

Understanding the Wavefront-Optimized ALLEGRETTO WAVE™

Summary

The induction of higher-order aberrations is one of the most significant post-operative problems attributed to refractive laser surgery,^{1,2} and has been shown to degrade best spectacle-corrected image quality.^{3,4} Before the first wavefront-guided treatment was ever performed, Professor Theo Seiler and his team of engineers set out to design a laser that would reduce the induction of such aberrations to increase the effectiveness of LASIK treatments. This led to the development of the unique wavefront-optimized algorithm in the ALLEGRETTO WAVE (WaveLight Laser Technologie AG, Erlangen, Germany).

WaveLight is the first company to incorporate wavefront principles into its standard excimer laser system. The term, “wavefront-optimized”, describes the unique ablation profile and proprietary algorithms incorporated into the ALLEGRETTO WAVE platform. In order to fully understand the significance of wavefront-optimization, it is first necessary to consider the ideal pre- and post-operative shape of the cornea.

Corneal Shape and Asphericity

The natural shape of the human cornea is aspheric with a prolate shape (where the optical power is less in the corneal periphery). In a normal pre-operative eye, corneal steepness decreases from the central cornea to the periphery with progressive peripheral flattening.

All refractive laser systems utilize a light beam (whether broadbeam or scanning spot) that is fixed in one position, striking parallel through the axis and perpendicular to the central cornea. When laser pulses hit the center of the cornea, they are fully absorbed. But in the corneal periphery, the laser beam meets the cornea at an incline due to the cornea’s curved shape. Changing the angle of incidence will alter the round spot into a larger, elliptical shape, thereby distributing laser energy over a larger surface. The photoablative effect, therefore, decreases, causing a reduction in effective peripheral ablation (*Figure 1*). At an optical zone of 8 mm, the effective energy (energy over a surface) used for corneal tissue ablation at the periphery is reduced by as much as 20% compared with the ablation at the central cornea.⁵

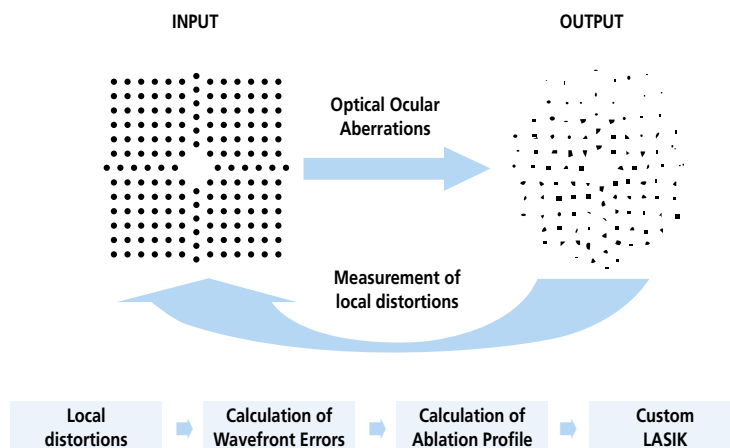


Figure 1. In a perfect visual system, a sheet of light would travel through the ocular media and reach the retina remaining as a perfect sheet of light.

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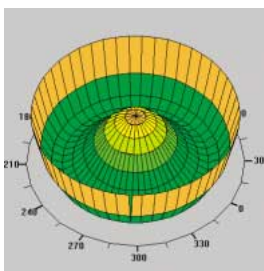
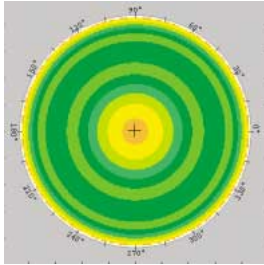


Figure 2.
Wavefront map of 4th order spherical aberrations. Note that spherical aberrations are radially concentric differences in refractive power.

Clinical studies have shown that conventional laser surgery results in a significant induction of higher order aberrations.^{1,2,6,7,8,9} The most significant increase in the type of higher order aberration following refractive surgery occurred for spherical aberrations. Aberrations describe a distortion of light through an optical system; spherical aberrations are like concentric rings of power (Figure 2). If the normal corneal asphericity is changed, it will result in induced spherical aberrations.

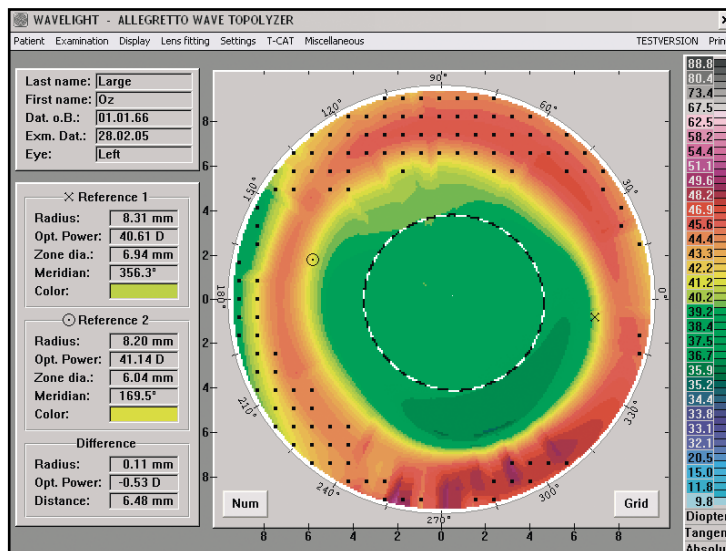
The Wavefront-Optimized ALLEGRETTO WAVE

To overcome the induction of spherical aberrations resulting from reflection and reduced photoablative effect beyond the central cornea, the ALLEGRETTO WAVE applies additional pulses in the periphery of the cornea to pre-compensate for these energy losses. The wavefront-optimized algorithm takes into consideration each patient's pre-operative keratometry value (or corneal steepness). The desired post-operative aspheric contour is maintained, even in the outer areas of the cornea, resulting in a large, true optical zone (Figure 3). Due to the additional peripheral ablation, the actual blend zone (shown in green) is minimized.

By minimizing and preventing the induction of spherical aberrations, quality of vision is enhanced with a reduction in post-operative visual symptoms such as glare and haloes and patients experience better night vision.

Michael Mrochen and Theo Seiler substantiated the importance of corneal curvature in calculating customized ablation profiles.⁵ In a study involving more than one hundred patients, Michael Mrochen, et.al. varied the percentage of additional laser pulses added to the periphery of the cornea to create an even ablation. By measuring spherical aberrations produced after these treatments, they determined the percentage of additional pulses that must be added to the corneal periphery to minimize the average induction of spherical aberrations.^{10,11} This critical information has been incorporated into the platform of the ALLEGRETTO WAVE.

Figure 3.
Corneal topography on a patient showing a large, true optical zone and a minimized transition zone following a standard treatment with the ALLEGRETTO WAVE.



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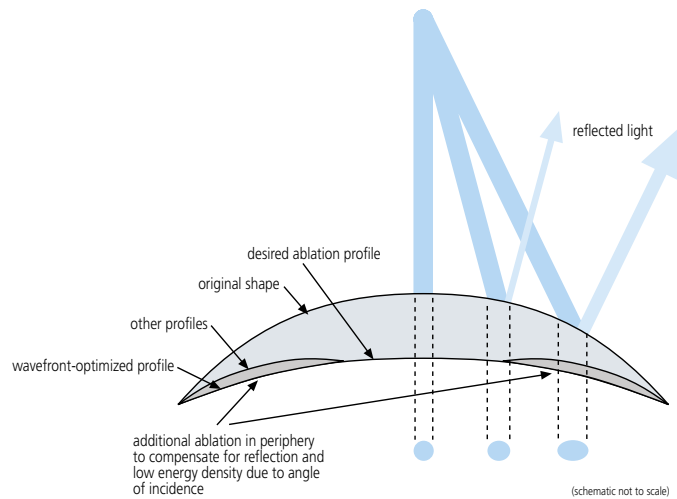


Figure 4.
Compensation for energy losses with additional pulses to the corneal periphery.

Clinical Implications

The first wavefront-guided treatment was performed by WaveLight in the year 1999 and the term, wavefront-optimized, was developed to show that every treatment with the ALLEGRETTO WAVE takes wavefront into account. The key to understanding wavefront-optimized ablations is in knowing that every procedure is customized to each patient's individual corneal shape.

As a prerequisite for performing wavefront-guided treatments, WaveLight determined that they must first minimize the induction of aberrations. If you perform a treatment aimed at correcting aberrations, such as trefoil and coma, but at the same time you are inducing spherical aberrations, outcomes will not be optimized. With the ALLEGRETTO WAVE laser, it is not necessary for surgeons to always take the wavefront-guided path, which is more complex and time-consuming. Correcting all pre-operative aberrations may not be essential to achieving excellent quality of vision. For routine primary cases, an ablation that minimally induces a change in the amount of higher order aberrations is the most critical factor in achieving outstanding visual outcomes.

Understanding Spherical Aberration

The Hubble space-based telescope sits 380 miles above the earth's surface and is internationally recognized for furthering our understanding of stars, black holes, galaxies and beyond. When the Hubble telescope was first launched in 1990, it was determined that a spherical aberration equivalent to 1/50 of a human hair made it impossible to focus on faint objects. Scientists solved this dilemma by adding a special lens, thus compensating for these spherical aberrations. Wavefront principles were derived from astronomy and are used to describe the behavior of light as it passes through refractive media.

Understanding the Wavefront-Optimized ALLEGRETTO WAVE™

Understanding Wavefront

Wavefront is the sum of visual distortions that are created when light travels through the entire optical system of the eye. Rays of light passing through the visual system are distorted by the cornea, lens and vitreous until they reach the retina. These rays of light will no longer be perfectly focused to a point, but blurred. Zernike developed a mathematical method of describing all the optical errors occurring in the visual system.

Imagine a sheet or wave of light entering the eye. If the eye were a perfect visual system, the sheet of light would penetrate the eye maintaining its precise shape (*Figure 4*). As the visual system is not perfect, some of the light rays may meet the retina earlier, some later, and the sheet would then appear somewhat crumpled or wavy. Wavefront error is equivalent to the distance between the perfectly straight sheet and the somewhat crumpled sheet at every point. Zernike developed a mathematical description of the optical errors for optical systems with polynomials. The combination of all Zernike factors adds up to the total wavefront-error. With the wavefront-optimized platform, the goal is to avoid inducing Zernike factor C12, the so-called higher order spherical aberration.

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