

Wavefront Technology – Part 3

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Optimal Eye Correction. Supervision? Possibilities and constraints with contact lenses. John de Brabander is Senior Lecturer at the University of Maastricht, the Netherlands. His teaching and research assignments involve all aspects of measuring the human visual system in relation to diagnostic procedures and optical correction. For the first two articles in this series, John received the Global CONTACT Award 2004 in October this year.

Summary

In this series of articles we describe some of the backgrounds and history of wavefront technology as it is used in various optical applications. The first article (Global Contact 2004;36:32-4) described some of the basic concepts of wavefront technology. In the second article (Global Contact 2004;37:44-9) the principles behind measuring the eye in classical ways and with an aberrometer are described. Also, the ideas and the practical (clinical) use of the now globally accepted convention to describe wavefront aberration in the eye by the so-called Zernike terms were described.

In the present article the possibilities of correcting the eye for higher order aberrations especially with contact lenses is further explored. The question is asked what the theoretical possibilities are to improve human vision with the extra correction of higher order wavefront aberrations. Are we able to create something like supervision? What constraints are there in the production and application of contact lenses?

The series of articles is not specially written for scientists, clinicians or technicians. Our primary aim is to provide some basic understanding on the subject for all that are involved in the area of contact lenses. For more in

depth study of wavefront technology we give at the end of this article a list of recommended literature.

The future of measuring the eye is aberrometry and it is near!

Place a point light source at the retina. Let the light come out of the eye. Image it using a Shack-Hartmann micro lenslet array and a CCD sensor. This way we can reconstruct the wavefront coming out of the eye. This is the principle of a modern

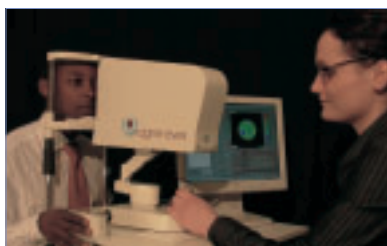


Fig. 1. A modern aberrometer is a small and easy to use device. Photograph of a prototype device, courtesy of Dr. N. Chateau, Imagine Eyes, Orsay, France.

aberrometer (Fig. 1).

Although these devices are at present expensive and used primarily for research and to some extent in refractive surgery, within some years it is estimated that they will become a new standard in objectively measuring the eye.

By subtracting the wavefront

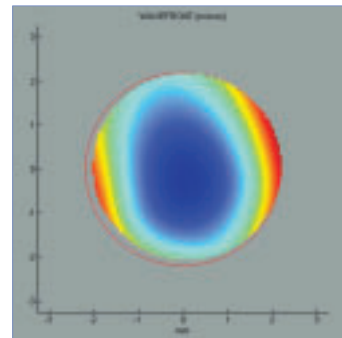


Fig. 2a.

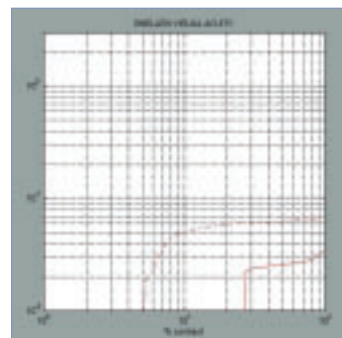


Fig. 2b.

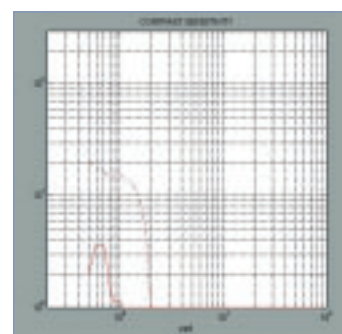


Fig. 2c.



Fig. 2d.

Fig. 2. Aberrometry on a keratoconus eye. (a) wavefront aberration map, (b) predicted VA, (c) predicted CSF, (d) predicted retinal image.

that comes out of the eye from an ideal flat wavefront (representing perfect emmetropia) we could gain a map of all optical aberration of that particular eye (Fig. 2a). The system to specify the →

optical aberrations and thus also to specify the needed correction is the Zernike polynomial system as explained in the articles before. Research using aberrometry has confirmed that this measuring system not only extends the information on the optical properties of the eye but that it also provides us with a better understanding of the clinical



Fig. 3. Eagle eyes?

consequences of these optical aberrations. From wavefront aberration

... We can improve visual acuity substantially ...

measurements, it is possible to predict the patient's theoretical visual acuity (VA Fig. 2b) and also the contrast sensitivity function (CSF Fig. 2c). One can also visualize the retinal image for a patient observing certain opto types like an E (Fig. 2d).

The Optical Society of America (OSA) has already been involved in

setting standards for the description of optical aberrations of the eye using the Zernike system. Scientifically this is all very sound. It seems, therefore, almost sure that aberrometers will in the near future replace the today widely used auto refractors. For the contact lens industry it is important to be prepared!

Supervision? Idea or reality? Some theoretical concepts and limitations

If we were able to correct all optical aberrations of the eye, we would end up with a perfect optical correction. Would such a perfect optical eye correction also imply supervision? Can we supply mankind with eagle eyes in all cases (Fig. 3)?

It seems very simple. Measure all the optical aberrations of the eye and

by some means provide a perfect correction. Until now, in normal practice we have achieved the best result by applying a spherical, a cylindrical, or a combination of both a toric optical correction. For this we can use spectacles, contact lenses, refractive surgery or implants.

When you recall the Zernike theory as explained before, these corrections used in daily practice are up to the second order.

These are also called lower order aberrations, specifically defocus and

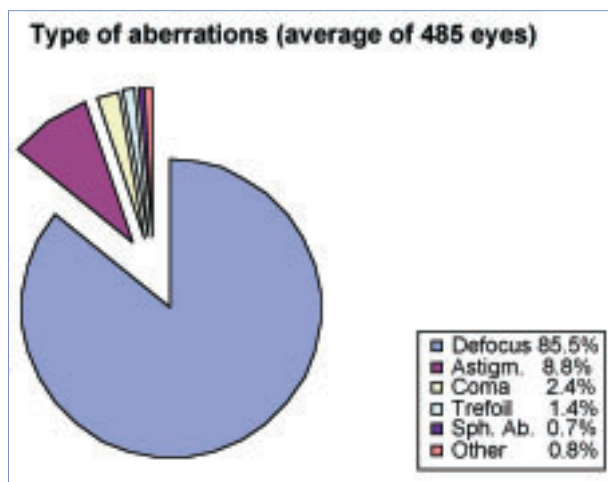


Fig. 4. Distribution of aberration in a group of children age 12 years.

providing lower order optical corrections using simple spectacles. Contact lenses sometimes do even better. The question is, can we surplus visual function by a planned incorporation of higher order aberration correction in a contact lens? Now it becomes complicated.

Retinal image quality, visual quality and eye dynamics

Wavefront technology is widely used to enhance image quality e.g. in pictures of outer space objects in astronomy. Usually this is done by placing a special wavefront-correcting device in the optical system. This device consists of many small mirrors that can be placed at any angle. This way we are able to correct the local slopes of the light rays that make up the wavefront. Such a system can optimize the wavefront, and thus enhance image quality and is therefore called adaptive optics. The results with adaptive optics systems are very convincing, image quality can be enhanced manifold, and details that originally were obscured become clearly visible. If we used adaptive optics systems with the eye and compute the theoretically resulted enhancement in VA, we would indeed end up with supervision. VA would be enhanced to something like 3.0 compared to the normal 1.0. This is the background of the story on getting eagle eyes.

However, for the eye it is not true. It is not even true theoretically.

... VA of 2.0 is the limit for the resolution that can be reached...

astigmatism. Lower order aberration sounds like "it helps but is far from optimal." This is not entirely true, since in a normal eye the lower order optical aberrations account for the larger part of the ametropia (Fig. 4). We can, therefore, in normal cases improve visual acuity (VA) substantially by

For this there are three main reasons. First: the eye is not a static perfectly aligned optical system, second: the eye is not a stable optical system, and third: the eye sensor (retina and brain) is not something like a CCD camera system with standard software. In this article we can only briefly explain some of the

backgrounds. For detailed information we refer to the list of very good articles written by leading vision scientists.

By "the eye is not a static optical system" we refer to the changes in the wavefront aberration that take place with the dynamics of pupil size and accommodation. With pupil constriction or dilatation not only the diameter changes but also there is an individually based translation of its centre. The same accounts with accommodation, not only the optical power of the eye lens changes but also its position. The problem is that these changes are not systematic, but vary within cases even between eyes of the same patient.

By "the eye is not a stable optical system" we mean that the optical aberrations change with age, probably even during the day. So, the situation that represents the ideal and perfect correction today might become doubtful in some years.

Last, but in this case not at all least, is the fact that the sensor we use to see is not at all comparable with sensors that are used in optical imaging. Next to some inherent limits in the optics of the eye, also our retinal processes and our brain do things that are broadly known today but are also not very predictable. A simple limit to supervision is the size of our sensors in the retina. Given the average size of a retina receptor, a VA of 2.0 is the limit for the resolution that can be reached.

So, the idea of supervision only accounts for the theoretical gain in the enhancement of the retinal image quality given a static and stable optical system. As you can appreciate from our brief explanation, visual quality is something entirely different. I am sorry

... can we provide supervision?

to say that the promise of providing patients with supervision is more like

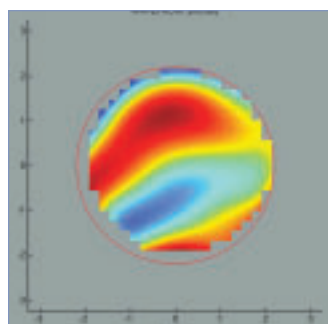


Fig. 5a.

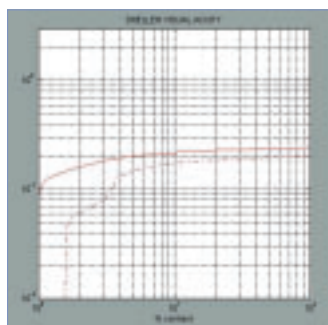


Fig. 5b.

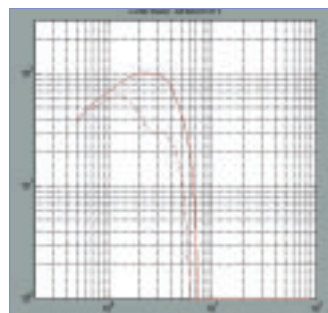


Fig. 5c.

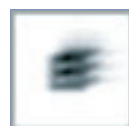


Fig. 5d.

Fig. 5. Aberrometry on a keratoconus eye with spectacle lens correction. (a) wavefront aberration map, (b) predicted VA, (c) predicted CSF, (d) predicted retinal image.

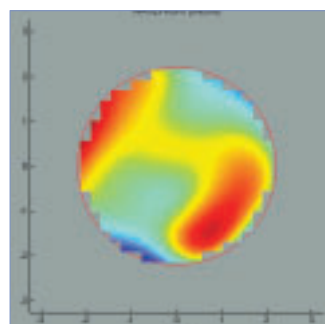


Fig. 6a.

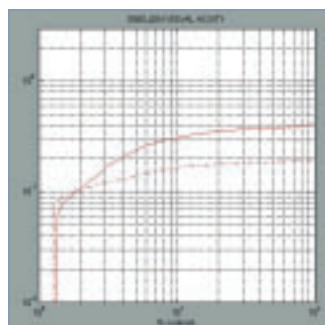


Fig. 6b.

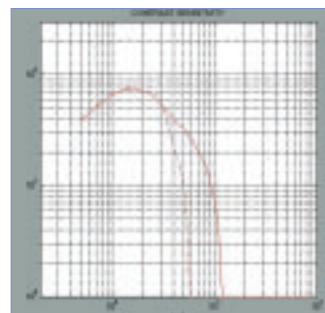


Fig. 6c.



Fig. 6d.

Fig. 6. Aberrometry on a keratoconus eye with spherical RGP correction. (a) wavefront aberration map, (b) predicted VA, (c) predicted CSF, (d) predicted retinal image.

advertising than scientifically sound.

Correction of higher order aberrations?

We could produce a spectacle lens incorporating a correction for all aberrations of the eye. It would optically be a very strange lens but it would enhance the retinal image. However, the patient's eye must

the spectacle lens would immediately degrade the perfect image. Since the spectacle lens is placed at some distance to the eye (vertex) the effects on induced aberrations by a change in fixation are dramatic. The best we can do with spectacle lenses is to only integrate lower order aberrations (sphere and cylinder). In Figs. 5a-d we show the results of wavefront measurements with spectacle lenses for the same eye as depicted in Figs. 2a-d but now wearing a spectacle lens. As you can see the result is not very good.

With spherical rigid contact lenses →

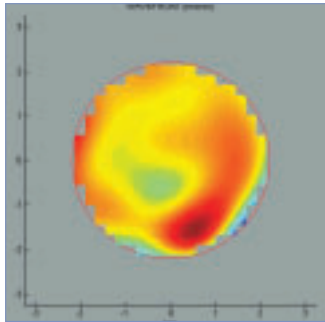


Fig. 7a.

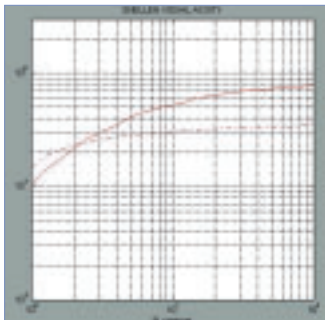


Fig. 7b.

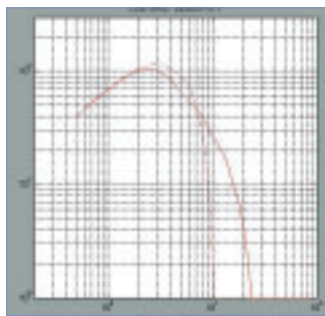


Fig. 7c.



Fig. 7d.

Fig. 7. Aberrometry on a keratoconus eye with toric RGP correction. (a) wavefront aberration map, (b) predicted VA, (c) predicted CSF, (d) predicted retinal image.

the situation has been much better since the contact lens, given that it centers at the cornea moves with the eye (Figs. 6a-d). If we apply a toric RGP lens to the same eye the situation improves significantly (Figs. 7a-d). High contrast VA with this lens becomes normal (Snellen VA 1.0). Typically, visual function could be further enhanced by correcting the most important remaining higher order aberrations. This would apart from further improvement of the retinal image (Fig. 8a) also bring the contrast



Fig. 8a.

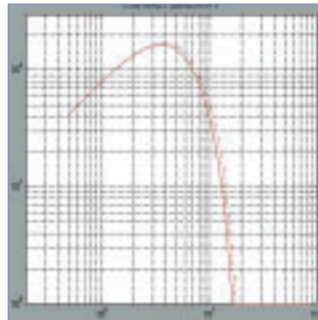


Fig. 8b.

Fig. 8. Predicted retinal image (a) and contrast sensitivity function (b) for a keratoconus eye with a stabilized contact lens including most higher order aberrations.

sensitivity function up to a normal level (Fig. 8b). This series of pictures looks spectacular. So can we provide supervision?

No, in this case the eye was suffering from keratoconus, which means that severe optical aberrations were present at the cornea. First, in these cases a correction for wavefront aberrations is very useful and brings the eye to normal VA, not supervision but as you can imagine for this patient it would be super! Second, we have measured the wavefront aberration in an average well-centered position of the contact lens. Contact lenses do and must move with the blink and they also rotate on the eye. Rigid contact lenses move more than soft lenses. So, to correct higher order aberrations (like in Figs. 8a, b) soft contact lenses are favored over rigid contact lenses. The effects of translation and rotation on degradation of an ideal correction is shown in Fig 9. From research we have found that in severe aberrated eyes like in keratoconus, translations of more than 0.5 mm can degrade the retinal image such that the gain in visual function is lost again. Rotation is less critical, 10 degrees is acceptable. This means that for a complete correction of higher order optical aberrations, the

contact lens must also be designed such that optimal stabilization on the eye can be reached. This combination asks for a fully customized contact lens.

The technical elements to produce such contact lenses are here today. Question is who puts them together such that finally the patients can benefit?

Conclusions

Optical aberration of the eye can be measured with devices that within some years will replace auto refractors.

With the Zernike system we are able to mathematically describe the wavefront aberrations of the eye.

Using the Zernike system also the optical design of a corrective contact lens can be described and with modern lathe techniques it is possible to produce such lenses.

This type of contact lenses must optically be custom made.

Since stabilization of the contact lens is crucial, the geometrics of the contact lens must also be custom made.

There is a technical problem in the metrology of such lenses.

Supervision is an illusion. However, with wavefront technology we have a potential tool to provide patients with severe optical (mostly corneal) defects with optimal retinal image quality.

Correcting higher order optical aberrations by contact lenses is no longer "exotic"; it is a challenge to that part of the contact lens industry that focuses on custom made solutions for visual problems.

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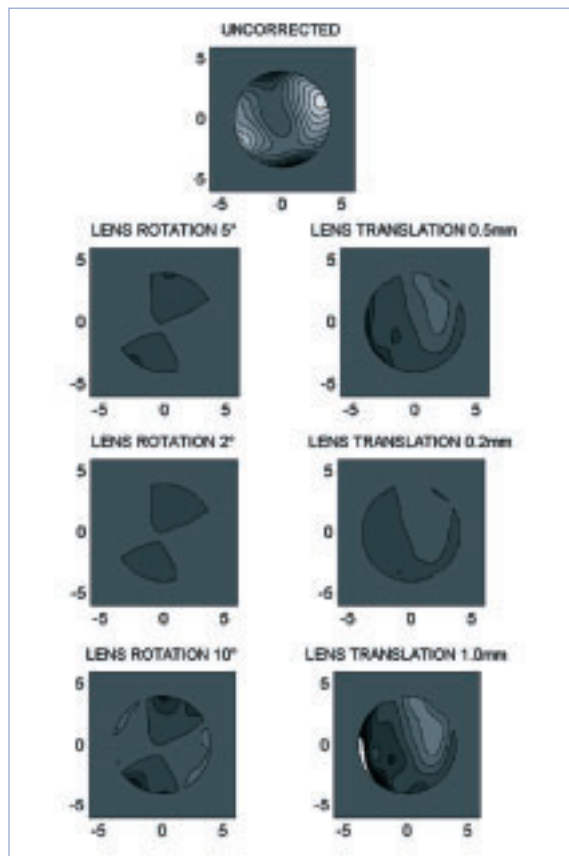


Fig. 9. Effects of translation and rotation on a theoretically perfect contact lens correction in severe keratoconus