

Fully Automated OCT Analysis of Eyes Healing From Macular Hole Surgery

A biomedical data science approach reveals how preoperative SD-OCT scans can help surgeons prepare for macular hole repair.

BY THEODORE LENG, MD, MS

Modern macular hole surgery is a rapid, efficient, and relatively low-risk procedure that results in favorable visual acuity outcomes. It typically consists of pars plana vitrectomy (PPV) followed by internal limiting membrane (ILM) peeling and gas endotamponade. Face-down positioning (in variable amounts) is prescribed, and closure of most macular holes occurs during the first 3 to 7 days after surgery. Published rates of anatomic closure of macular holes are well over 90%, and a majority of patients report improved vision after closure¹; however, a subset of patients do not improve despite apparent anatomic closure of the macular hole. Thus, there is a need to be able to assess eyes undergoing surgery for macular hole repair in order to better prepare surgeons for patient outcomes.

THE ROLE OF SPECTRAL-DOMAIN OPTICAL COHERENCE TOMOGRAPHY

Spectral-domain optical coherence tomography (SD-OCT) is a fast, noncontact imaging modality that provides histologic quality resolution of the macula. It is an invaluable tool in the management of many retinal diseases and is routinely used in diagnosing, staging, and monitoring macular holes. Many surgeons also obtain SD-OCT scans postoperatively to assess the anatomic success of their surgeries.

A common use of OCT has been to find the central B-scan and qualitatively examine it to determine that a full thickness macular hole exists. This allows the surgeon to make the decision to perform surgery. Some surgeons make quantitative measures using a caliper function built into review software to measure the diameter of the macular hole. Now, other features associated with macular holes (eg, the presence of cystoid edema at the edges of the hole and the status of the vitreomacular interface) can

At a Glance

- SD-OCT can identify several features associated with macular holes that may help determine the presence of PVD or ERM.
- A group at Stanford determined that a decreasing area of ellipsoid zone band defects in the foveal and parafoveal regions was a good predictor for postoperative recovery of visual acuity.
- The Stanford study also showed that patients with larger preoperative macular holes had greater improvements in visual acuity than those with smaller macular holes.

also be assessed on SD-OCT. The status of these features helps surgeons determine the presence of a posterior vitreous detachment (PVD) or an epiretinal membrane (ERM) in association with the macular hole, as well as whether there is ongoing vitreomacular adhesion.

Not only can these features aid in determining whether surgery is necessary, they can also be useful in surgical planning. For example, SD-OCT can help to determine whether the surgeon will have to induce a PVD during vitrectomy, or if an ERM will require peeling before the ILM is peeled, and, if so, whether the ERM will block or prevent proper staining of the ILM with a vital dye. A preoperative SD-OCT scan can prepare the surgeon as much as possible for macular hole repair surgery.

COMPUTER-AIDED ANALYSIS

Examining a preoperative SD-OCT scan may prove helpful in planning the surgical approach, but what can

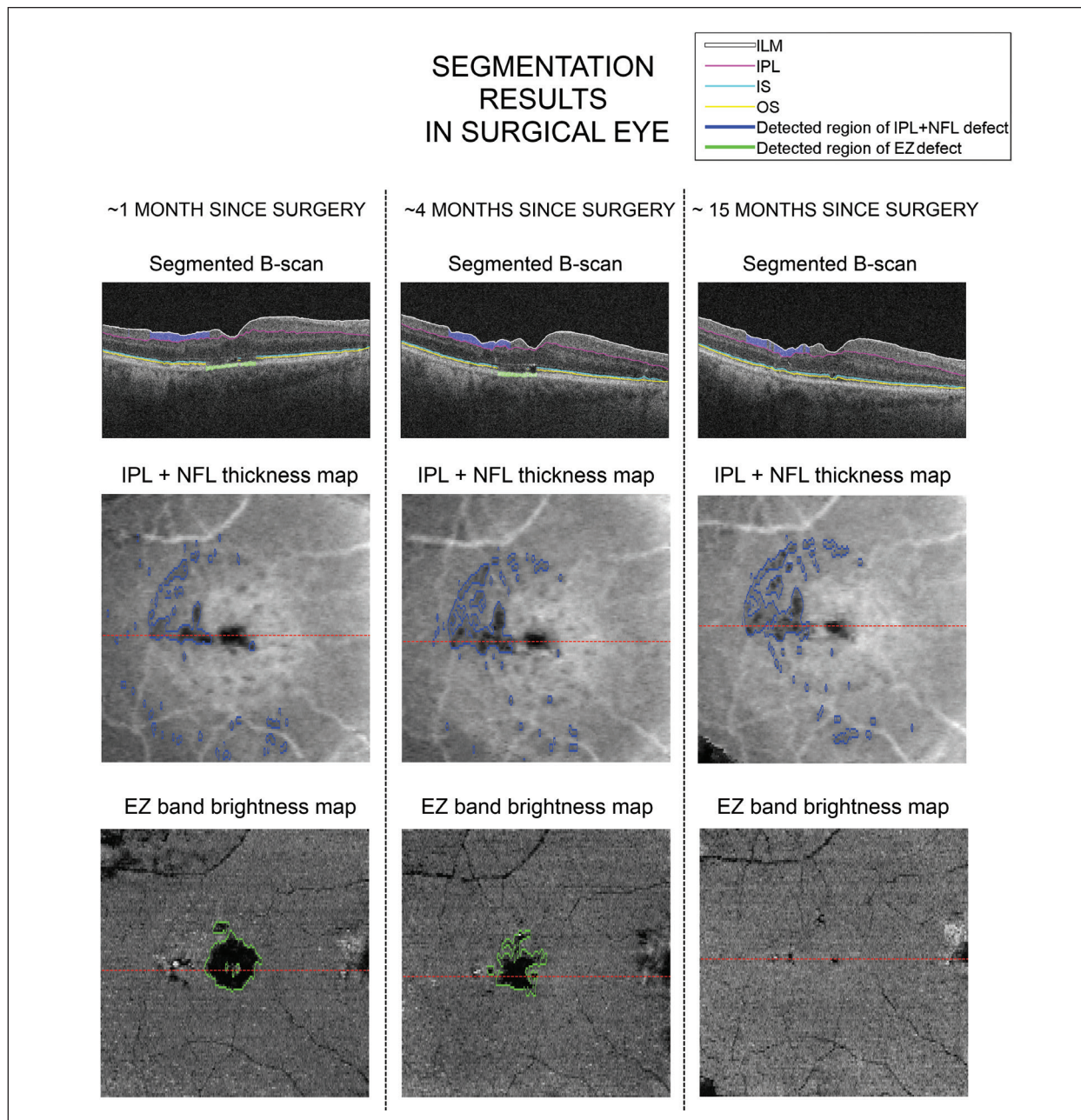


Figure. Retinal boundary and defect segmentation results for a single eye. The first, second, and third columns display the results at approximately 1 month, 4 months, and 15 months after macular hole repair surgery, respectively. The first row displays a horizontal B-scan across the center of the fovea with white, magenta, light blue, and yellow markings indicating the location of the ILM, inner plexiform layer (IPL), inner segment, and outer segment boundaries, respectively. The region of blue shading between the ILM and IPL and green shading around the RPE region correspond to regions of segmented IPL and nerve fiber layer (NFL) defects (ie, dimples) and regions of EZ band defects, respectively. The corresponding IPL and NFL topographic thickness maps and EZ band brightness maps are displayed in the second and third rows, respectively, together with outlines of the corresponding defect segmentation results. The red line in the topographic maps indicates the location of the B-scan in the top row. This analysis technique demonstrates the resolution of both inner and outer retinal defects over time as the retina heals from surgery. Some inner retinal defects persisted even after 1 year, while the EZ band defects completely resolved.

it tell us about visual acuity outcomes after surgery? When their macular holes are anatomically closed, why do some patients fare better than others?

Previously, the analysis of postoperative SD-OCT data in macular hole patients was limited to the manual annotation of defects in a single B-scan localized at the foveal center.² Our group at Stanford took a different approach to using OCT data to answer the questions posed above. Rather than simply looking at one 2-D B-scan, we designed a fully automated analysis algorithm to segment and analyze entire 3-D OCT cubes, each of which contain more than 67 million voxels.³ (A voxel is a 3-D pixel.) After segmenting the retinal layers with a home-grown algorithm,⁴ we extracted features that could be associated with visual acuity outcomes in eyes healing from macular hole surgery.

Specifically, we looked at the areas and locations of ellipsoid zone (EZ) defects as well as defects in the inner retina by extracting a set of image features related to the topographic extent and location of these defects. We examined the correlation of these imaging features on a pixel-by-pixel basis with visual acuity in postoperative macular hole longitudinal SD-OCT scans (Figure). Our method improved results compared with previous studies, as automated 3-D analysis allowed us to quantitatively assess the entire macula topographically, instead of in single horizontal or vertical B-scans, where some defects would be hard to visualize or might not even be displayed.

THE STUDY IN A NUTSHELL

Design

This study used data from 35 patients who underwent surgical repair in one eye (45.7% right eyes) after being diagnosed with stage 3 or stage 4 macular hole by funduscopy and SD-OCT examination. All surgeries were performed by 25-gauge three-port PPV. After the vitreous was removed, the ILM was stained with indocyanine green (ICG; 2.5 mg/mL in 5% dextrose water) for 20 seconds. End-grasping ILM forceps were used to elevate and peel the ILM from the macula and from around the macular hole. A gas endotamponade (14% C3F8 or 18% SF6) was used in all cases, and 10 days of face-down positioning was prescribed.

Results

Our study showed significant correlation of EZ band defects in the fovea and regions surrounding the fovea with postoperative visual acuity outcomes. Looking at scans 6 to 12 months after surgery, we found that certain characteristics correlated with visual acuity: EZ band defects in the foveal subfield, the temporal-inner subfield, the inferior-inner subfield; the size of defects in the foveal

subfield; and their circularity. These EZ band defects became gradually smaller over time (Figure, bottom row). Additionally, defects located in the inner retina, likely attributed to ILM staining with ICG or to surgical trauma, did not correlate with visual acuity and also did not recover like the EZ band defects did (Figure, middle row). However, patients who had larger numbers of thinning dimples in the inner retina, specifically in the superior outer quadrant of the macula, had worse visual outcomes.

THE POWER OF BIOMEDICAL DATA SCIENCE

Regarding the predictive ability of the features we extracted, we found that a decreasing area of EZ band defects in the foveal and parafoveal regions was a good predictor for postoperative recovery of visual acuity. Patients with more extensive atrophic changes appeared to have slower or worse visual acuity recovery despite closure of the macular hole. Interestingly, we also found that patients with larger preoperative macular holes had greater improvements in visual acuity than those with smaller macular holes.

Given that inner retinal defects did not seem to recover over time, surgical techniques that minimize inner retinal damage may be valuable for macular hole surgery.

By using thousands of computing cores operating in parallel, we were able to take a volumetric approach and analyze every voxel in each OCT scan. We were able to fully scrutinize every aspect of these patients' scans as they recovered from macular hole surgery. Topographic analysis of each segmented retinal layer was powerful in that it allowed the identification of defects at different retinal depths that correlated with visual acuity outcomes. Computer-aided diagnosis and modeling is the future of image analysis. We look forward to applying these techniques to other retinal conditions. ■

Theodore Leng, MD, MS, is director of ophthalmic diagnostics at the Byers Eye Institute at Stanford University and is a clinical assistant professor of ophthalmology at the Stanford University School of Medicine, Palo Alto, Calif. He has no financial relationships relevant to the material described in this article. Dr. Leng may be followed at @tedleng and reached at +1-650-498-4264; fax: +1-888-565-2640; or tedleng@stanford.edu.



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