The Ins and Outs of Intraoperative OCT

By Prithvi Mruthyunjaya, MD

We all use spectral-domain optical coherence tomography (SD-OCT) as a critical tool in preoperative planning for our most routine surgical cases like macular holes, epiretinal membranes, and vitreomacular traction. After our case is completed, we can see the result with SD-OCT: a closed macular hole, removed epiretinal membrane (ERM), and release of macular traction with foveal relaxation.

But what happens during surgical manipulation of the retina and preretinal structures? We can see, en face, with the aid of the surgical microscope, but just as in the pre-OCT era in the clinic, our knowledge of what is happening across and beneath the retinal layers is limited. With each forceps grab or scrape with a diamond-dusted instrument, do you really know what is happening to the retina?

The current answer is no. The implication is that either you may not be achieving your surgical goals (ie, incomplete release of traction due to hyloid schisis), or you may be inducing more trauma to the retina than intended, resulting in unexpected visual or anatomic outcomes.

In this installment of Break It Down, we review current progress with intraoperative OCT using hand-held and microscope-integrated technology and hear from some of the leaders and pioneers in the field.

The Origins of Intraoperative OCT

Moving from time-domain to SD-OCT, scan acquisition times were greatly reduced while scan resolution improved. Tabletop models allowed assessment of macular conditions in adults with great ease. Children were also imaged when they were able to still for scan acquisition. However, younger children (under the age of 3 years) with complicated retinal diseases, such as retinopathy of prematurity or traction retinal detachment or epiretinal membranes, could not be imaged in the clinic.

The major breakthrough to facilitate intraoperative imaging occurred in 2007, when Biotigen, Inc. (Bioptigen SDIOS system) and Joseph Izatt, PhD, Professor of Biomedical Engineering at Duke University, developed a portable, hand-held SD-OCT system that allowed nonupright imaging of patients with excellent axial resolution. The system allowed for noncontact imaging with the examiner controlling the distance from the eye and manually orienting the hand-held probe to allow multiple scan angles and imaging of the peripheral retina. The scanning probe is tethered to a computer capture station that provides a real-time scanning image as well as a sum-voxel projection after image capture.

Cynthia A. Toth, MD, Professor of Ophthalmology and Biomedical Engineering at Duke, was an early pioneer in using this technology to image full-term infants under anesthesia and described successful imaging of a variety of developmental and structural anomalies not visible with ophthalmoscopy. The work at Duke was extended to image non-sedated, premature infants and has revealed numerous insights into retinal structural development in neonatal eyes and vascular changes in retinopathy of prematurity.

Current Use of Intraoperative OCT

The extension of this early work resulted in expanding interest in bringing SD-OCT to the OR. There are 4 ways intraoperative OCT is currently being used.

Modified table-top systems. Early reports describe the use of tabletop SD-OCT systems to image infants who were under anesthesia. These tabletop units were specially mounted to allow imaging of supine patients. Imaging was focused primarily on the posterior pole while peripheral views were limited due to the mounting arms. Subsequently, several centers reported modifying their commercial systems by separating the imaging head from the base to allow a modified hand-held system to image infants. These modifications require engineering controls.
Hand-held imaging. Hand-held intraoperative imaging allows for acquisition of OCT images before and following surgical manipulation that allows rapid feedback to the surgeon regarding the microarchitectural changes resulting from the surgical manipulation. Currently, 2 commercial systems are available: Bioptigen Envisu SDOIS and the Optovue iVue.

Presurgical images are typically obtained to establish a baseline and to orient the surgeon with respect to the acquired image. To perform intraoperative imaging, the surgical procedure must be stopped. The OCT scanning head and cord are draped with a sterile plastic cover and are held by the surgeon who is also wearing a sterile gown and gloves. The OCT unit is brought over the lubricated corneal surface without touching the cornea. Image acquisition occurs quickly and the unit can be oriented to give vertical, horizontal, or oblique scans.

There is a learning curve involved in capturing and optimizing these images. Corneal and lenticular opacity can limit scan clarity. This process typically requires an assistant to control the computer system, which saves and processes the images. Imaging of the retinal surface, however, has been demonstrated through perfluorocarbon liquid, silicone oil, and air-filled eyes, although with less robust images.

**Microscope-mounted OCT.** Early adaptors of hand-held intraoperative OCT recognized some limitations in the scanning process, particularly having to move the microscope off the surgical field to facilitate imaging and image quality due to poor stabilization of the scanning head. Collaborators at Duke, Emory University, and the Cole Eye Institute have sought to overcome these issues by attaching a custom mounting arm to hold the OCT scanning head that is directly fixed to the side of the surgical microscope (Figure 1). The scanning head can be secured onto the mount prior to the start of the surgery. When imaging is required, the surgical microscope is adjusted to center the OCT head over the cornea. The microscope foot pedal is used to focus the scan image by fine adjustments to the imaging distance from the corneal surface. Multiple images can easily be obtained with good reproducibility as the microscope itself provides stabilization of the scanning head.

This unique modification is currently being used by Sunil K. Srivastava, MD, and Justis P. Ehlers, MD, at the Cole Eye Institute, as part of their PIONEER study, which is a prospective multisurgeon study examining intraoperative OCT for posterior and anterior segment surgery. The limitation of this approach is the noncommercial nature of the mounting arm that needs to be tailored for individual microscopes.

**Microscope-integrated OCT.** The next technological advance in real-time OCT timing during VR surgery will be to integrate the OCT scanning device into the optical pathway of the surgical operating microscope. Ideally, this would allow the surgeon to focus in on a structure as seen with widefield viewing and engage the OCT device to image that exact location without having to move the microscope or bring in a separate imaging unit.

A prototype unit has been constructed at Duke University that utilized a 840-nm superluminescent diode scanner that is integrated into the optical pathway of the operating microscope. This unit preserves the surgeon’s view while creating a common focal plane between the OCT scanner and the surgical microscope to allow coordinated imaging at the exact focal plane the surgeon is interested in viewing.

Safety testing, feasibility, and intraoperative imaging are currently being performed by Dr. Toth and colleagues. Early results demonstrate good image acquisition without significant compromise of the surgeon’s view through the microscope, although a learning curve was required for image optimization. Suzanne Binder, MD, from Vienna, Austria, has reported on the use of a prototype 830-nm OCT source integrated with the optical pathway Zeiss OPMI VISU 200 (Carl Zeiss Meditec) surgical microscope during surgical maneuvers. Neither system is currently commercially available.

**What Has Intraoperative OCT Taught Us?**

Intraoperative OCT shows us an anatomical “snapshot” of changes that have occurred during surgery (Figure 2). Some of these are expected and deliberate (eg, the removal of an ERM), but other changes have been described that may not have been expected. These include subfoveal neurosensory retinal separation following routine membrane peeling, incomplete peeling of ERMs, persistence of subretinal fluid in the macula while under perfluorocarbon liquid during retinal detachment repair, and the persistence of hyloid despite presumed removal in highly myopic eyes.

According to Paul Hahn, MD, PhD, from Duke, “the significance of many of these findings is still unknown, but I predict they will have profound prognostic implications for patients with previously unexplainable or variable postoperative outcomes.”

**The Virtual-reality Vitreoretinal Surgeon?**

According to Dr. Ehlers, handheld imaging has significant challenges such as image stability, surgical field

*Figure 2. Intraoperative SD-OCT of the retina pre- and postepiretinal membrane peeling. The red arrow denotes increased subretinal hyporeflectivity following membrane peeling, possibly suggesting photoreceptor stretching. (Images are courtesy of Dr. Ehlers.)*
contamination, and point-of-interest image reproducibility. Folding the optics of the OCT into the microscope optics allows the OCT to be parfocal with the surgeon view, which allows for improved efficiency because the microscope does not need to be moved away from the surgical field for imaging. Research is ongoing to allow for real-time OCT tracking of instruments that show spatial relationship and forces placed on retinal structures during surgery. Integrating the OCT into the microscope display will allow seamless integration of the OCT image during surgical maneuvers to provide real-time feedback to the surgeon and potentially 3-D images during surgery.

The Future Is Now

According to Dr. Toth, the commercial availability of the Bioptigen and Optovue handheld systems allows for anyone to begin evaluating the retina before and after surgical manipulations, such as after membrane peeling and retinal reattachment. Dr. Srivastava suggests that intraoperative OCT provides important information that can change intraoperative decisions such as if a membrane is not seen to be completely peeled on OCT, a surgeon can remove any residual membrane thus impacting the surgical plan. “In a more complex setting, intraoperative OCT could provide us with new endpoints where we perform surgical maneuvers until we reach an OCT endpoint that correlates with potential vision gain,” said Dr. Srivastava.

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