined measurements of aberrometry and corneal topography in RPG CL fitting. By using this methodology, we have been able to evaluate the contribution of the anterior surface of the RGP CL and the internal ocular optics on the optical performance of eyes wearing RGP CL. This information provides an accurate analysis of CL fitting in individual eyes, and allows, for example, to track individual aberration terms through the different optical elements involved (contact lens, cornea, internal optics).

We have shown that RGP CLs can improve significantly the natural optics of the subject, provided that corneal aberrations are predominant, and the lens flexure is well controlled. As there is previous evidence that internal aberrations usually compensate to some extent the aberrations of the cornea[20], we conclude that a custom control on lens flexure can improve the cornea/internal optics aberration ratio and result in an improvement of the subject's visual performance.

Finally, we have shown that spherical RGP CLs do not induce higher final spherical aberration on the eyes measured. While the anterior lens surface shows higher spherical aberration than the natural cornea, we found negligible values of total spherical aberration in all our four subjects wearing their RGP CLs.

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