

A Microscope-Integrated OCT System for True Intrasurgical OCT Acquisition

Intraoperative OCT may introduce new surgical techniques and improve understanding of surgical outcomes.

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Optical coherence tomography (OCT) has unquestionably been a transforming technology in clinical management of vitreoretinal conditions. With its ability to visualize anatomic structures in 3-D and in high resolution, OCT is well-suited for intraoperative imaging during vitreoretinal and other intraocular surgeries, in which 3-D viewing is limited by stereopsis that is often reduced by multiple lens systems.¹

INTRAOPERATIVE IMAGING: HHOCT

Currently, the standard for intraoperative OCT imaging uses a handheld OCT (HHOCT) device. Cynthia A. Toth, MD, at the Duke Eye Center reported the first results of intraoperative HHOCT imaging using a BiopTigen system (Figure 1A).² During a pause in surgery, the surgeon removes the microscope from the surgical field and uses a

noncontact handheld probe, covered in a sterile wrap, to image an area of interest. Intraoperative HHOCT imaging has been useful in identifying surgical changes not readily apparent under the surgical microscope, including relief of macular traction surrounding a full-thickness macular hole (FTMH) following internal limiting membrane (ILM) peel, elimination of vitreomacular traction following surgical elevation of the posterior hyaloid, and the presence of a secondary epiretinal membrane (ERM) following peeling of an initial superficial membrane.^{2,3} Intraoperative HHOCT has also shed light on poorly understood mechanisms of disease pathogenesis, for example by demonstrating a potential communication between the vitreous cavity and intraretinal fluid in optic pit-associated schisis.⁴ Additionally, intraoperative HHOCT imaging has demonstrated surprising intraoperative findings, including the

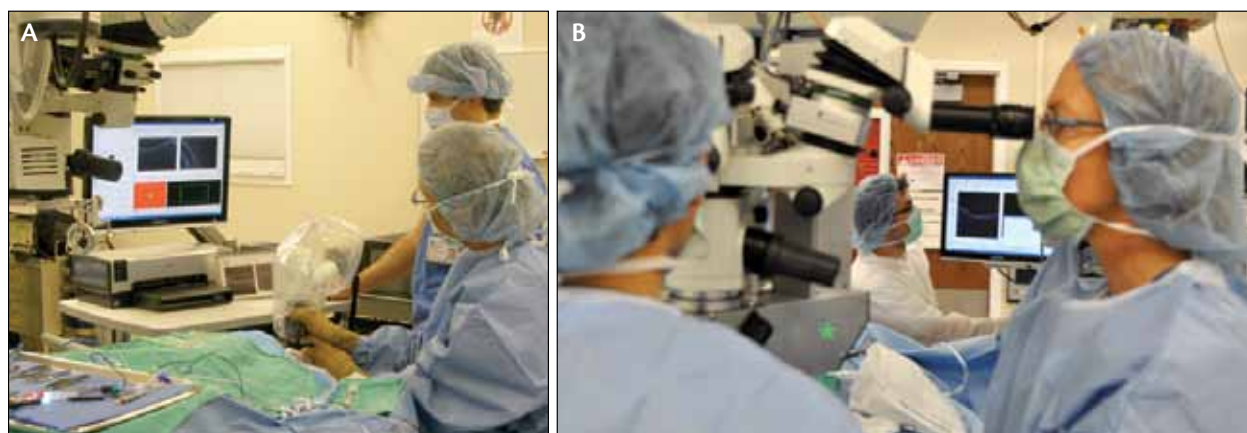


Figure 1. Handheld OCT (HHOCT) vs microscope-integrated OCT (MIOCT). Intraoperative HHOCT imaging is performed at a pause in surgery. The microscope must be removed from the surgical field. OCT images are sent to a mobile computer workstation (A). Images with the MIOCT device (green asterisk) are acquired in the same Duke operating room while maintaining a surgical view through the operating microscope. Until integrated displays are developed, MIOCT images are similarly sent to a mobile computer workstation (B).

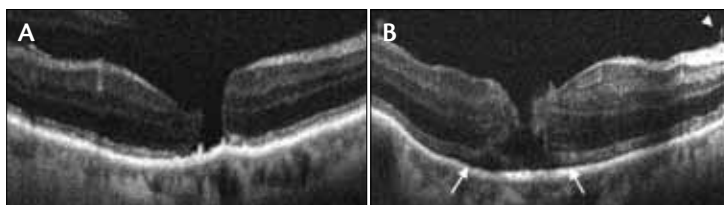


Figure 2. Intraoperative HHOCT obtained during vitrectomy with ILM peel for FTMH. The pre-incision image confirms the diagnosis of a FTMH (A). Following ILM peel, edges of peeled ILM (arrowhead) can be observed. The leaflets of the macular hole exhibit subretinal fluid (arrows) (B).

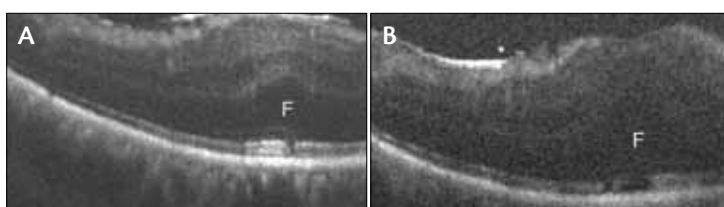


Figure 3. Intraoperative MIOCT imaging obtained during vitrectomy with membrane peel for ERM. MIOCT imaging at a preincision time point confirms a diffuse ERM extending over the fovea (A; notation F). Intraoperative MIOCT imaging, obtained with instruments removed from the eye after membrane peel, identifies an edge of peeled ERM (asterisk), confirming successful peeling off the foveal center (B; notation F).

persistence of subclinical subretinal fluid during FTMH repair as well as under perfluorocarbon liquid during retinal detachment repair^{5,6}; the significance of these findings, however, is unclear. Sunil Srivastava, MD, and Justis Ehlers, MD, at the Cleveland Clinic are conducting a prospective intraoperative and perioperative OCT (PIONEER) study, which will likely reveal additional applications for use of intraoperative handheld OCT imaging.

CASE 1: INTRAOPERATIVE HHOCT DURING VITRECTOMY WITH ILM PEEL FOR FTMH

HHOCT imaging obtained with the patient fully prepped and draped in the OR at a preincision time point confirms the preoperative diagnosis (Figure 2). Immediately following ILM peel, HHOCT imaging demonstrates the edges of peeled ILM, distant from the fovea. New subretinal fluid adjacent to the hole is now visible following ILM peel. The corrugated, relaxed appearance of the retina following peel suggests relief of tangential traction.

LIMITATIONS OF HANDHELD INTRAOPERATIVE OCT

Although intraoperative HHOCT imaging has provided important information not previously available to the surgeon, intraoperative imaging with a handheld device is fundamentally limited in that the surgeon must halt

surgical maneuvers in order to obtain images. Even with a custom microscope mount, which Drs. Srivastava and Ehlers have developed to improve imaging efficiency, the position of the microscope must be remanipulated out of the surgical field prior to HHOCT imaging. In addition to the decreased surgical efficiency, a more significant consequence is that intraoperative HHOCT imaging is unable to image live surgical maneuvers with surgical instruments in the eye.

A CUSTOM MICROSCOPE-INTEGRATED OCT DEVICE FOR INTRASURGICAL OCT ACQUISITION

To address these limitations, our team at the Duke Eye Center, led by Dr. Toth and Joseph A. Izatt, PhD, has developed a microscope-integrated OCT (MIOCT) system. With the optical path of a spectral-domain OCT scanner folded into that of the surgical microscope, the MIOCT unit enables simultaneous OCT acquisition concurrent with intraocular surgical manipulations without impairing the surgeon's view through the surgical microscope. MIOCT images can therefore be acquired as the surgeon maintains a surgical view (Figure 1B).

We are currently assessing the ability of the MIOCT system to obtain intraoperative images in human patients undergoing macular surgery. Under an institutional review board-approved protocol, we have prospectively studied the use of MIOCT first to obtain intraoperative images without instruments in the eye, similar to intraoperative HHOCT protocols.

CASE 2: INTRAOPERATIVE MIOCT IMAGING DURING VITRECTOMY WITH MEMBRANE PEEL FOR ERM

Intraoperative MIOCT imaging demonstrates successful peeling of an epiretinal membrane, with a visible edge of residual membrane away from the foveal center (Figure 3). These intraoperative MIOCT images are qualitatively identical to those that can be obtained with HHOCT. The use of MIOCT does not require maneuvering of the microscope away from the surgical field, as is required with HHOCT imaging, resulting in likely increased imaging efficiency.

CASES 3 AND 4: INTRAOPERATIVE MIOCT IMAGING WITH INSTRUMENTS OVERLYING THE RETINA

An integral advantage of MIOCT lies in its ability to obtain images with instruments in the eye, which can-

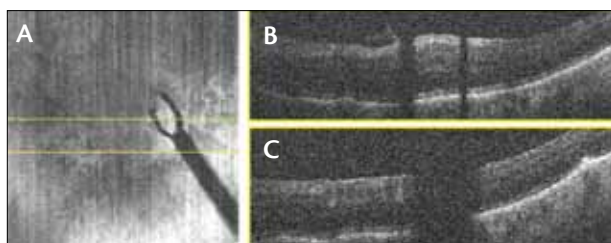


Figure 4. Intraoperative MIOCT imaging obtained with forceps overlying the retina and suspended safely in the mid-vitreous cavity demonstrates complete shadowing under the metallic instrument (A-C). Different shadowing characteristics (B-C) reflect differences in tool configuration between the tip and the shaft.

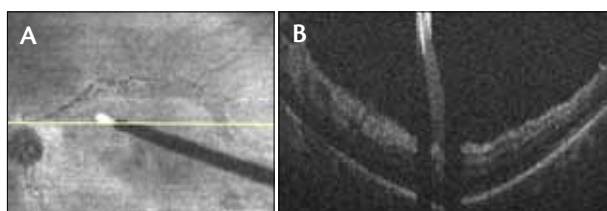


Figure 5. Intraoperative MIOCT imaging obtained with a Tano diamond-dusted scraper overlying the retina and suspended safely in the mid-vitreous cavity demonstrates visibility of underlying retinal structures through the silicone tip (A-B). A mirror artifact, similar to that observed in the clinic with OCT images of staphylomatous myopic retinas, falsely suggests that the tool is passing through the retina (B).

not be performed with HH OCT. We have prospectively assessed the use of MIOCT to obtain intraoperative images with instruments suspended safely in the mid-vitreous cavity.

MIOCT images can be successfully obtained with instruments in the human eye, suspended safely in the mid-vitreous cavity (Figures 4-5). Different material composition imparts variable degrees of visibility of underlying retinal structures.

THE IMMINENT FUTURE: INTRASURGICAL MIOCT IMAGING

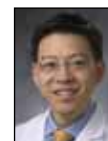
The development of MIOCT heralds a distinction between intraoperative imaging, herein defined as imaging using MIOCT or HH OCT obtained in the OR before or at a pause in surgical maneuvers, and intra-surgical imaging, or imaging obtained concurrent with surgical manipulations. Our group at the Duke Eye Center has previously demonstrated true intrasurgical image acquisition with real-time video imaging of surgical maneuvers in animal eyes,⁷ and we have demonstrated intraoperative image acquisition in human patients undergoing vitreoretinal surgery. We are excit-

ed to be currently assessing and developing MIOCT for true intrasurgical imaging in human eyes.

As we develop this system toward a seamless, fully integrated surgical experience, it will be critical to develop integrated display options to allow the surgeon to simultaneously visualize the surgical field and the OCT output. More important, development of real-time tracking algorithms will be critical to target the OCT scanner to a constantly moving area of interest, such as an instrument tip.

Other groups are developing similar devices designed toward intrasurgical imaging.⁸⁻¹⁰ The technology is developing rapidly, and we are beginning to investigate the prognostic value of intraoperative and intrasurgical OCT findings for postsurgical outcomes. We predict that OCT imaging will revolutionize surgical practice as it already has in the clinic, providing a platform for the development of novel surgical techniques and a basis for understanding variable surgical outcomes. We invite you to stay tuned. ■

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