

INTRAOPERATIVE 4-D MICROSCOPE-INTEGRATED OCT

Real-time image acquisition can provide new types of information to the retina surgeon.

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Optical coherence tomography (OCT) has revolutionized the clinical practice of ophthalmology, but until a few years ago its use was limited to pre- and postoperative assessment of patients in clinic. In 2009, Toth and col-

leagues brought a handheld spectral-domain OCT (SD-OCT) system into the OR.¹ The primary drawback of this system was its restriction for use only during pauses in surgery. In 2010, Tao et al first demonstrated the use of microscope-integrated OCT (MIOCT) capable of providing simultaneous microscope and OCT imaging of the human retina.²

Over the past few years, further extensive research has facilitated seamless integration of SD-OCT into the operating microscope. This integration now enables real-time intraoperative OCT imaging during different stages of surgery. Numerous studies have described the role of this technology in anterior and posterior segment procedures.³⁻⁹ These studies reported excellent live 2-D (ie, B-scan) visualization of the anatomic alterations that occur during surgery. Although volumetric OCT images could be obtained with these systems, acquisition time was relatively slow (2-10 seconds), and rendering was restricted to postprocessing.¹⁰ Live volumetric imaging of surgery was therefore not feasible, and feedback from intraoperative OCT was limited to 2-D images (B-scan and en face views).

LIVE VOLUMETRIC INTRAOPERATIVE OCT

With further advances in intraoperative OCT technology, our group at Duke University Medical School developed a research prototype intraoperative swept-source MIOCT (SS-MIOCT) capable of imaging and rendering up to 10 volumes per second. This high volumetric frame rate is achieved by using an ultrahigh-speed swept-frequency source centered at 1040 nm wavelength. Consequently, SS-MIOCT is capable of producing real-time live volumetric 4-D (ie, 3-D over time) imaging, in addition to conventional 2-D B-scans, for visualization of anterior and posterior segment surgeries.

In 2016, Carrasco-Zevallos et al showed that SS-MIOCT

could successfully image either the pathology or surgical site of interest in 95% of surgeries included in their study.¹¹ To provide real-time stereo 4-D MIOCT visualization to the surgeon, we use a heads-up display (HUD) integrated into the operating microscope (Figure 1). Within the oculars, the surgeon is able to see the B-scan and 4-D imaging, and he or she can change the volume orientation using a foot-controlled joystick. The images are also displayed on external monitors in the operating suite.

RATIONALE FOR 4-D INTRAOPERATIVE OCT

The 4-D intraoperative imaging capability of this system can be useful in a number of ways.

Intraoperative Visualization of Intraocular Structures

Moving 2-D B-scans across an area of interest can provide important feedback during surgery,³⁻⁹ but a 3-D or 4-D view can facilitate more comprehensive visualization of structures of interest in relation to the retina. One example is in the intraoperative detection of pathologies. Two-dimensional B-scans show only a cut section of a selected location at a time, with limited information on tissue relationships one or more cuts away. By contrast, the 3-D volumes can be cut away and positioned to display the site of interest and adjacent structures above, below, and on



AT A GLANCE

- A research prototype intraoperative swept-source microscope-integrated OCT (SS-MIOCT) capable of imaging and rendering up to 10 volumes per second has been developed at Duke University.
- The instrument can perform volume rotation, allowing the surgeon to get a comprehensive 3-D view of the retina and helping to guide intraoperative procedures.
- Future research will have to answer questions such as how best to present this new additional information to the surgeon.

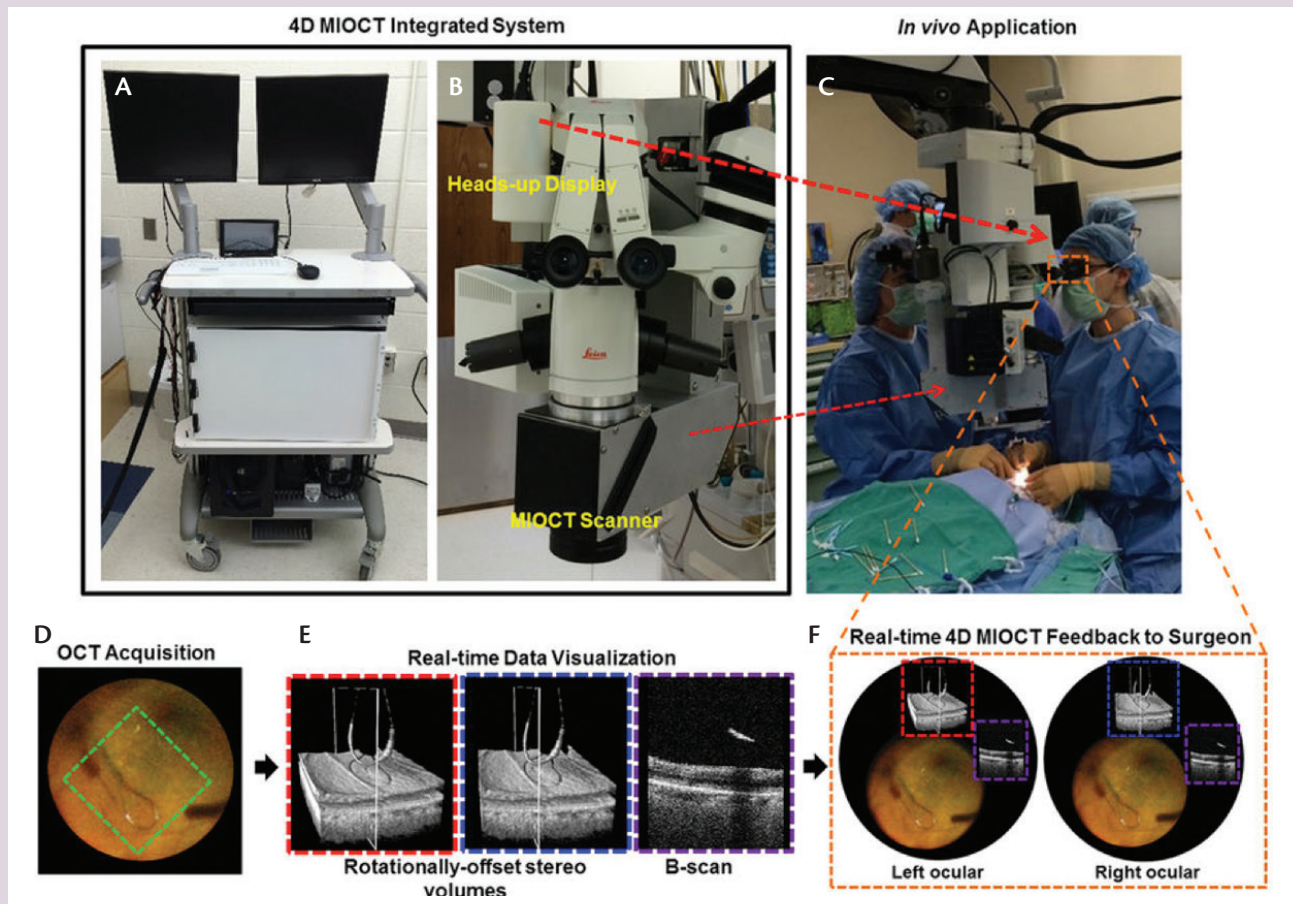


Figure 1. Photograph of the 4-D MIOCT system portable cart housing the OCT laser, interferometer, electronics, and processing computer (A). Photograph of the MIOCT scanner, operating microscope, and heads-up display (HUD); the HUD and MIOCT scanner are integrated seamlessly into the microscope (B). Photograph of system in use during human surgery. The microscope-integrated design enabled OCT data acquisition during live surgery (C). A 4-D MIOCT acquisition with the scan (green box) oriented to the axis of the surgical instrument. The MIOCT scan axis can be arbitrarily rotated and shifted laterally to scan the surgical site of interest (D). Rotationally offset stereo MIOCT volumes and B-scans rendered in real time (E). Projection of 4-D MIOCT data and other supporting surgical data into the oculars for real-time OCT feedback to the surgeon (F).¹¹

either side of the site. This gives the surgeon a better orientation and understanding of a specific pathologic structure in relation to the retina at a certain location.

This capability was particularly helpful in patients with diabetes undergoing vitrectomy for tractional retinal detachment,¹² due to complexity of the pathologies in these cases. The pathologies associated with these cases (such as tractional schisis or detachment, dense membranes, and subretinal or intraretinal fluid) could be present at different levels—subretinal, intraretinal, and preretinal—and across multiple locations in the retina.

The ability to perform volume rotation is also important for getting a comprehensive 3-D view of the retina. Volume rotation is a valuable tool that can provide the surgeon with different angles of visualization of an area of interest. As structures and their orientation dynamically change during the course of surgery, live 3-D visualization can provide

the surgeon with new information that cannot be obtained through a conventional microscope or 2-D B-scans. This additional information can facilitate intraoperative decision-making and help to confirm the completion of surgical goals.

Intraoperative Guidance of Surgical Maneuvers

This OCT imaging modality can perform live volumetric tracking of dynamic surgical maneuvers, thereby providing real-time intraoperative guidance to the surgeon. With 3-D/4-D imaging, SS-MIOCT can reveal not only a cross-sectional (B-scan) view of a surgical instrument but also the structure of the instrument tip or tissue of interest relative to the retina. This allows the surgeon to gauge more accurately the distance between the instrument tip and the surface of the retina or the membrane of interest.

Moreover, volume rotation using the surgeon-controlled joystick can provide more details, allowing viewing

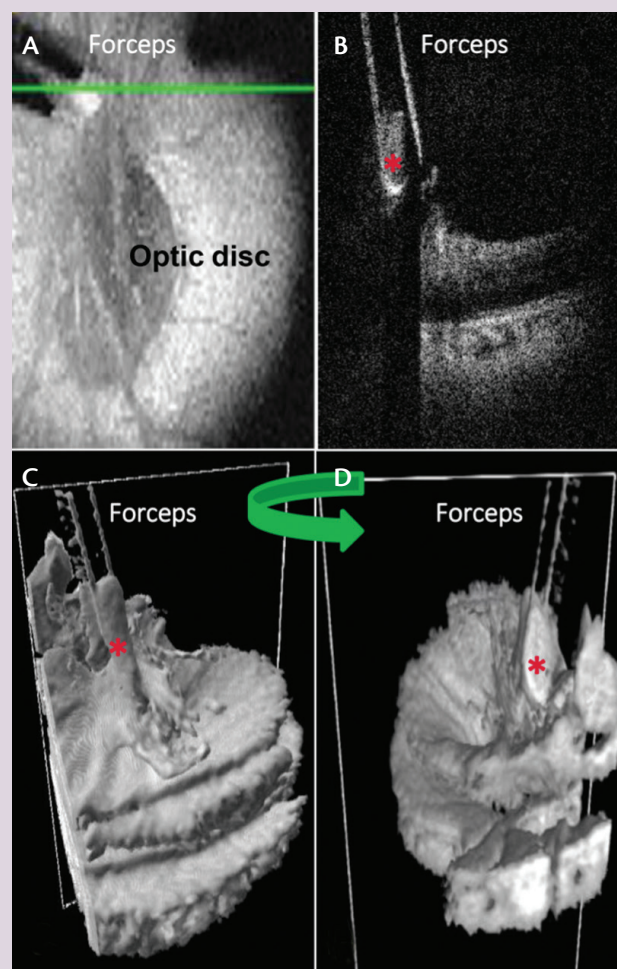


Figure 2. Membrane delamination: en face view (A); B-scan (B); volume rotation with 3-D image from two different angles (C and D). Asterisk (*) indicates fibrovascular membrane.¹²

of dynamic interactions between instruments and membranes from multiple angles (Figure 2). The surgeon can gain important guidance, especially in complex surgical maneuvers such as peeling, viscodissection of dense membranes,¹² or submacular surgery.¹³⁻¹⁵

LIMITATIONS

Although 4-D scans provide a comprehensive view of an area of surgical interest, the field of view is small. Artifacts can sometimes undermine image quality and limit the feedback we get. Also, instrument shadowing of underlying tissues is still a setback, as is the case with all intraoperative OCT systems.

Furthermore, supplying *too much* information to the surgeon may also be considered a drawback. Within the microscope oculars, the surgeon can see the conventional microscope view, 2-D B-scans, and 4-D OCT scans, in addition to having the ability to perform volume rotations to provide different visual perspectives for the same area of interest. We now face important questions about this capability. Is this too much feedback to the surgeon? Can the surgeon usefully process all these data while

performing surgical maneuvers? What is the best surgeon-friendly interface to deliver all this information?

FUTURE ADVANCES

Research is ongoing to address the aforementioned limitations. Increasing OCT scan speed can provide faster volumetric frame rate acquisition, which could facilitate more seamless tracking of surgical maneuvers. Manufacturers may step up to design OCT-compatible instruments that can minimize the shadowing induced by currently available instruments. Recent advances have brought us 3-D retina surgery visualization using a large external HUD, such as the Ngenuity 3D Visualization System (Alcon). Integration of our 4-D intraoperative OCT system into this technology could begin a new era in visualization modalities for vitreo-retinal surgery. ■

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