Fingerprinting the eye

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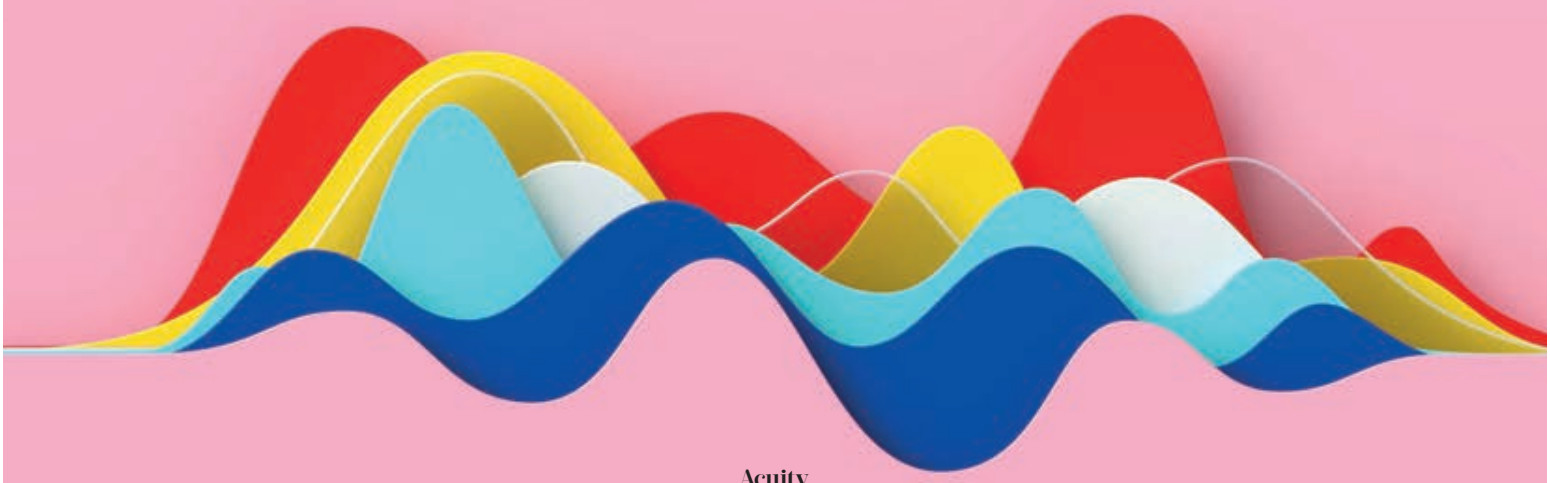
FINGERPRINTING THE EYE

Adrian O'Dowd asks if the growing use of topography in community optometry will lead to wavefront analysis gaining traction as a complementary tool.



Lower-order aberrations (LOAs) such as myopia (positive defocus), hyperopia (negative defocus) and astigmatism are well known to optometrists, but more subtle and complex refractive errors, known as higher-order aberrations (HOAs), require a different approach to diagnosis and correction.

HOAs are changes to the waves of light as they pass through the optical structures of the eye (tear film, cornea, aqueous, lens and vitreous humour). All eyes have some form of HOA but, in some cases, they result in clinically significant changes, resulting in a less than perfect image being perceived. The aberrations can affect a person's contrast sensitivity and sharpness and cause changes in magnification and focus. Examples include coma, spherical aberration and trefoil. Symptoms of these aberrations can include blurred vision, difficulty seeing at night, double vision, ghost images and halos.

Optometrists can map these HOAs using wavefront analysis carried out with specialised aberrometers, as explained below. The technology of wavefront mapping makes custom laser eye surgery possible because it precisely measures and maps the optical system's aberrations (Herz et al, 2010). Zernike polynomials are used to classify and represent HOAs as their orthogonal shape allows them to mathematically cover the entire open unit disc of the eye (see Figure 1).

HOW ABERROMETERS WORK

A corneal wavefront aberrometer accurately records data taken from several points across the surface of the cornea to produce a map of the imperfections on the corneal surface, allowing a partial analysis of the visual system. Different aberrometers measure different numbers of points,

ranging from as low as 60 to as high as 40,000. The higher the resolution in the analyser, the sharper the image, as it will contain more data.

Professor Dan Reinstein, Consultant Ophthalmic Surgeon at the London Vision Clinic, says: "The wavefront could be described as a fingerprint of the eye as it is almost impossible for two eyes to be identical at this level of detail.

"Using wavefront aberrometry allows the surgeon, undertaking refractive surgery, to decide if a patient might benefit from a wavefront-guided laser eye surgery treatment, which aims to improve on the optical imperfections of the eye, beyond what glasses alone can correct. The information mapped by a wavefront aberrometer can be fed into the refractive laser to achieve better results. Wavefront technology can also detect certain eye conditions [such as keratoconus] that would preclude a patient from getting an optimal laser eye surgery result."

STANDARDS AND SYSTEMS

Findings are produced by optical systems using three separate methods and can be divided into three clinically available categories of aberrometers (Wong and Petito, 2018):

- Outgoing wavefront aberrometers (such as the Hartmann-Shack wavefront sensor)
- Ingoing retinal imaging aberrometers (such as the Tscherning aberrometer and the Tracey retinal ray tracing)
- Ingoing feedback aberrometers (including the Marco/Nidek Optical Path Difference (OPD)-Scan III).

Differences between these devices include measurement speed, refractive error range and display options.

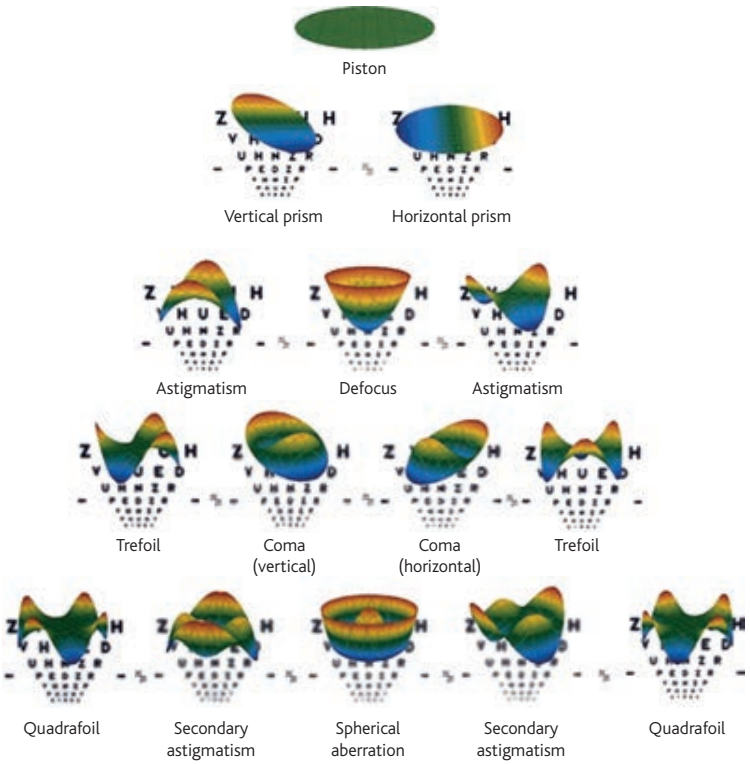
The most common method used to measure wavefront aberrations is a device based on the Hartmann-Shack principle. A Hartmann-Shack aberrometer sends a focused beam of light into the eye, from which the device's series of tiny lenses (lenslets) refract the reflected wavefronts exiting at the pupil plane. The lenslets focus the exiting wavefronts onto a highly sensitive charge-coupled device (CCD) sensor, then produce images that take the form of multiple, minute spots. The device's software then processes the image's pattern to reproduce the approximate shape of the wavefront using Zernike polynomials or sometimes Fourier transformations.

Dr Amit Jinabhai MCOptom, Senior Lecturer in Optometry at the School of Health Sciences at the University of Manchester, says: "I think the technology in this field could be developed further – for example, the very latest measurement technique makes use of a sophisticated prism, which improves the number of sampling points and resolution. This device is more commonly known as a pyramidal aberrometer.

"This technique is based on the four-sided oscillating pyramidal prism design that was first proposed for use in the field of astronomy [Ragazzoni, 1996]. The latest pyramidal aberrometers can analyse over 40,000 points across a maximum pupil diameter of 9mm, at a rate of approximately 30 images per second, and can provide an astonishing resolution of around 45µm.

"The original Hartmann-Shack aberrometer pioneered in 1994 could only evaluate 225 points in the pupil plane [Liang et al, 1994]. It is likely that the four-sided prism within the pyramidal aberrometer could be developed further, which might potentially allow further improvements in both sampling points and resolution – so it is a case of 'Watch this space.'"

Figure 1: Higher-order aberrations



WAVEFRONT BENEFITS

Wavefront aberrometry is a useful tool when identifying and managing various corneal conditions as well as for evaluating patients for soft multifocal contact lenses (Wong and Petito, 2018).

Although wavefront analysis may not seem that useful to correct refractive problems for most optometrists, its potential to be helpful is still important, according to Amit.

"The vast majority of patients' refractive problems will simply be due to spherical and/or cylindrical errors, which are satisfactorily correctable using long-standing methods such as contact lenses and spectacles. So, for these patients, wavefront analysis serves very little purpose," he explains.

"However, optometrists do on occasion evaluate symptomatic normal, healthy patients who complain of significant and problematic halos, glare and/or ghosting at night, even while wearing the correct contact lenses/spectacles, or examine patients who have previously undergone some unsuccessful form of refractive surgery procedure.

"It is in these sorts of cases that aberrometry measurements could prove to be useful in potentially exploring what is causing the patient's symptoms."

In addition, optometrists who are managing patients with corneal diseases such as keratoconus could find wavefront aberration measurements useful, he continues, as this condition induces HOAs even in the very early stages (Bühren et al, 2007) and certain aberrations can continue to increase as the disease progresses.

Fitting these patients with rigid gas-permeable or scleral-type contact lenses can help to reduce the scale of their manifest HOAs, thus improving the patient's optical quality beyond what could be achieved with spectacles or soft toric contact lenses, but the correction of such aberrations is only quantifiable using an aberrometer with the appropriate software.

Another benefit of wavefront is in the correction of presbyopia using spherical aberration to increase the depth of field.

The London Vision Clinic has developed Presbyond Laser Blended Vision – a surgical technique that uses an optimised ablation profile that controls postoperative spherical aberration so it increases the depth of field of each eye without significantly compromising visual quality, contrast sensitivity or night vision.

COMBINING ABERROMETRY AND CORNEAL TOPOGRAPHY

Stephen Hannan MCOptom, Clinical Services Director at Optical Express, is enthusiastic about the technology.

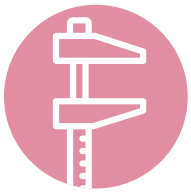
"HOAs can impact on quality of vision and are often linked to glare and halos that may cause night vision problems, which patients may seek to correct by the means of a surgical solution," he explains.

"In patients without corneal pathology, wavefront-guided laser eye surgery can provide a more regular shape to the cornea, reducing light scatter and symptoms of dysphotopsia."

Use of the computer-assisted diagnostic tool of corneal topography that creates a three-dimensional map of the surface curvature of the cornea is a well-established way of producing a detailed, visual description of the shape and power of the cornea (Medical Eye Center, 2018).

This type of analysis provides the professional with fine details about the

Get the most accurate wavefront information



Dr Amit Jinabhai MCOptom shares some tips for interpreting data from aberrometers:

- Ensure you are familiar with how HOAs vary with changes in the tear film between blinks, with "active" accommodation, and with increasing age.
- Always confirm the pupil size value before you begin to analyse any wavefront map, individual Zernike aberrations or root-mean-square (RMS) error data, as the magnitude of all aberrations is proportional to the patient's pupil size.
- Be wary of using the higher-order RMS error (HORMS) metric in isolation, as it is not very representative of visual acuity. Instead, look at metrics that are based on the visual Strehl ratio (VSX).
- In normal eyes, you should typically expect the fourth-order ocular spherical aberration term (Z4,0) to have a positive sign and higher magnitude compared with other terms.

IMAGES: GETTY

condition of the corneal surface that can then be used to diagnose, monitor and treat eye conditions as well as help fit contact lenses and plan surgery, including laser vision correction.

With thinning of the cornea (corneal ectasia) – the most common form being keratoconus – professionals can use wavefront aberrometry, corneal topography and medical imaging to detect and manage this problem (Wong and Petito, 2018).

Although wavefront aberrometers reveal the characteristics of the total optics of the eye, their value is restricted when considering patients' suitability for contact lenses because they do not provide information on the functional consequences of each specific optic location.

If aberrometry is combined with corneal topography and pupillometry, professionals can assess the alignment of the optical structures in the eye, as well as locate LOAs and HOAs in the optical pathway while analysing the effects of pupil size (Wong and Petito, 2018).

In addition, the larger diameter analysis of refractive error can aid a professional in their decision of which contact lens to choose during a patient's evaluation.

Similarly, for laser vision correction, the corneal topography map can be used with other tests to determine exactly how much corneal tissue will be removed to correct vision.

Other experts have argued that, for the best results with customised refractive surgery, a combination of wavefront and topographical analysis of the eye's optical errors is necessary (Donald, 2005).

COMMUNITY PRACTICE

Currently, the use of aberrometers in optometric practice is not that common, but the indications are that this could change, to the benefit of all.

Dan explains: "Most optometrists have had very little exposure to aberrometers and only a minority would be able to describe what the main HOAs are and what effect these may have on the vision.

"This will change once aberrometers become more widely used in routine optometric practice."

Wavefront analysis is relevant to community practice, insists Timothy Archer, Research Manager at the London Vision Clinic. "Measurement of HOAs is useful in general clinical practice as it provides an objective measurement of the irregularities in the optical system. This data can be evaluated alongside the clinical exam and help to diagnose the cause for visual symptoms that a patient may be complaining of."

> HOAs are linked to glare and halos that cause night vision problems

The advantages of wavefront analysis to community practice are real, argues Stephen. "I see this becoming more commonplace in community optometry practices," he says. "It is a form of technology, like topography, ocular coherence tomography [OCT] and wide-angle fundus cameras that will become the standard of care in the not-too-distant future."

Amit says: "If the practice's patient base is typically comprised of straightforward, non-symptomatic patients that only require regular spectacles, contact lenses, clinical monitoring or onward referral, then I would argue that an aberrometer is not really relevant and is unlikely to be used to its potential, such that its outlay cost might never be recovered by the practice.

"In my professional opinion, that practice would be much wiser investing in a more essential diagnostic device, like OCT, instead.

"However, if the community practice regularly serves more complex patients, for example those with keratoconus, or symptomatic postoperative refractive surgery patients whose treatment has been unsuccessful, then an aberrometer is extremely important."

DATA INTERPRETATION

Interpreting data from aberrometers is not necessarily straightforward for optometrists who may have had scant experience of it.

Amit says: "Optometrists could have difficulties in interpreting the data from aberrometers, partly because of some key information that they might not have come across in their training.

"For example, the magnitude of HOAs is directly proportional to pupil size. So the accurate correction of aberrations is rather challenging, as the dynamic human pupil is constantly fluctuating in its diameter.

"HOAs also change with variations in the thickness of the pre-corneal tear film in-between blinks [Mihashi et al, 2006]."

Nevertheless, Stephen is convinced that use of wavefront analysis in optometry will grow. "The data can be challenging to interpret initially," he says. "However, with appropriate training and increasing user experience it can really enhance your practice and the care you provide to your patients."

MEMBER RESOURCE

Analysis of HOAs in *Investigative Ophthalmology and Visual Science*: college-optometrists.org/analysis-of-HOA-journal