RAY TRACING TECHNOLOGY: A BOON FOR REFRACTIVE SURGEONS

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The goal of refractive surgery is to provide the patient with his or her best possible visual performance. To obtain this optical quality, surgery (eg, corneal ablation, IOL implantation, etc.) must change the refracting structures of the eye. Accurate methods of calculation are required to achieve satisfactory surgical outcomes. In ophthalmology, traditional planning methods for IOL power calculations or corneal laser ablation profiles are based on simplified formulas that are derived from paraxial optics. These formulas fail to consider the eye's multiple lenticular structures, or they may incorporate addition theorems for small aberrations in cases where they are not valid. Already somewhat theoretical, such formulations were found to incompletely correct some types of aberrations or to induce errors, specifically in eyes of atypical size or with preexisting aberrations.

Even the planning of refractive treatments using wavefront technology, which is known to measure the entirety of the eye's optical characteristics, is based on an approximation. It is presumed that the total measured wavefront aberration of a multilens system can be compensated for by applying the corresponding correction profile to a single refractive surface of the system without further adjustments of the profile. This is not exactly the case.1 In fact, these assumptions limit the accuracy of today's planning methods and therefore limits their applicability for future fields of interest. Aspects of these calculations, however, can be addressed easily by the ray-tracing method.

RAY-TRACING METHOD

Ray tracing is a computer-based method used to calculate an ablation profile for a refractive laser by incorporating data derived from several types of measurements. By considering all optical surfaces of the eye, such as the back and front surfaces of the cornea and the crystalline lens, ray tracing offers the highest possible accuracy to improve the refractive predictability of corneal laser surgery or lens implantation both in terms of predictability (accuracy) and safety (lines of best-corrected visual acuity (VA) either lost or gained).2

The highest possible accuracy in ablation profile planning can only be achieved by taking all of the optical structures in the patient's eye into consideration. With the advent of partial coherence reflectometry (similar to IOL Master technology for calculating IOL powers) the intraocular structures and dimensions can now be measured with extreme accuracy.

The ray tracing ablation profile is calculated using the following data:

1. Wavefront maps of the optics of the entire eye are collected with a Tscherning Wavefront Analyser.
2. Topographical corneal data is collected with the Pentacam (Oculus GmbH, Germany) or Allegro Oculyzer (W a v e L i g h t G m b H , Ge rma n y) .
3. Posterior corneal surface data is collected by the Pentacam or Allegro Oculyzer.
4. Biometric data such as corneal pachymetry, anterior chamber depth, lens thickness, and axial length are all collected by the Allegro BioGraph (WaveLight GmbH, Germany)

The current ray tracing study protocols use the Scheimpflug principles of the Pentacam and/or Allegro Oculyzer to obtain both anterior and posterior corneal surface data . Based on the Optical Low Coherence Reflectometry (OLCR) measuring principle, the Allegro BioGraph is a multifunctional biometry device used to determine the axial dimensions of the eye, as well as the complete anterior segment. This optical

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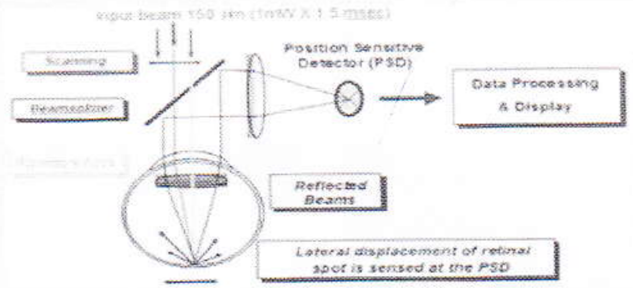
system will combine future technologies with established biometry applications. Its applications include central corneal thickness measurement, anatomic anterior chamber depth measurement, axial length measurement, central lens thickness measurement, retina thickness measurement, keratometry, 'white to white' measurement, and pupillometry (Figure 3). It also measures the patient's visual-optical line to the fovea, which leads to improved VA when compared to calculations based on the theoretically-derived optical axis from the Gullstrand schematic eye.



RAY TRACING ABERROMETRY

Ray tracing concept:

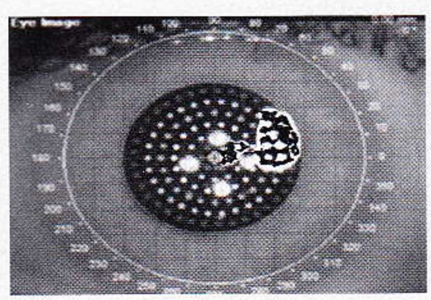
Aberrometry based on the principle of Ray Tracing is, a two-step, serial technique that uses forward projection and which can be used either subjectively or objectively. The ray tracing method uses a laser beam parallel to the line of sight through the pupil. It measures the exact location where the laser beam reaches the retina by means of the retro-reflected light captured by reference lineal sensors X, Y. Local aberrations in the path of the laser beam through the cornea and the internal structures cause a shift in the location on the retina. Once the position 1 has been determined the laser beam is shifted to another position, which is then located in the retina. This process continues until several separated points are projected into the entrance pupil. This way a connection is obtained between the direction that the light beams have taken while entering and leaving, allowing a reconstruction of the real wavefront error. This principle measures «forward» aberrations of the light that goes through the eye. It is more physiological to measure these anterior aberrations as the natural trajectory of the light in the eye is analysed.

The only aberrometer that is commercialised for clinical use is the iTrace (Tracey Technologies, Houston, Tx). The iTrace uses this fundamental principle of Ray Tracing where a sequential series of infrared beams on the order of 100 microns and a 785 nm wavelength each is projected into the entrance pupil parallel to the eye's line of sight.

In Figure 2, a diagram of the Ray Tracing technique developed by Tracey Technologies is shown.

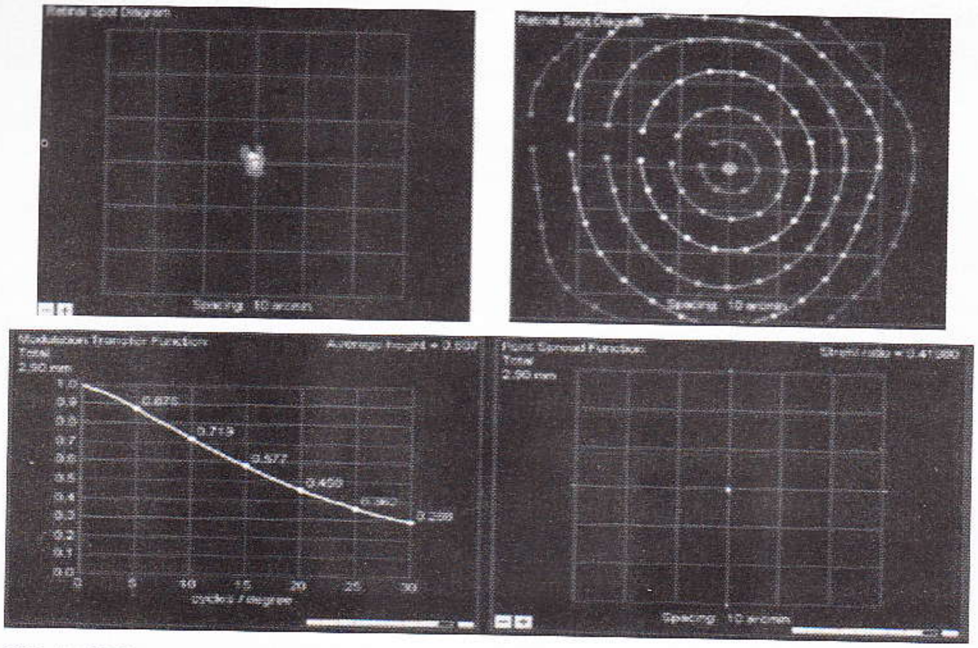
This process continues until 64 laser beams have been projected through the entrance pupil 4 times each (256 points) at high speed (approximately 250 milliseconds). Each of these points represents the entrance of parallel light rays into the eye, which become refracted by the eye's optical power and eventually focus on the retina. If the eye were emmetropic, all 256 points would be concentrated at a single point in the centre of the macula. In other words, the fovea is represented by the conjugate focal point of the system. Generally, local aberrations at the beam's entry point on the cornea or the lens cause a shift in the location on the retina with respect to a position of reference.

. The iTrace uses a pattern of concentric rings (fig. 3).



Retinal Spot Diagram (RSD) Concept. Obtaining PSF and MTF When a set of points is sequentially projected in the entrance pupil a retinal spot diagram (RSD) is created. The RSD contains all the information related to the patient's refraction, aberrations and point spread function (PSF). Analysing the RDS's morphology, we get an idea of the degree of the wavefront's qualitative aberration (fig. 4). The smaller the RSD the higher the concentration of photons that reaches any point of the retina.

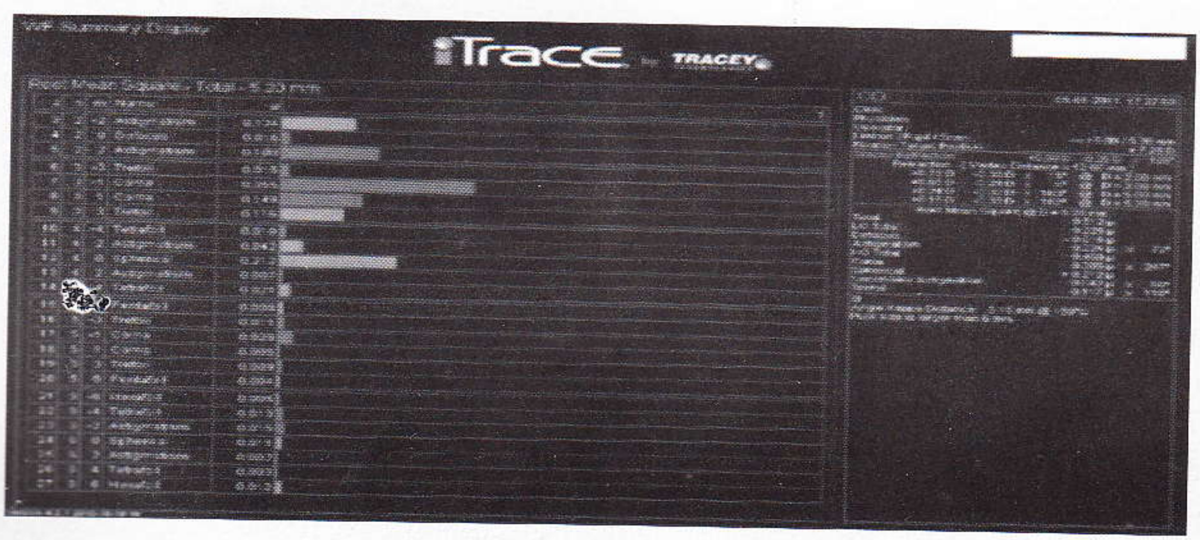
From the RSD we obtain the PSF (Point Spread Function). PSF shows the image obtained in the retina when the patient sees the source of a point of light. The smaller and the sharper the better. The MTF describes how the optical system reproduces detail from the object to the image produced by the lens; therefore, both the MTF and PSF help to describe the optical system's ability.



BASIC DATA GRAPHS WITH THE i-TRACE

– ***Wavefront map Total and High-order Aberrations (HOA) (Wavefront Total and Wavefront HOA).***

– The ***RMS (Root Mean Square)*** is the measurement of the magnitude of the aberration. A total RMS value for the total aberration of the eye and a specific value of RMS for each Zernike term or component of the eye aberrations can be obtained.



-*Total refractive and HOA refractive maps.*
Emmetropia is represented in green. Myopia in red and hypermetropia in blue. This map in combination with the topographic one can indicate if the astigmatism is purely corneal or if it has a lenticular component.

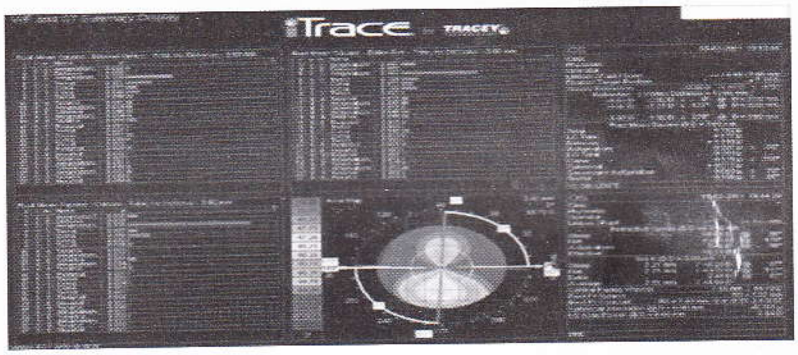
-***PSF Total and HOA PSF. PSF (Point Spread Function)*** is a figure of merit representing the quality of the image of an optic system, determined by the aberrations to a simple point of light.

-***Snellen Letter Total and high-order aberrations (HOA).***

The Snellen Letter («E») is a simulation of the iTrace system based on an estimate mathematically derived (convolution) from how the eye «would see» the letter «E» projected in different sizes such as 20/20, 20/40, 20/100 and 20/200.

-***Zernike polynomials***. It is a bar graph and a table of the terms or polynomials of Zernike, which show a detailed analysis of the specific aberrations in an eye.

The iTrace shows the Zernike polynomials up to the 6th order (27 terms) and can show the totals for the eye («Total»), only the corneal and the difference between the corneal and the totals (internal optics) figure x)



-**Aberration of internal optics analysis.** Wavefront combined analysis and corneal topography.

This graph provides us with very valuable information unique to the iTrace system. Through corneal topography the corneal aberrations map can be mathematically generated and these aberrations can be adequately subtracted from the total aberrations of the entire eye (fig. x1). The resulting difference obtained by subtracting the corneal aberrations from the total aberrations mainly represents the aberrations of the internal optics; in this way aberrations from the cornea can be separated from those from the interior of the eye. Most of the aberrations of the internal optics are induced by the crystalline lens.

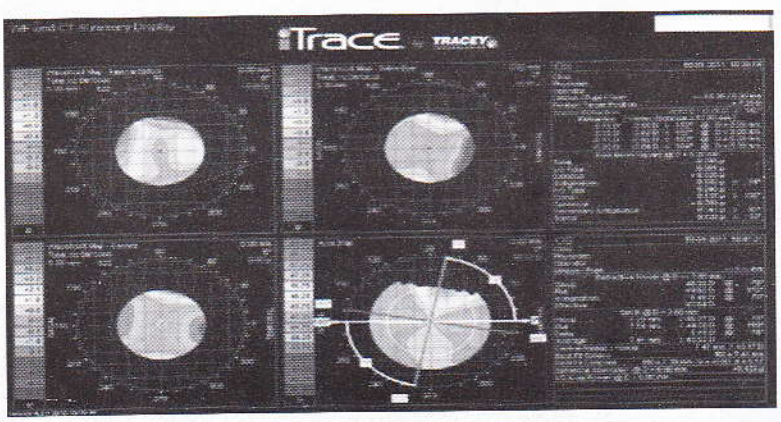


Figure x2 : Analysis of the entire optics of the eye

From a clinical point of view this can help us in certain situations:

If a patient has high total aberrations we can know if the refractive procedure we are planning is better in the cornea or in the crystalline.

If a patient has undergone a phacolensectomy we study the aberrations (induced or compensated) introduced by the IOL with a map before and after (analyzing the aberrations of the internal optics, cornea and total).

Different types of IOL can also be analysed.

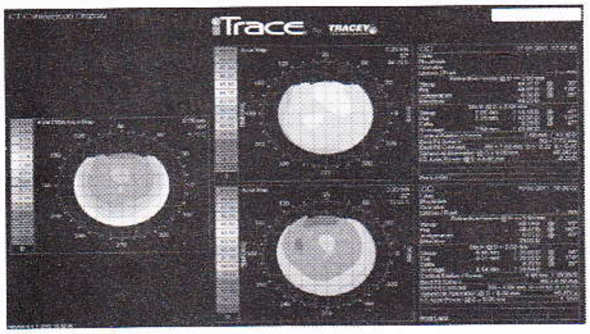
We can analyse in an opacified crystalline how many aberrations it is inducing in the total of the eye.

CLINICAL APPLICATIONS :

Lasik

For a 26-year-old patient who underwent surgery 6 months ago optimized Lasik treatment with an aspheric ablation pattern was used.

If we focus on the axial map prior to (top) and post surgery (bottom) as well as the values obtained from them, we see that after Lasik the cornea is more oblate. However, the positive corneal spherical aberration induced after myopic ablation is practically non-existent, i.e. the previous positive value is maintained. It is due to the pattern of spherical ablation produced, taking into account the previous Q value and that expected after Lasik.



A comparison between the total spherical aberration maps (Z 4.0) pre and post Lasik was made. Maintaining the positive spherical aberration of the cornea prevents an increase in total aberration as the patient is young and the lens

compensates with a negative spherical aberration to keep the total close to 0 and to obtain good quality of vision.

<u>Selection of IOLS :</u>

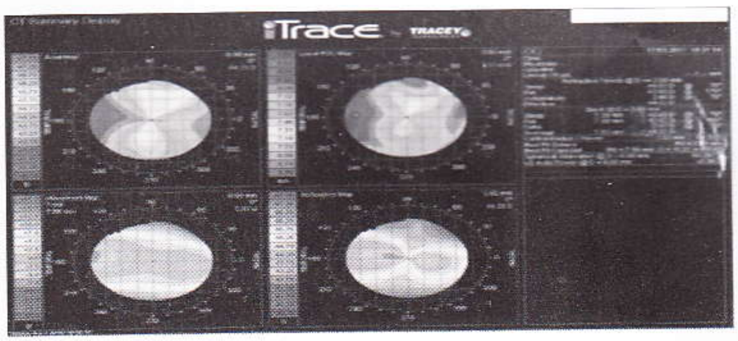
- Example : A patient had a previous myopic LASIK and presented with interest in cataract surgery.
- **High (+) Spherical Aberrations.**
- **The AMO TECNIS® offers _0.27 which is currently the maximum in (_) lenticular aberration correction.**

Therefore, because of the patients high (+) corneal S.A. at 6mm, Tecnis will be the planned IOL for this patient's upcoming cataract surgery to offset the (+) spherical aberration

- **Example 2: A patient had a previous hyperopic LASIK procedure some years back. High negative spherical abberation due to LASIK**
- **Resulting highly prolate cornea (Q= _1.03) which is a markedly negative aspheric corneal shape.**
- **Opted to use a traditional spherical IOL which offers a (+) spherical aberration to offset the (_) spherical aberration of the cornea.**

Phakic lens :

A 29-year-old patient with refraction in her RE of –9.00 (–6.00) 175 and VA 0.4. We analysed topography using CT, detecting corneal astigmatism of nearly 3.00 D. The other 3.00 D are therefore derived from the internal optics. Implantation of an anterior chamber phakic toric IOL to compensate overall sphero-cylindrical refraction.



Once this IOL was implanted, we analysed aberrometric status and the visual quality of this patient. Combining the WF with CT we noticed a corneal aberrometric map typical of astigmatism, neutralised by the IOL. It should be noted that both WF maps are symmetrical but present inverted colours, this makes the WF total map very homogeneous, with colours close to green and with a total RMS of 0.361 microns. For a more comprehensive study, we chose the option of decomposing each map into the di#erent Zernike polynomials through a bar graph. The IOL compensates overall corneal astigmatism but to a certain degree also induces this, evident in total refraction (–0.75 to 99°). It also induces a mild comatic aberration.