A Brief History of Optical Coherence Tomography: A Personal Perspective

Carmen A. Puliafito, MD, MBA
Editor-in-Chief

ABSTRACT
The historical highlights of the development of optical coherence tomography (OCT) are reviewed as an introduction to a journal issue devoted to spectral domain OCT. [Ophthalmic Surg Lasers Imaging 2008;39:S6-S7.]

In the fall of 1981, I was a senior resident in ophthalmology at the Massachusetts Eye and Ear Infirmary in Boston. I traveled to Atlanta for the annual meeting of the American Academy of Ophthalmology. Looking back to that time, less than 30 years ago, ophthalmic technology appears primeval compared to what the average practitioner has readily available today. Lasers were used only for photocoagulation (in the retina or trabecular meshwork); retinal “imaging” consisted of fundus photography and fluorescein angiography. Phacoemulsification and intraocular lenses were still controversial in many quarters. Laser surgery of the cornea had not been imagined even as medical science fiction.

But the winds of technologic change were beginning to blow. On the way back to Boston, I recall a conversation in the Eastern Airlines terminal with Ralph Hinckley and Dick Simmons, two prominent New England ophthalmologists. Had I heard, they asked, about the new laser that Danielle Aron-Rosa had been using in France to open opacified posterior capsules following cataract surgery? Aron-Rosa’s laser used picosecond pulses of light from the Nd:YAG laser to create a “spark” (optical breakdown) to produce a tissue effect that we now recognize as “photodisruption.” In Switzerland, Franz Fankhauser was using nanosecond pulses for the same application. A debate was raging in Europe: which was better (or safer) for ophthalmic use—nanosecond or picosecond lasers?

Back in Boston, I concluded that this debate was a worthy topic for scientific investigation. I convinced a colleague, Dr. Roger Steinert, that studying the physics of ophthalmic Nd:YAG lasers would win us academic recognition and provide us entrée to an important, yet still virtually unknown, clinical innovation. We traveled across the Charles River to Cambridge where Professor Michael Feld of the Massachusetts Institute of Technology (MIT) provided us access to the MIT Regional Laser Center, where our laser research career started and we began our comparison of the laser bioeffects of nanosecond and picosecond laser pulses.

Early in 1982, I learned about the work of MIT Professor Erich P. Ippen in the generation, measurement, and application of ultrashort—femtosecond—laser pulses. I was intrigued by the possible biomedical application of such pulses. Professor Ippen warmly welcomed our interest, and introduced us to James G. Fujimoto, who was then a graduate student in electrical engineering and computer science. Thus began a long scientific collaboration which, within 10 years, produced biomedical optical coherence tomography. Jim is a brilliant scientist whose
impact upon the development of biomedical technology has been considerable.

It quickly became clear that then-available femtosecond laser sources had limited applicability for intraocular surgery (of course, subsequent developments have demonstrated their usefulness as an ophthalmic surgical tool). Instead, the focus of research was on using femtosecond pulses for optical ranging experiments—that is, to perform biometry of ocular structures using laser-based time of flight measurements.\textsuperscript{1,2} Fascinated by the potential of this approach, but looking for a more practical light source, Jim suggested the use of low coherence light sources and Michelson interferometry. This approach, which we referred to as OCDR (optical coherence domain reflectometry), was used to make A-scan measurements of the eye.

An important breakthrough was suggested by Jim and David Huang, then a Harvard Medical student, and now a professor of ophthalmology at the Keck School of Medicine of the University of Southern California. That was the use of computed tomographic techniques to integrate the A-scan data to create images. Eric Swanson of MIT’s Lincoln Laboratory’s satellite communications group played a vital role in the creation of this approach as well. The result was a U.S. patent (United States Patent 5,321,501, Swanson, Eric A.; Huang, David; Fujimoto, James G.; Puliafito, Carmen A.; Lin, Charles P.; Schuman, Joel S. Method and apparatus for optical imaging with means for controlling the longitudinal range of the sample), and the seminal publication in Science in November 1991.\textsuperscript{3} Of the inventors named in the patent, three were from MIT (Fujimoto, Swanson, and Huang) and three from Harvard (Puliafito, Schuman, and Lin).

In September 1991, I moved to Tufts University School of Medicine as Chair of Ophthalmology and founding director of the New England Eye Center. It was at Tufts and New England Eye Center that all the initial clinical evaluation of OCT occurred. The first clinical device was built by a team under the direction of Eric Swanson and Jim Fujimoto and was first used in 1993 and 1994. Dr. Joel Schuman played an important role in developing OCT clinical applications, in particular those relating to glaucoma. The first paper documenting the use of OCT for the study of macular diseases was published in 1995.\textsuperscript{4} Michael Hee, a Harvard Medical student, played an important role in writing the initial image analysis software.

When we presented our initial clinical results in 1994, they were greeted with a mixture of fascination, enthusiasm, and skepticism. That single device at the New England Eye Center in Boston has multiplied to more than 8,000 ophthalmic clinical OCT systems around the world. OCT has become a routine tool in the hands of ophthalmologists everywhere. OCT has shown itself to be a technology that is both robust and simple to use. In 1991, there was a single paper published on OCT. Now there are almost a thousand papers published annually.

This special issue of Ophthalmic Surgery, Lasers & Imaging features the latest extension of OCT technology: spectral domain OCT (SD-OCT). SD-OCT offers the clinician some advantages over the existing time domain technology. With improved semiconductor diode light sources, the resolution of individual images is enhanced. The vitreoretinal interface is better imaged, so disorders such as vitreomacular traction (VMT) syndrome can be more easily studied. One can reproducibly study the same retinal site on multiple studies, because of SD-OCT’s capability of registration and fundus reconstruction. New metrics for evaluating the effects of retinal pharmacologic agents, such as macular volume, can be deployed. In following the progression of dry age-related macular degeneration, SD-OCT will have the capability of measuring the volume and area of drusen over time.

Optical coherence tomography has emerged as one of the cornerstones of modern ophthalmic practice. OCT technology continues to evolve and advance and with this forward motion comes new clinical applications that promise to improve patient care.

*REFERENCES*