Introduction
Optical aberrations are a major cause for poor quality of vision. It occurs when light from one point, after transmission through an optical system, does not converge to or diverge from a single point. Any deviation of the optical system from paraxial optics results in aberrations. In the eye, the various refracting surfaces like tear film, cornea and lens are primarily responsible for inducing ocular aberrations. The difference in shape of the wave-front entering the eye and that exiting the eye defines the type of aberration. The ocular aberrations are classified into lower order aberration (LOA) (zero order- piston; first order- horizontal and vertical tilt; second order- spherical defocus and astigmatism) and higher order aberrations (HOA) (third order - coma and trefoil; fourth order - quatrefoil, secondary astigmatism and spherical aberrations; fifth order - pentafoil; sixth order - hexafoil). LOA can be corrected with spectacles; however, HOA can’t be corrected by spectacles and are a source of poor quality of vision. Aberrometers work to identify and quantify the errors in the optical system and work on various principles such as Hartmann-Shack (outgoing reflection aberrometry), Tscherning, Ray Tracing (Retinal imaging aberrometry) and automatic retinoscopy (slit skiascopy). iTRACE is a ray tracing aberrometer which combines both the wavefront aberrometry as well as placido based corneal topography. Hence, it has an advantage over other aberrometers in providing results individually for corneal and internal aberrations in addition to the total aberrations. Recently, iTrace has gained immense popularity for pre-operative evaluation and planning in cataract and refractive surgery patients.

Principle
The ray tracing aberrometer uses a laser beam (655 nm wavelength) parallel to the visual axis through the pupil and measures the exact location where the laser beam reaches the retina by using a retro reflected light captured by the reference linear sensors X and Y. Sixty-four such laser beams are projected sequentially for four times at different locations on the retina, making a total of 256 points which are projected into the eye. The retinal positions of all these projected rays are mapped forming a Retinal Spot Diagram (RSD) and a wavefront is reconstructed by the emergent rays from these points. In an emmetropic eye, all these points would focus on the fovea but in most of the cases, local aberrations at the level of cornea and lens result in shifting of the location on the retina with respect to the reference. Deviation of the emergent wavefront from the wavefront entering the eye gives the results for ocular aberrations. The iTRACE has a data acquisition unit which projects and processes the light beam, provides an adjustable focus target, has a pupil size detector and an internal optometer which aligns line of sight with laser axis and relaxes accommodation. In addition, it has placido based corneal topographic analysis built in the same equipment (Figure 1).

Wavefront verification display allows manual adjustment of pupil size even after data acquisition. It also helps to study the changes in spherical aberrations with change in pupil size. Colour coded points in map of entrance pupil based on the wavefront aberration are displayed.

Figure 1: An iTrace image showing the corneal topography display with details of keratometry

Abstract
Modern ophthalmology focusses on visual quality and not just visual acuity. The quality of vision is affected by both lower and higher order aberrations. An optical aberration is a departure of the performance of an optical system from the prediction of paraxial optics. In this article, we analyse the iTrace Ray-tracing aberrometry and its applications in daily clinical practice. The iTrace system integrates corneal topography with wavefront aberrometry, thereby providing a unique analysis that subtracts corneal from total aberrations in order to isolate the internal aberrations of the eye. It is an extremely useful tool for objective evaluation of dysfunctional lens, improving cataract and refractive surgery outcomes and planning of premium intraocular lenses. Thus, the clinicians must explore this instrument as it is an advanced diagnostic tool that can help the surgeon at all stages of patient care in achieving premium outcomes.

Keywords: Aberrometer, ray tracing aberrometer, iTrace, ocular aberration

instrument focus

iTrace – A Ray Tracing Aberrometer

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Modern ophthalmology focusses on visual quality and not just visual acuity. The quality of vision is affected by both lower and higher order aberrations. An optical aberration is a departure of the performance of an optical system from the prediction of paraxial optics. In this article, we analyse the iTrace Ray-tracing aberrometry and its applications in daily clinical practice. The iTrace system integrates corneal topography with wavefront aberrometry, thereby providing a unique analysis that subtracts corneal from total aberrations in order to isolate the internal aberrations of the eye. It is an extremely useful tool for objective evaluation of dysfunctional lens, improving cataract and refractive surgery outcomes and planning of premium intraocular lenses. Thus, the clinicians must explore this instrument as it is an advanced diagnostic tool that can help the surgeon at all stages of patient care in achieving premium outcomes.
on refractive error at each point helps assess visual function. Non-measured or rejected points are also displayed and if is >9, the exam is invalid. Also, the horizontal point profile and vertical point profile should be uniform for a valid exam (Figure 2). A very distorted Retinal Spot Diagram indicates either error in measurement or many aberrations in the eye.

Parameters Assessed

iTrace gives results for all ocular aberrations (LOA and HOA) with separate values for both corneal and internal aberrations. The Point Spread Function (PSF) and Modulation Transfer Function (MTF) is derived from the RSD. iTrace also functions like an auto-refractometer and gives a multi-zone refraction analysis.

The pupil size plays a major role when assessing the aberration profile of the eye. While the aberrations detected are minimal with a small pupil size, the real-life scenario is different. The mesopic and scotopic pupil size is much larger resulting in more aberrations and visual blur due to paraxial rays entering the eye from the peripheral cornea. Therefore, it is important to look at the pupil size before interpreting the maps.

The iTrace has a few basic maps that one needs to understand in order to interpret its results. The details of individual maps are discussed below.

1. Wavefront Map Total & HOA
   In this map, the total ocular aberrations (LOA + HOA) measured in microns are depicted in a colour coded fashion with red representing a wavefront positioned in front of the reference plane, blue representing a wavefront positioned behind the reference plane and green for little or no aberrometric error (Figure 3). A similar map can also be obtained for analysing only the HOAs.

2. Root Mean Square
   The root mean square (RMS) gives the quantitative measurement of the ocular aberrations measured in microns (Figure 4). RMS is obtained for total ocular aberration as well as for each component of the ocular aberrations. Upto 6th order of ocular aberrations are assessed including 27 zernike polynomials reported separately for cornea and internal optics.

3. Total Refractive & HOA Refractive Map
   In this colour coded map, the refractive error of the eye is represented in diopters. The red colours depicting myopia, green emmetropia, and blue hyperopia. An objective assessment of accommodation can also be performed by comparing these maps at different distances and measuring the change in refraction.

4. Point Spread Function
   The PSF map represents the image obtained on the retina on seeing a point source of light. Small and sharp image is better (Figure 5).

5. Snellen Letter Total & HOA
   The iTrace system estimates “how the patient sees” the snellen letter “E” in different sizes. It helps to objectively document the visual symptoms reported by the patient (Figure 6).

6. Modulation Transfer Function
   MTF is the image produced by the optical system in terms of details of the object. It is a measure of resolution of the image assessed at different spatial frequency of the object and is used as an objective measure of the ocular contrast sensitivity (Figure 7).
Clinical Applications

1. **Quality of vision:** Snellen Letter graph (total or HOA) allows to objectively determine the visual discomfort the patient feels. A distorted retinal spot diagram also points toward presence of multiple aberrations in the eye.

2. **Refraction:** Zernicke coefficients are used to calculate conventional refractive indices. Refractive map both total or higher order refractive map show refractive power of the whole eye. Along with the topography map which can be used to deduce if astigmatism is just corneal or with a lenticular factor. It also gives a multi-zone refraction analysis. In this system, the accommodation can be minimized by using an open field. The objective assessment of accommodation can also be done with this system.

3. **Angle Kappa:** Angle Kappa is the angle between the visual axis and the pupillary axis. High angle kappa is considered a contraindication for implantation of multifocal or ERV intraocular lens (IOLs) as a decentration of these premium IOLs often result in poor post-operative visual outcomes.

4. **Assess Aberropia:** HOAs cause subjective symptoms such as glare and halo which cannot be quantified by refraction and corrected by spectacles or soft contact lenses. These are of importance in cases following cataract and refractive surgery who complaint of poor vision despite of achieving a good visual acuity. HOAs can also be induced by squint surgery, corneal inlay surgery and orthokeratology which can be identified by ray tracing aberrometry.

5. **Wavefront guided treatment:** Customized Wavefront-guided refractive corneal laser treatments are designed to reduce existing ocular aberrations and to help prevent the creation of new aberrations. Wavefront customised lenses can also be developed for spectacles.

6. **Designing and choosing Lenses:** Preoperative aberrometry can help to choose IOLs with positive, negative or aspheric SA based on the patient’s corneal aberrations to achieve a nearly zero total aberration profile post-operatively for best outcomes. This is of special importance in patients undergoing cataract surgery following refractive surgery.

7. **Accommodation:** iTrace can quantify accommodation up to 4 dioptres.

8. **Contrast sensitivity:** The modulation transfer function (MTF), RMS and PSF are all indirect indicators of contrast sensativity.
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