
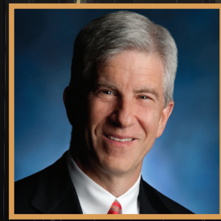

From Cosmos to Cornea

The journey of wavefront technology in modern LASIK.

BY STEPHEN C. COLEMAN, MD, AND COLMAN R. KRAFF, MD

The Birth of Wavefront Technology

BY STEPHEN C. COLEMAN, MD

WATCH IT NOW

The 1st International Wavefront Congress was held in Santa Fe, New Mexico, in 2000. Because the meeting was nearby and I was free that weekend, I went. In many ways, the experience changed my life. Most attendees were optical scientists and engineers, but among the smaller group of ophthalmologists present was Theo Seiler, MD, who had flown in from Dresden, Germany. I learned that day that, depending on what it is made of, a mirror can deform, and I was introduced to the field of adaptive optics. (Scan the QR code to watch my TED Talk on the evolution of wavefront technology.)

KEY DEVELOPMENTS IN WAVEFRONT TECHNOLOGY

The story of the iDesign Refractive Studio (Johnson & Johnson Vision), the wavefront-guided (WFG) system I use and that is used around the world, begins here in New Mexico with Dan R. Neal, PhD. Scientists eager to avoid the optical problems that nearly doomed the Hubble Space Telescope turned to Neal and his team of researchers at Sandia National Laboratories to fine-tune the giant mirror on the James Webb Space Telescope to ensure that it returns sharp images of the universe.

Neal adapted the same technology that helps image objects in deep space for use in an aberrometer—an instrument used to capture information about an eye and subsequently drive the laser profile for LASIK. Visx (now Johnson & Johnson Vision), in a prescient move, purchased Neal's system around 2001 and called it the WaveScan System. I consider this to be one of the most significant advances in the nearly 3 decades that I have been performing LASIK. It has largely fueled the excellent results and reputation that we surgeons enjoy today with modern LASIK.

The aberrometer has an array of approximately 5,000 lenses, each with the diameter of a human hair. They are housed in a chip about the size of a thumbnail. The sensor measures the direction that light is traveling at many points across the pupil to produce a highly accurate characterization of the light path. The versatility of the aberrometer allows it to measure any kind of light, whether it is bounced off a mirror or, as is the case with LASIK, reflected from the retina.

TECHNOLOGICAL ADVANCES IN LASIK

LASIK is fundamentally about math, which, fortunately, I love. A WFG-LASIK procedure applies precise calculations directly to the cornea to create the ideal shape for a given eye. The concepts of myopia and astigmatism have been around for centuries. These lower-order aberrations are what glasses and contact lenses address.

Higher-Order Aberrations

A WFG procedure addresses the next level of mathematical terms, known as *higher-order aberrations* (HOAs), which also contribute to the way a person sees. The Zernike polynomial describing these aberrations is theoretically infinite. HOAs include spherical aberration, coma, trefoil, and quadrafoil. They are a small refractive component of vision, but they can be measured and treated. Correcting HOAs creates an opportunity for patients to see better after LASIK than they did before surgery with their glasses or contact lenses.

Laser Profile Evolution

Together with the ability to gather more information from an aberrometer came the change in the laser profiles required to treat these newly acquired measurements. Eliminating myopia and astigmatism can be efficiently accomplished with a relatively straightforward beam profile. Treating the mathematical terms that are much smaller but also affect vision requires far more precise laser pulsing and, more specifically, the ability to change pulse diameter and speed rapidly, resulting in an exceptionally accurate correction.

Individualized Treatments

Every wavefront procedure is unique to the individual eye and, by definition, cannot be repeated. Treatment can address not only a prescription but also a symptom. For instance, what a patient calls *halos* wavefront scientists call *spherical aberration*, and a correction for this is built into the laser algorithm as part of the treatment.

PARADIGM SHIFT

I was a principal investigator on all of the US FDA clinical trials for this WFG laser technology, starting with the initial one in 2002, and the results have made me a true believer. Conventional LASIK essentially matches a Placido disc image from a topographer to a patient's prescription. A WFG procedure takes into consideration a patient's entire optical system from back to front. This was a paradigm shift in our approach to laser vision correction. This is not hyperbole. I remember receiving a phone call from Colman R. Kraff, MD, halfway through the first study for low myopia during which he exclaimed, "This is game-changing technology!"

Marc Odrich, MD, one of the most influential ophthalmologists to greatly improve our understanding of this technological advancement, described it to me with the following analogy: If a patient's prescription is like a wall that needs painting, a conventional treatment accomplishes this using a roller. It's effective but lacks precision. A WFG procedure also uses a roller but, more importantly, can use multiple small, fine paintbrushes for added accuracy and precision to make the corners and edges just right.

A consequence of this precision is that a WFG procedure is often the cleanup hitter for other amazing refractive procedures currently offered to patients. Whether a procedure is lens-based or intracorneal, its outcome requires fine-tuning or enhancement in a small percentage of patients, and this is generally accomplished with a WFG correction, either on the surface or under a flap.

COLLABORATIVE EFFORTS AND FUTURE PROSPECTS

Many consider our current era of vision correction to be one of the greatest collaborative efforts in the history of medicine. Ophthalmologists, optometrists, opticians, optical scientists, engineers, celebrities, venture capitalists, patients, big pharma, LASIK corporations, and the US military are just some of the players who have contributed significantly. This team effort, coupled with patient demand, is a fundamental reason why the future of LASIK remains very, very bright.

The Evolution of Wavefront Technology

BY COLMAN R. KRAFF, MD

In his portion of this article, Stephen C. Coleman, MD, describes the early days of the WFG technology currently used to treat LASIK patients worldwide. I, too, recall the first patients I treated with Visx technology. In 1999, the initial WFG treatments in my office used the Visx WaveScan aberrometer. Patient treatment tables were calculated manually using Microsoft Excel (Microsoft) spreadsheets. The first patients obtained excellent results, which spurred the expansion of US FDA trials across the country using the WFG Visx system.

Nearly 2.5 decades later, multiple laser manufacturers offer variations of this wavefront technology for laser vision correction worldwide. This progress required a commitment from refractive surgeons to conduct US FDA trials and clinical studies, investments from medical device manufacturers, and patients who believed in the technology and sought a lifestyle free from glasses and contact lenses. Over the years, the technology has evolved significantly, and the Table reflects a nonexhaustive list of the current excimer laser systems that are used to perform these customized treatments.

MY JOURNEY AS A PRINCIPAL INVESTIGATOR

As an early principal investigator focused on refractive surgery, I participated in numerous US FDA clinical

TABLE. EXCIMER LASER SYSTEMS FOR CUSTOMIZED ABLATION TREATMENTS					
System	Ablation Speed	Customization	Eye Tracking	Repetition Rate	Applications
iDesign Refractive Studio With Star S4 IR Excimer Laser System (Johnson & Johnson Vision)[1]	10 seconds per diopter for myopia correction	Supports topography-integrated, wavefront-guided procedures	60-Hz active eye tracking with automatic centering	20- to 50-Hz variable spot scanning	LASIK and PRK for myopia, astigmatism, hyperopia, mixed astigmatism, monovision, and PTK
MEL 90 (Carl Zeiss Meditec)[2]	Intraoperatively ablates 1.00 D in 1.3 seconds	Facilitates both wavefront-guided and topography-guided treatments	1,000-Hz active eye tracking	250/500 Hz	LASIK, PRK, and PTK
Navex Quest EC-5000 Excimer Laser System (Nidek)[3]	Variable repetition rates for different corrections (Myopia: 5, 10, 20, 30, 40, 50 Hz; Hyperopia: 34, 41, 46 Hz)	Integrates wavefront-guided technology and topography-guided capabilities using the OPD-Scan III and Final Fit software (both from Nidek)	200-Hz eye-tracking system with torsion error detection	Up to 50 Hz	LASIK for myopia and myopic astigmatism, P RK, and PTK
Schwind Amaris (Schwind eye-tech-solutions)[4]	Intraoperatively ablates 1.00 D in 1.3 seconds	Intraoperatively ablates 1.00 D in 1.3 seconds Offers both ocular wavefront-guided and corneal wavefront-guided treatments with Schwind Cam software	6D/7D active eye tracking	750/1,050 Hz	LASIK for myopia, hyperopia, and myopic astigmatism, PRK, and PTK
WaveLight Refractive Suite With EX500 Excimer Laser (Alcon)[5]	Approximately 1.2 seconds per diopter	Supports wavefront-guided and topography-guided treatments	1,740-Hz eye-tracking system	500 Hz	LASIK for myopia, hyperopia, and mixed-astigmatism, PRK, and PTK

Abbreviation: PTK, phototherapeutic keratectomy.

trials. Today, commercially available technology provides outstanding clinical outcomes for a wide range of refractive errors. This was not always the case. Robert Maloney, MD, Dr. Coleman, and I were among dozens of investigators treating patients under stringent US FDA–guided clinical trials using what is now the iDesign Refractive Studio.

TRANSITION TO COMMERCIAL USE

After completing the most recent US FDA trial that led to the approval of the iDesign system for the treatment of myopia, hyperopia, and astigmatism, my fellow investigators and I aimed to replicate the trial results in a real-world setting. Treating patients in a commercial setting versus a highly regulated US FDA trial can be significantly different. Our study used similar approved indications and labeling. The goal was to create a simple nomogram for surgeons of any skill level using the iDesign Refractive Studio and then, in a clinical setting, replicate the results achieved in the US FDA trial. Our results were published in the *Journal of Cataract & Refractive Surgery*.[6] This study is one of many published in peer-reviewed journals worldwide using this and similar technologies from various medical device manufacturers.

THE IMPACT AND FUTURE OF WAVEFRONT TECHNOLOGY

The development of new technologies during the period when the original Visx platform was released and their evolution raised the bar on patient safety and outcomes. What began as an idea at Sandia Labs in New Mexico 25 years ago has become an industry that enables refractive surgeons to provide excellence to patients seeking freedom from spectacles. ■

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