UTILITY OF INTRAOPERATIVE OPTICAL COHERENCE TOMOGRAPHY DURING VITRECTOMY SURGERY FOR VITREOMACULAR TRACTION SYNDROME

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Purpose: To assess the microarchitectural changes occurring during surgery for vitreomacular traction using intraoperative optical coherence tomography (*i*OCT).

Methods: A retrospective, consecutive case series of eyes undergoing pars plana vitrectomy for vitreomacular traction with performance of concurrent *i*OCT. A custom, microscope-mounted portable spectral domain optical coherence tomography system was used. Clinical characteristics and *i*OCT images were analyzed.

Results: Twelve eyes of 12 patients were included with a mean preoperative visual acuity of 20/78 improving to 20/51 ($P = 0.02$), postoperatively. Intraoperative optical coherence tomography was successfully performed in 100% of cases. Microarchitectural changes were noted on *i*OCT after surgical release of the vitreomacular traction particularly in the outer retina with increased subretinal hyporeflectivity (e.g., expansion of the distance between the retinal pigment epithelium and photoreceptor layers). In 5 of 12 eyes (42%), *i*OCT findings altered the surgical procedure (e.g., internal limiting membrane peeling, gas tamponade) to address the subclinical findings (e.g., full-thickness macular hole formation, residual membrane).

Conclusion: Intrasurgical imaging using *i*OCT during vitreomacular traction surgery may identify subclinical changes (e.g., occult full-thickness macular hole formation) that may impact surgical decision making. Architectural changes may occur after surgical maneuvers that are particularly noted in the outer retina. The functional significance of these changes requires further investigation.

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Anomalous posterior vitreous separation and abnormal vitreomacular adhesion result in vitreomacular traction (VMT).[1] When VMT results in visual loss and metamorphopsia, therapeutic intervention may be needed. Until recently, the only treatment for VMT was pars plana vitrectomy (PPV). The recent approval of ocriplasmin (Jetrea; Thrombogenics, Iselin, NJ) offers a pharmacologic therapeutic alternative for select cases.[2] Spectral domain optical coherence tomography has yielded high-resolution, in vivo tomographic views of macular pathology, which has resoundingly impacted the understanding in the diagnosis and management of VMT in the clinic setting.[3]

The application of OCT technology to the operating room has the potential to impact surgical management of VMT. The feasibility of intraoperative OCT (*i*OCT) has been described in numerous conditions including macular holes, optic pit-related maculopathy, epiretinal membrane (ERM), retinal detachment, and retinopathy of prematurity.[4–10] The objective of VMT surgery is to remove all epiretinal tissues (e.g., posterior hyaloid, ERM) that are imposing traction on the fovea, and in some cases the removal of internal limiting

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membrane (ILM) may be indicated. Surgical elevation of the hyaloid may result in unroofing of foveal cysts or full-thickness macular hole (FTMH) formation. The ability to discern the microarchitectural structure of the vitreoretinal interface and any significant surgical alterations (e.g., FTMH formation) could result in alterations to surgical procedures that might improve surgical outcomes and patient management. In this study, we describe the *i*OCT findings in the intrasurgical management of VMT using a microscope-mounted *i*OCT system, and we delineate the significant microarchitectual alterations noted after surgical manipulation. Additionally, we outline the role that *i*OCT may have in influencing surgical decision making and management in cases with VMT.

Methods

A retrospective consecutive multisurgeon case series was performed for all eyes undergoing PPV for VMT with concurrent *i*OCT imaging. All eyes underwent preoperative OCT scanning with Cirrus spectral domain optical coherence tomography system (Carl Zeiss Meditec, Dublin, CA) with verified VMT in the clinic before surgery. No cases were noted to have FTMH on the preoperative OCT performed in the clinic. Twelve eyes from 12 patients were identified. This study was approved by the Cleveland Clinic Foundation Institutional Review Board and all tenets of the Declaration of Helsinki were followed.

Surgical Procedure

All patients underwent standard 3-port PPV (23- or 25-gauge) repair of VMT. After completion of the core PPV, the hyaloid was carefully elevated using the vitreous cutter. Based on surgeon preference, dilute triamcinolone acetonide was used to stain the hyaloid for enhanced visualization in some cases. The ILM was also peeled in cases with an ERM that was noted on OCT either preoperatively (in the clinic) or on the first *i*OCT scan before initiating peeling. Additionally, ILM peeling was performed if an FTMH was noted on *i*OCT scanning. If the ILM was peeled, indocyanine green was applied to stain the ILM to aid in visualization. The membrane peeling technique was performed with either vitreoretinal forceps or a diamond-dusted membrane scraper combined with vitreoretinal forceps for peel completion. A partial or complete air–fluid was performed based on surgeon preference. After air–fluid exchange, gas selection was chosen based on surgeon preference and surgical indication. Any specific postoperative positioning was also based on surgeon preference and surgical indication.

Intraoperative Optical Coherence Tomography Scanning System

Using a custom microscope-mounted system, the Bioptigen Envisu SDOIS (Bioptigen, Research Triangle Park, NC) handheld probe was attached to the ophthalmic microscope, as previously described (Figure 1).[4,5] Intraoperative OCT was performed at various surgical milestones as determined by the surgeon including preincision, posthyaloid elevation, and after ILM peeling. A consistent image acquisition protocol was used, including cubic 10 mm × 10 mm volume scans (at 0 and 90°) and 10-mm radial volume scans. Each scan consisted of 100 B-scans distributed across the area with 1000 A-scans per B-scan. For the 10 mm × 10 mm cube scans, this translated to a scan density of 1 B-scan every 0.1 mm.

Intraoperative Optical Coherence Tomography Image Analysis

All scanning sequences were exported for image analysis. Qualitative and quantitative analysis was performed by two independent reviewers. Quantitative analysis was performed using ImageJ (NIH Freeware, Bethesda, MD) software. Two independent reviewers

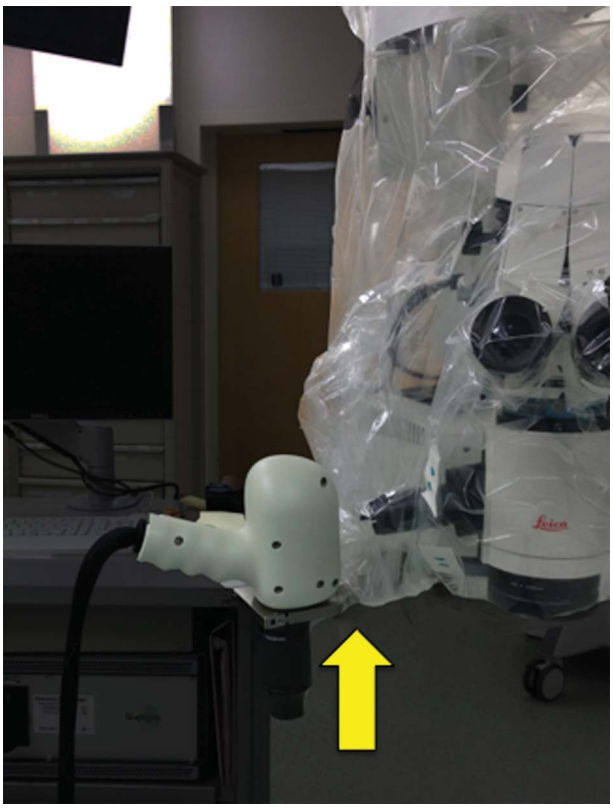

Fig. 1. Microscope-mounted spectral domain optical coherence tomography system (Bioptigen SDOIS) used for intraoperative scanning.

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reviewed each scan for two quantitative variables before and after hyaloid elevation: subretinal hyporeflectivity (i.e., ellipsoid zone [i.e., inner segment/outer segment] to retinal pigment epithelium [RPE] distance) and central foveal thickness. The outer boundary used for measurement was the middle of the RPE. The inner boundary varied based on the location of interest (e.g., ILM, the middle of ellipsoid zone). The preincision and posthyaloid measurements were compared using paired *t*-test.

Results

Clinical Characteristics and Demographics

Twelve eyes of 12 patients were identified that underwent surgical repair for a preoperative diagnosis of VMT who had concurrent *i*OCT imaging. The median age was 73.5 years (range, 56–83 years). There were 5 men (42%) and 7 women (58%). The mean preoperative visual acuity was 20/72 (range, 20/30–20/200). Four eyes (33%) were phakic and 3 of those 4 eyes underwent cataract extraction with intraocular lens placement at the time of PPV. All other eyes were pseudophakic at the time of PPV. One eye (8%) underwent 25-gauge PPV and 11 eyes (92%) underwent 23-gauge PPV. Six of 12 eyes (50%) had associated ERM that was noted in the preoperative OCT scan in the clinic and the preincision scan on *i*OCT. No postoperative surgical complications were noted. The mean postoperative visual acuity improved to 20/51 ($P = 0.02$).

Qualitative iOCT Analysis and iOCT Impact on Surgical Procedures

Eleven of 12 eyes had *i*OCT scans completed immediately before beginning the PPV. One eye was not imaged before PPV because of poor signal strength and surgeon preference but was subsequently imaged after hyaloid elevation. Twelve of 12 eyes showed complete clearance of tractional forces surrounding the fovea on *i*OCT before completing the surgical procedure. After the removal of the foveal traction (e.g., release of the posterior hyaloid, membrane peeling), there seemed to be an immediate reduction in foveal height. Additionally, an increase in the ellipsoid zone–RPE distance was also visualized in the subfoveal space and in the areas of membrane peeling (Figure 2).

For 2 of 11 eyes (18%), the preincision *i*OCT scans immediately before vitrectomy revealed conversion from VMT without macular hole (confirmed on the preoperative scan obtained in the clinic) to an FTMH (Figure 3). When the PPV was commenced in both cases, the FTMH was subclinical because of its small size. In both of these cases, the surgeon altered the surgical plan based on the *i*OCT findings to include ILM peeling, long-term gas tamponade, and postoperative facedown positioning to address the FTMH. Both eyes showed successful closure of the FTMH in the postoperative period. These two eyes were excluded from additional quantitative analysis, given the change in pathology from VMT to FTMH.

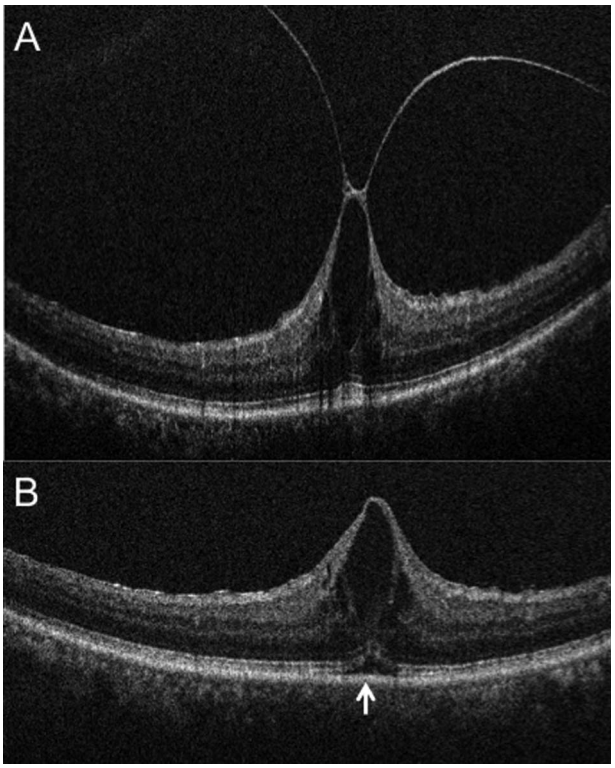

Fig. 2. Intraoperative optical coherence tomography (*i*OCT) 10-mm B-scan showing (**A**) vitreomacular traction (arrowhead) prominent foveal traction before elevation of the hyaloid. **B.** Intraoperative ophthalmic coherence tomography 10-mm B-scan revealing complete release of traction with reduction in central foveal thickness. Increased subretinal hyporeflectance is noted (arrow). The slight variation in RPE curvature is due to subtle changes in scanner alignment that occur in the operating room environment.

Of the remaining eyes, 10 of 10 eyes had *i*OCT imaging performed after hyaloid elevation. After the release of the hyaloid, 2 eyes showed loss of inner retinal integrity with possible FTMH formation (Figure 4). These changes were not apparent clinically to the surgeon and were only definitively visualized with *i*OCT. In both of these cases, the surgeon altered the surgical plan to include ILM peeling, gas tamponade, and postoperative facedown positioning based on the *i*OCT findings. Both eyes showed successful closure of the FTMH.

In the seven eyes with underlying ERM, all seven had ILM/ERM peeling and *i*OCT imaging was performed after this peel. After peeling, 1 of 7 eyes (14%) with ERM was noted on *i*OCT to have a residual

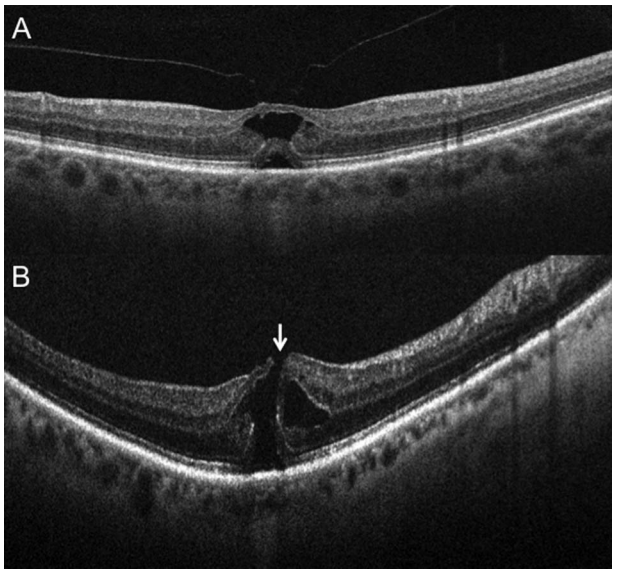

Fig. 3. Subclinical interval development of an FTMH. **A.** Preoperative 6-mm B-scan (Cirrus) at the time of surgical scheduling in the clinic revealing VMT without full-thickness defect. **B.** Intraoperative OCT 10-mm B-scan (Bioptigen) showing interval development of subclinical FTMH immediately before vitrectomy (arrow). This altered surgical approach with gas tamponade and ILM peeling.

membrane within the macular arcade that the surgeon determined the required additional membrane peeling because of its proximity to the fovea (Figure 5).

Overall, *i*OCT impacted the surgical plan in 5 of 12 eyes (42%) (e.g., ILM peeling, gas tamponade, positioning, additional peeling). Two eyes were noted to have subclinical FTMH before initiating the procedure, two eyes were noted to have a possible/definitive FTMH after hyaloid elevation, and one eye was noted to have residual ERM after an initial peel that required additional membrane peeling.

Quantitative Intraoperative Optical Coherence Tomography Analysis

Nine of nine eyes, where both preincision and posthyaloid scan were obtained of sufficient quality

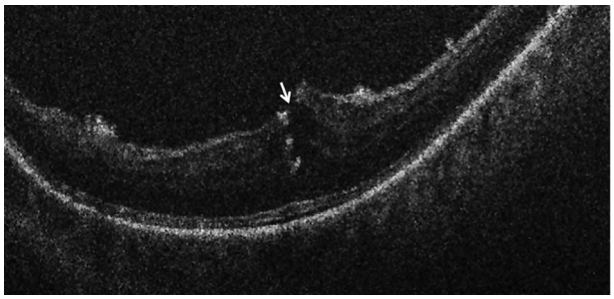

Fig. 4. Intraoperative OCT B-scan after posterior hyaloid release revealing the loss of integrity of the inner retina. Hyperreflective areas within the retinal substance represent intraretinal triamcinolone particles after the loss of inner retinal integrity.

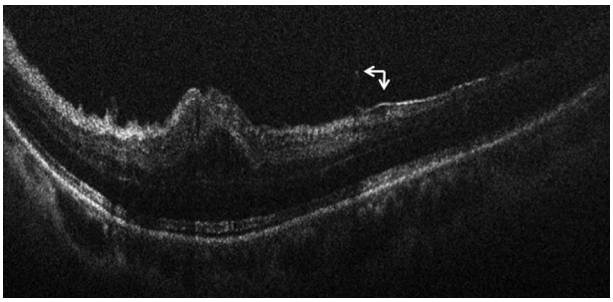

Fig. 5. Intraoperative OCT B-scan after membrane peeling and release of hyaloid traction revealing residual occult membrane (arrow) in close proximity to the fovea, requiring additional membrane peeling.

to measure, exhibited a decrease in central foveal thickness. Mean preoperative central foveal thickness was 792 μm (range, 488–1546 μm). After hyaloid release, the mean central foveal thickness was 694 μm (range, 428–1354 μm). This represented a mean decrease of 98 μm (−12%) after the release of the hyaloid traction ($P = 0.002$) (Figure 6). Of these nine eyes, all seemed to have subfoveal expansion of hyporeflectivity (e.g., increased RPE to ellipsoid zone distance). Only five eyes had both preincision and posthyaloid scans of sufficient quality to accurately measure the distance between the RPE and ellipsoid zone. Four of 5 eyes (80%) showed increased distance between the RPE and ellipsoid zone lines with expansion of subretinal hyporeflectivity. The mean change in RPE to ellipsoid zone distance was +28 μm (25%), $P = 0.05$ (Figure 6).

Discussion

Optimal management for VMT continues to evolve. The use of *i*OCT during VMT surgery may provide an important adjunct to verify the achievement of surgical objectives and identify alterations in foveal anatomy that may require an altered surgical approach. In this study, we find that significant alterations occur in foveal architecture and outer retinal structure after surgical release of the posterior hyaloid. Additionally, we find that in a large percentage of cases (42%), *i*OCT seemed to have a direct impact on surgical decision making and provided important information to the surgeon that altered the surgical approach. In one example, *i*OCT revealed a residual membrane that was not otherwise visualized by the surgeon through the surgical microscope. Currently, adjuncts (e.g., triamcinolone, indocyanine green) are typically used to maximize membrane visualization and removal. In this case, restaining was not performed because *i*OCT revealed the membrane. Restaining may have identified the membrane without *i*OCT. Further research is needed to better assess the

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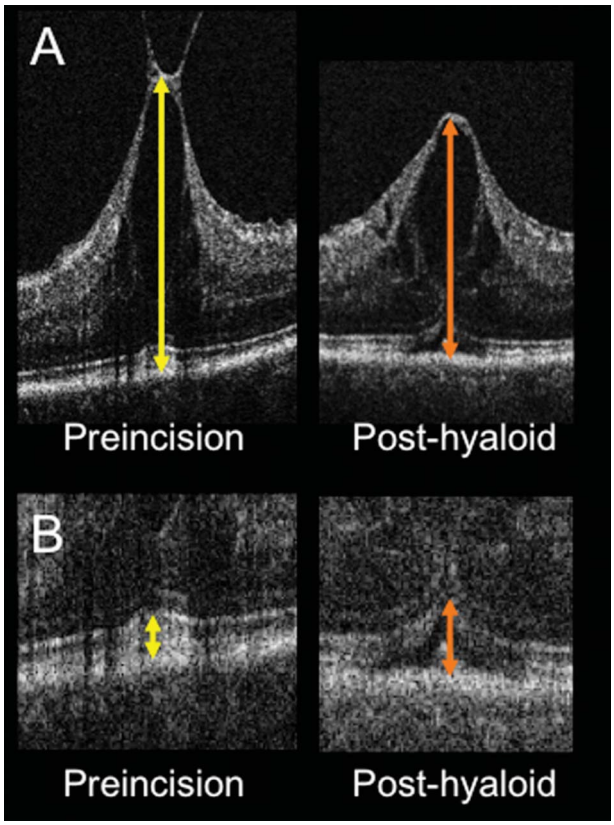

Fig. 6. A. Intraoperative OCT B-scan showing rapid change in contour and decreased central foveal thickness (arrows) after release of the posterior hyaloid. **B.** Intraoperative OCT B-scan revealing increased subretinal hyporeflectivity (arrows) after elevation of the posterior hyaloid.

role of *i*OCT in membrane visualization and the relative utility of contrast dyes and *i*OCT. The combined use of contrast dyes and *i*OCT may also have value in enhanced visualization of anatomical structures (e.g., posterior hyaloid relationships).[11]

To our knowledge, only a single case report has been published regarding the use of *i*OCT and VMT. In that report by Dayani et al, tractional release was confirmed after hyaloid elevation using *i*OCT visualization. There was a suggestion of improved contour, however, no quantitative analysis was performed. In the current study, several qualitative features were noted on *i*OCT after the release of VMT. After elevation, a high percentage of eyes seemed to show outer retinal alterations with the increased height of hyporeflective band between the ellipsoid zone and the RPE. This may represent photoreceptor stretching secondary to induced traction during hyaloid elevation. Alternatively, this may reflect subclinical neurosensory retinal detachment with photoreceptor disinsertion. The functional implications of these alterations are unknown and further research is needed to better correlate the outer retinal alterations with visual function/recovery. Interestingly, changes in the outer retina have been reported on spectral domain optical coherence tomography after pharmacological vitreolysis with ocriplasmin including alterations to the ellipsoid zone and increased subfoveal hyporeflectivity (e.g., subfoveal fluid).[12] Whether these changes are similar to the changes noted intrasurgically deserves further investigation.

Subclinical anatomical alterations may occur between preoperative imaging and surgical intervention that would otherwise alter the surgeon's plan. This study revealed that, in 2 of 11 cases with VMT, progression occurred to a subclinical FTMH before surgical intervention. Two weeks and 6 weeks had passed in these cases, respectively, between the preoperative scan in the clinic and the preincision *i*OCT scan. Same-day standard spectral domain optical coherence tomography would have also revealed the change, but this is not usually standard clinical practice. In addition to changes that occur between the clinical visit and the surgical intervention, retinal anatomy may also change during surgical intervention. In this study, two additional cases were noted to have potential FTMH on *i*OCT during surgical intervention. This resulted in 33% of cases being treated surgically as an FTMH (e.g., ILM peeling, gas tamponade) rather than with routine VMT surgical management, which may not have occurred without the assistance of *i*OCT.

Additional information regarding intrasurgical dynamics during VMT surgery could be potentially obtained using a microscope-integrated OCT system (in contrast to the microscope-mounted system in this study). Currently, although not commercially available in the United States, these predominantly research systems have been used to describe real-time surgical maneuvers, visualization of microsurgical instrumentation, and dynamic imaging of instrument motion and tissue interaction.[13–16]

This study has several limitations including its retrospective nature and relatively small sample size. The current OCT systems that are used for intraoperative imaging, including the Bioptigen system used in this study, lack image registration and tracking. This greatly hampers comparative measurements. To account for some of these limitations, scans were taken from multiple orientation (e.g., 0°, 90°, radial) to maximize visualization of the area of interest. Because of the retrospective nature of the study, functional correlation with the anatomical changes was unable to be assessed in an optimal manner. In addition, specific staining or restaining with dyes such as indocyanine green was not mandated. Some of the alterations visualized with *i*OCT could have also been visualized with restaining, although not clinically apparent through the surgical microscope.

This study continues to build on the body of evidence that *i*OCT may provide important insights to the pathophysiology of surgical ophthalmic diseases while acting as a unique surgeon feedback tool that may impact surgical decision making.[4–10,16] The novel outer retinal architectural changes identified need additional study, particularly in relation to the impact on functional outcomes. Additionally, the direct impact of *i*OCT on surgical decision making in VMT surgery needs to be studied on a larger prospective scale to better delineate its role. To answer some of these questions, we have initiated a prospective multisurgeon *i*OCT study, PIONEER, examining many of these issues as they relate to *i*OCT in ophthalmic surgery, including VMT.

Key words: optical coherence tomography, intraoperative OCT, intrasurgical OCT, vitreomacular traction syndrome, VMT, retinal surgery, vitreomacular adhesion.

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