

Seeing the Invisible With Combined OCT-SLO

Combining the two methods of imaging provides new insights into posterior segment conditions.

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Invisible by design, and thus historically not regarded as significant,^{1,2} vitreous (Figure 1) has recently become a tissue of great interest. Increased knowledge of vitreous biochemistry, anatomy, and pathology has spawned a greater appreciation of the role of vitreous in retinal diseases and blindness.^{3,4} A limitation in this development has been the inability to adequately image vitreous in the laboratory, the examination room, and the operating room.² The introduction of combined optical coherence tomography and scanning laser ophthalmoscopy (OCT-SLO; Opko Instrumentation, Toronto) has greatly improved our ability to image vitreous and the vitreoretinal interface, enabling an improved understanding of pathophysiology and an enhanced approach to therapy and prevention. The combined OCT-SLO imaging system also provides the capability to assess visual function, currently with microperimetry, but in the future with other testing paradigms.⁵

ADVANCED IMAGING

The combined OCT-SLO system incorporates a dual-channel scanner linked to an interferometer and a confocal receiver. An infrared superluminescent diode with a central wavelength of 820 nm provides the light source. In the longitudinal (B-scan) mode, the OCT-SLO employs a galvano-scanning mirror system to move the beam transversely in successively deeper linear horizontal sweeps of the retina to create cross-sectional images. In the coronal (C-scan) mode, planar (x,y) images are captured by opposing pairs of x- and y-axis galvano scanners

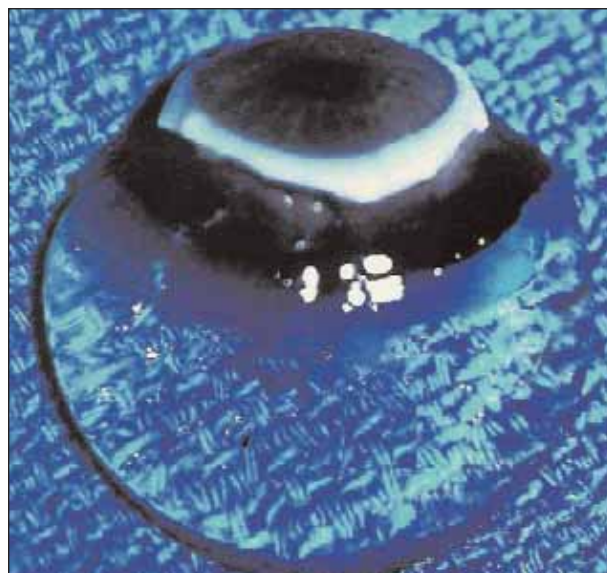


Figure 1. Intact vitreous body from a 9-month-old child still attached to the anterior segment after dissection of the sclera, choroid, and retina.

that move the beam in a raster fashion across the surface of the retina. Stacks for 3-D reconstruction can be generated by capturing these C-scan (x,y) planar images at successive z-axis depths.

In the time-domain instrument, the axial or depth resolution was approximately 10 μm and the transverse resolution was approximately 20 μm . The current spectral-domain OCT-SLO instrument executes 27,000 A-scans per second and 64 B-scan frames per

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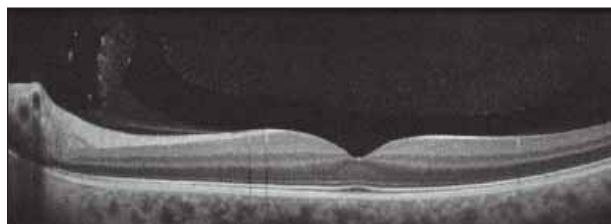


Figure 2. Enhanced OCT-SLO imaging with autotracking.

second, achieving an axial resolution of 5 μm and a lateral resolution of 15 μm .

The extremely high resolution and superb image quality of the combined OCT-SLO technology is demonstrated in Figure 2. Gel vitreous can be visualized anterior to the optic disc (extreme left), as can the posterior vitreous cortex attachment to the macula and the bursa pre-macularis of Worst. Exquisite details of chorioretinal anatomy can also be appreciated. Beyond demonstrating these details of fundus structure, however, the OCT-SLO has contributed greatly to our understanding of vitreoretinal pathology. This is primarily due to the useful methods for image analysis that are incorporated as standard features of this imaging technology.

Figure 3 demonstrates the phenomenon of vitreoschisis,⁶ which is a split in the posterior vitreous cortex. A consequence of anomalous posterior vitreous detachment⁷ (PVD), vitreoschisis may be an important mechanism of disease in vitreomaculopathies. A study⁸ employing combined OCT-SLO imaging in 89 eyes identified vitreoschisis in 53% of eyes with macular hole and 43% of eyes with macular pucker. A subsequent study⁹ of 239 eyes found that vitreoschisis was present in only 13.2% of eyes with nonproliferative diabetic retinopathy, 5.9% of eyes with dry age-related

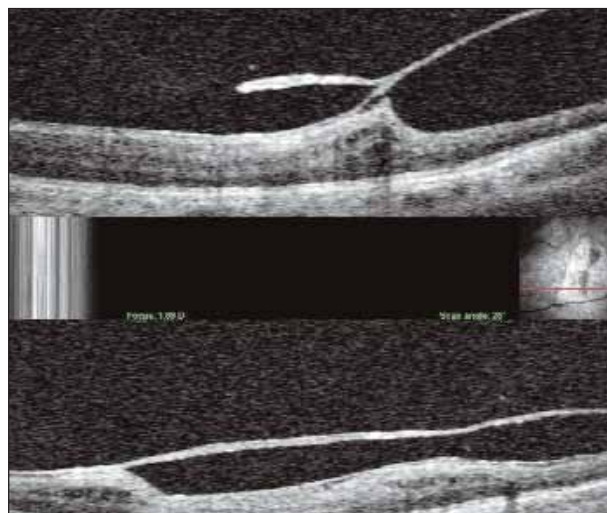


Figure 3. OCT-SLO imaging of vitreoschisis demonstrates that the posterior vitreous cortex is split into two layers, comprising what has been termed the lambda sign. The point of re-joining of the two layers into an intact full-thickness posterior vitreous cortex is the site of maximal vitreoretinal traction, as evidenced by the underlying cysts and retinal changes.

imaging modes have point-to-point registration, allowing accurate combination and cross-correlation of the OCT and SLO image sets.

The combination of a transverse color OCT image and a grayscale SLO image of the fundus that were obtained simultaneously is shown in Figure 4. The exact location of the transverse OCT imaging on the fundus is identified by the "intersecting planes" image analysis, as shown in this patient with profound vitreomacular traction syndrome.

This feature of the combined OCT-SLO system is currently being used to identify vitreo-papillary adhesion¹⁰ (VPA; Figure 5) in patients with macular holes and macular pucker. The results¹¹ showed VPA in 75% of eyes with macular holes, but in only 14% of eyes with macular pucker ($P=.02$). It is not yet clear how VPA impacts the vector of tangential traction at the macula, but persistent attachment to the optic disc may explain the different pathologies in these two vitreomaculopathies.

Another powerful image analysis feature of the combined OCT-SLO system is the ability to image in the coronal plane. Figure 6 demonstrates coronal plane fundus imaging in a patient with anomalous PVD and macular pucker. The point-to-point registration of the OCT and SLO imaging modalities allows the superimposition of the coronal plane (C-scan) OCT image upon the grayscale SLO fundus image, enabling a powerful topographic analysis of vitreomaculopathies. This perspective of the vitreoretinal interface is made easier to interpret when the color OCT image (Figure

The OCT-SLO has contributed greatly to our understanding of vitreoretinal pathology.

macular degeneration (AMD), and 6.7% of normal controls ($P<.0001$ in all comparisons to macular hole and macular pucker).

IMAGE ANALYSIS

This imaging technology is currently being used to further our understanding of the pathophysiology of these conditions, employing a unique feature of the combined OCT-SLO imaging system: ie, that the two

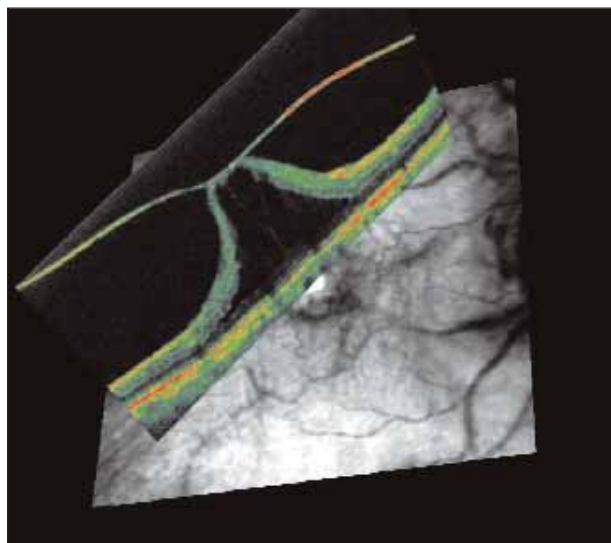


Figure 4. Combined OCT-SLO imaging of severe vitreomacular traction syndrome. This “intersecting planes” representation of the data demonstrates the precise location on the grayscale SLO fundus image of the color OCT scan.

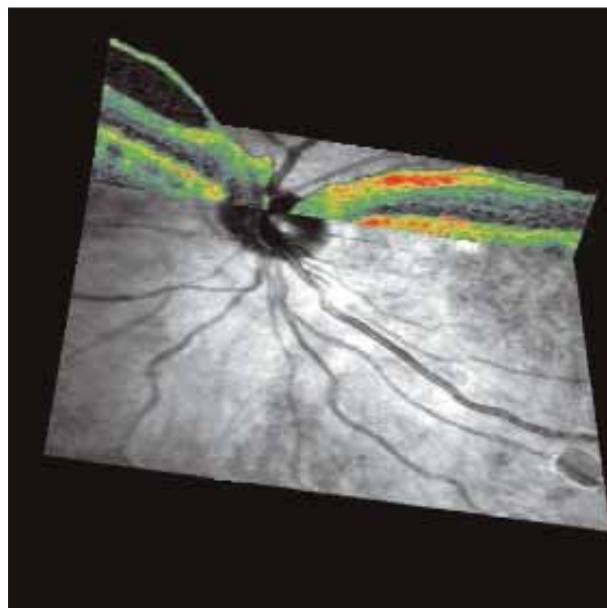


Figure 5. Intersecting-planes view of combined OCT-SLO imaging in a patient with vitreo-papillary adhesion.

6C) is integrated with the grayscale SLO image (Figure 6A) into one combined depiction (Figure 6B).

The coronal plane image analysis feature of the combined OCT-SLO imaging system was used to study 44 patients with macular pucker.¹² Two or more centers of retinal contraction were detected in nearly half of these patients. Figure 7 demonstrates that many eyes had three or four centers of retinal contraction. Correlating these findings with transverse OCT imaging demonstrated that eyes with three or four pucker centers had a threefold higher incidence of intraretinal cysts compared with eyes with one or two pucker centers ($P=.05$). There was also more thickening of the central macula in eyes with three or four pucker centers ($P=.05$). Thus, multifocal retinal contraction in macular pucker

appears to have clinical significance. Future studies will seek to determine whether the apparently greater impact on eyes with three or four pucker centers carries a poor prognosis, perhaps necessitating earlier surgical intervention. The topographic map provided by coronal plane imaging can also help plan the safest and most effective surgical approach in these cases.

Spectral-domain imaging has enabled the combined OCT-SLO system to present 3-D rendering of the vitreo-retinal interface. Here too, this technology has enhanced our understanding of the pathogenesis of vitreomaculopathies. Figure 8 demonstrates the course of a patient who developed a stage 3 macular hole. The “erupted volcano” appearance indicates that the vector of traction forces at the central macula is not only

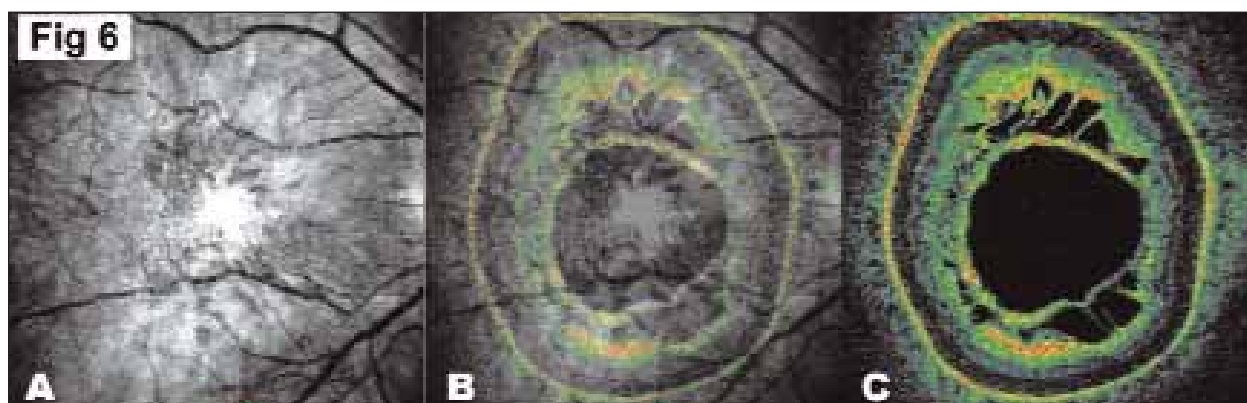


Figure 6. Coronal plane imaging of anomalous PVD with macular pucker. The grayscale SLO image (A) has point-to-point registration with the coronal plane OCT image (C), enabling precise superimposition of the two images (B).

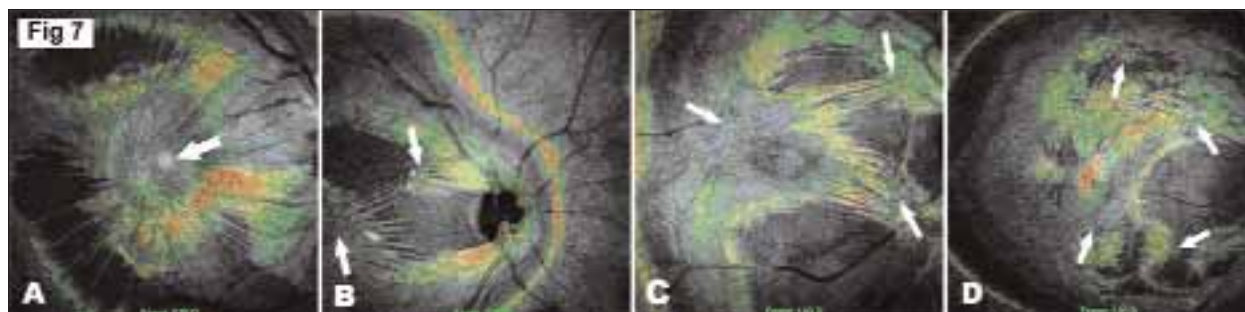


Figure 7. Coronal plane OCT-SLO imaging with superimposition of the color OCT images on the grayscale SLO fundus images demonstrates multifocal retinal contraction in macular pucker. Multiple foci of retinal contraction were detected in 20 of 44 eyes (45.5%). Intraretinal cysts were present in six of nine eyes (66.7%) with three or four contraction centers (C and D, respectively), as compared to 10 of 35 eyes (28.6%) with one or two contraction centers (A and B, respectively; $P=.05$). Eyes with three or four contraction centers had significantly thicker maculae ($369 \pm 98 \mu\text{m}$) compared with those with one or two contraction centers ($297 \pm 110 \mu\text{m}$; $P=.05$).

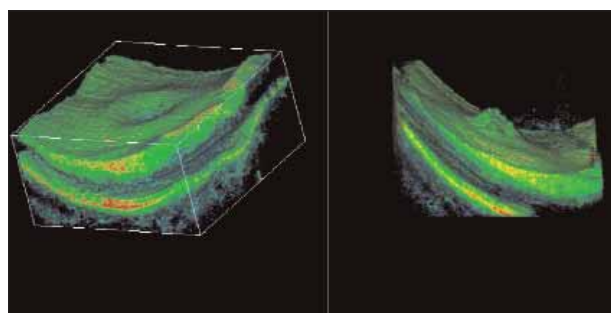


Figure 8. Spectral-domain OCT-SLO imaging with 3-D rendering of the vitreoretinal interface demonstrates the normal indentation at the fovea (left) and the marked elevation of the macula (right) during the formation of a stage 3 macular hole in the same patient.

tangential but may also be axial, as there is obvious elevation of the pericentral macula.

BETTER UNDERSTANDING OF THE VITREOUS

The combined OCT-SLO imaging system is currently being used to elucidate the role of vitreous in other conditions such as exudative AMD¹³⁻¹⁵ in the hopes that new therapeutic avenues will evolve. In this regard, the role of vitreous in promoting or at least facilitating choroidal neovascularization could be mitigated via pharmacologic vitreolysis.¹⁶⁻¹⁹ Indeed, this nonsurgical form of therapy could be quite useful as prophylaxis in a number of vitreomaculopathies.^{4,7,16,17}

The novel OCT-SLO imaging technology promises to continue to provide exciting new insights into the pathogenic mechanisms underlying vitreoretinal disorders with the aim of enabling new therapies for treatment and prevention. ■

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