As techniques and technology evolve, cataract surgery has become a refractive surgery, with extremely high technical as well as visual expectations from both surgeons and patients.

Wave front aberrometry is the science of understanding optical imperfections within the eye. Although aberrometry is not new, particularly to refractive surgeons, its clinical applications are now being recognized more and more even to the comprehensive ophthalmologist and the anterior segment surgeon. This article describes in further detail and discusses aberrations, the science of measuring wave front aberrations and its clinical applications in day to day practice.

What is Wavefront
The wavefront is a line drawn perpendicular to all rays of light entering / exiting the eye (Figure 1). While it is a bit more abstract in the sense of understanding the light paths, it is simple than rays because many rays can be represented by a single wavefront surface. For a parallel beam, the wavefront would be a plane wavefront, whereas, for a converging beam, the wavefront would be spherical, as shown in (Figure 1). Any optical aberrations in the refracting surfaces of the eye, that is, the cornea, the lens or the retina, can cause a deviation of the wavefront from its ideal shape. A wavefront that deviates from its intended shape is called an aberrated wave front1.

What are Aberrations
Aberrations are defined as a departure of the performance of an optical system from the predictions of paraxial optics. Wave aberrations are defined as the difference between the actual aberrated wavefront and the intended wavefront (Figure 2). Simply put, they are refractive errors.

For better understanding, aberrations are classified into:

- Lower order aberrations
- Higher order aberrations

Myopia, hyperopia, and astigmatism are refractive errors that are referred to as lower-order aberrations. For most normal eyes, the main refractive errors are just these lower-order aberrations. The other more complex refractive errors besides sphere and astigmatism are called the higher-order aberrations. Of these, the most clinically relevant ones are coma, spherical aberration and trefoil. However, there are several other kinds of higher order aberrations. Zernike polynomials is a system that classifies wavefront aberrations into a pyramidal hierarchical system, with increasingly complex shapes as we go lower in the pyramid. Most eyes do not have only a single kind of aberration. The Zernike system breaks down these aberrations further into its component Zernike aberrations.

Further, aberrations can also be classified as being Monochromatic or Chromatic. However, today’s wavefront technology can only measure monochromatic aberrations.

Figure 1: Wavefront formed by light rays coming from a distance source. Spherical wavefront caused by the convex lens surface.
What are aberrometers

Aberrometers are devices that can measure ocular aberrations, both lower and higher order. Like autorefractors, aberrometers project light into the eye, reflect it off the retina, and analyze the light emitted from the eye. If the eye were perfectly aberration-free, the wavefronts exiting the eye would be perfectly flat. Any refractive errors present in the eye would cause distortions in the wavefront’s shape. If we can analyze the wavefront’s shape, then we can determine which aberrations are present in the eye. Currently, the aberrometers available work on one of the following principles:

a) Outgoing reflection aberrometry: Hartmann Shack aberrometry.

b) Retinal imaging aberrometry: Tscherning and Ray tracing aberrometry.

c) Double pass aberrometry (slit skiascopy).

This article will further describe principles and applications of Ray tracing aberrometry (iTrace).

**Principle of iTrace Ray Tracing aberrometry**

The iTrace uses patented Ray Tracing technology to evaluate the lower and higher order aberrations in the patient’s visual system. It sends 256 individual, consecutive laser spots – one at a time - into the entrance pupil and maps where each spot lands on the retina. This is different from other technology which sends in one beam of light and measures it as it exits the eye, making it very difficult to read highly aberrated eyes, pseudophakes, over spectacles, and so on. We can select each beam point-by-point and view it’s entry and landing position – therefore avoiding data confusion. The advantages with this system are that it gives multi zone refraction, and there is a rapid sequential measurement of data points over the entrance pupil. Further, the iTrace combines ray tracing technology with corneal topography. This allows the clinician to measure total eye aberrations based on ray tracing, as well as corneal aberrations based on topography. Subtracting corneal aberrations from total eye aberrations gives the internal aberrations of the eye, most of which arise from the lens (Figure 3).

**What data do we get from iTrace**

Most of us as cataract surgeons find aberrometry both confusing and daunting. Basically, the iTrace gives us refractive error for every eye. Apart from that, it also gives the following information:

- Optical quality metrics – such as modulation transfer function (MTF) and point spread function (PSF)
- Simulated vision of the patient

When interpreting the data from the machine, the surgeon should try to find out two main things – which aberrations does the eye have, and, how good or bad are these aberrations. The standard aberrometer printout will tell us how bad each individual aberration is. But sometimes we want to know how bad combined aberrations are. For example, how bad are the total aberrations of an eye? This is described as the root mean square (RMS) wavefront error. The RMS wavefront error describes the magnitude of combined aberrations for any combination. Using Zernike coefficients, it is easy to compute the RMS wavefront error using a mathematical formula. The total RMS tells how bad the aberrations are for all aberrations (higher and lower orders) combined. We can also calculate total higher order RMS, which tells the magnitude of just the higher order aberrations combined.
How do we make sense of the data

One of the most important factors when interpreting data from aberrometry is the pupil size. When the pupil is small, there is little spreading due to defocus or aberrations. Therefore, essentially, the eye becomes a diffraction limited system. The only predominant aberration is diffraction at the pupil margin. This becomes significant only if there is extreme pupillary miosis. On the other hand, when the pupil is of a larger size, which is usually the case in mesopic and scotopic conditions, although the diffraction is reduced, the aberrations play a greater role, and there is more visual blur. Therefore, looking at the pupil size at which the scan was performed is crucial. It is advisable to perform a scan in a dark room, so as to simulate mesopic conditions, and thereby have a better idea of the clinical impact of various aberrations on the patient’s visual function.

Clinical relevance of the iTrace in day to day practice scenarios.

Preoperative evaluation in case of a cataract

The iTrace gives us valuable information regarding the expected mesopic pupil size of the patient, as well as the aberration profile for the eye. Understanding photopic as well as mesopic pupil size is very important, particularly when planning multifocal IOLs.

Also, the advantage of this combined platform aberrometry is that it will tell us how much of the total ocular aberrations are from the cornea, and how much from the internal optics, mainly the lens. Particularly when any ‘premium’ IOLs such as multifocal or Toric are being planned, it is crucial to have a cornea that does not have significant higher order aberrations or irregular astigmatism. The topography display available allows the surgeon to evaluate both the magnitude and regularity of astigmatism.

Evaluating spherical aberrations of the eye

An average human cornea is prolate in shape, that is, it is steeper in the centre and flattens towards the periphery. This results in peripheral rays of light focusing at a point more anterior than those passing through the centre of the cornea. This is known as spherical aberration. The average cornea has some degree of positive spherical aberration. In a phakic eye, this is balanced to some extent by the crystalline lens. However, once a spherical IOL is implanted, the uncompensated spherical aberrations can give rise to deterioration in visual quality, particularly in mesopic conditions. Further, with different aspheric IOL platforms available today, they all have varying degrees of negative spherical aberration incorporated within them. Thus, knowing the patient’s spherical aberration prior to surgery is helpful in selecting the IOL type.

Evaluating angle alpha and angle kappa

Surgeons are realizing more and more the importance of evaluating angle alpha and angle kappa when planning cataract surgery. Angle kappa is the distance in mm between the visual axis (line of sight) and the center of the pupil at the corneal plane. Angle alpha is the distance in mm between the visual axis (line of sight) and the anatomical center of the limbus (Figure 4). Their importance is that when the surgeon places an IOL in the bag, it is usually centered over the limbus or the pupil. However, if the patient’s line of sight is further away from the center of the IOL optic, the patient may experience uncomfortable visual symptoms postoperatively. This becomes more important with multifocal IOLs as well as aspheric IOLs.

Evaluating ocular astigmatism

Refractive astigmatism is often the only form of astigmatism that the patient understands. However, there are two contributors to total refractive astigmatism, that is, corneal astigmatism and internal astigmatism. Performing an iTrace examination will help the surgeon differentiate whether the eye has significant corneal astigmatism, or internal alone, or a combination of the two. Also, it is useful to demonstrate to the patients and counsel them regarding different astigmatism correction modalities including limbal relaxing incisions (LRIs) and Toric IOLs.

Postoperative evaluation following cataract surgery

We all face dissatisfied patients inspite of a technically perfect outcome, and a documented Snellen’s visual acuity of 6/9 or 6/6. Often, in such patients performing in iTrace may show underlying higher order aberrations in the cornea which may have been missed in the preoperative evaluation. Not only is this data helpful for the surgeon to understand the cause of patient dissatisfaction, but also it can
help the surgeon to decide whether any treatment should be performed, including LRIs or laser vision correction. Further, any tilt or decentration of the IOL can also give rise to higher order aberrations, particularly coma. This can lead to distortion of the image which is not amenable to correction by glasses or contact lenses.

Thus, ray tracing aberrometry helps the cataract surgeon at all stages of patient care, right from preoperative evaluation, to monitoring postoperative performance and decoding unhappy patients. What is even more important, the technology is user friendly, precise and has made the understanding of a seemingly complex science easy and widely applicable.

References
1. Wakil JS, Padrick TD, Molebny S. The iTrace combination corneal topography and wavefront system by Tracey Technologies-In: Corneal topography in the wavefront era. SLACK Inc. 177-188.