The bifurcation and bump signs: optical coherence tomography (OCT) findings overlying neurosensory retinal detachment

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Research Article

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Abstract

Purpose To expand the description of a common OCT finding of outer plexiform layer (OPL) splitting overlying neurosensory retinal detachment from various causes, along with a thickened outer plexiform bump at the transition from attached to detached retina.

Methods etrospective review of our practice's image teaching collection and database of retina journal articles looking for representative examples of OPL splitting overlying macular detachment. Each of our patient's scans were then analyzed to see if the location or angle of detachment influenced these findings.

Results We analyzed 12 eyes (12 patients) with splitting of the OPL within paracentral detached retina (the "bifurcation sign") from various causes. A localized thickening of the OPL (the "bump sign") was present in 6 of these eyes. Although explicitly described in only one publication, the bifurcation sign could be found in numerous prior publications within our journal database. The bump sign, also explicitly described in one prior publication, was also seen in most of these published cases. Surprisingly, these findings appeared unrelated to either the angle of detachment or nasal versus temporal location. We then synthesized our findings with the current literature to help elucidate what this can teach us about current OCT nomenclature for the outer plexiform and outer nuclear layers.

Conclusion OPL changes are commonly found with retinal detachment. We suggest a modified classification of the OCT OPL and outer nuclear layers which is only applicable when the normal OCT anatomy is altered either by the OCT technician or overlying retinal detachment.

Introduction

In 2009, Ahlers et al showed that 89% of 18 eyes with acute central serous chorioretinopathy (CSC) had diffuse hyperreflectivity in the outer nuclear layer (ONL) and outer plexiform layer (OPL) when imaged with high definition optical coherence tomography (OCT).[1] Ahlers et al were unsure whether these were real morphologic changes or secondary to altered reflectivity from changes in the orientation of the neurosensory retina. Otani et al[2] and Lujan at al[3] independently and simultaneously more formally suggested that the angle of the OPL with the incident OCT laser beam alters the OPL smoothness and thickness in the normal macula. The normal nasal OPL appears thicker with a roughened outer margin and temporally has a thinner and smoother outer margin. This reflectivity is reversed nasally and temporally depending on how the angle of the incident OCT beam is oriented by horizontally displacing the OCT beam's entry position toward the nasal or temporal edges of the pupil. Otani et al felt that this phenomenon was due to the OPL being a heterogenous structure: the outer two-thirds consisting of the Henle's layer component (photoreceptor axons interleaved with Muller cell processes) and the inner one-third consisting of the synaptic region. When the incident beam strikes Henle's layer more obliquely, only the thin synaptic layer is visualized but when the incident beam strikes Henle's layer more perpendicularly, the visualized OPL becomes thicker. Lujan et al also noticed that significant changes in Henle's layer reflectivity appeared in two patients with macular pathology from age-related macular degeneration and CSC.

Ouyang et al later expanded on these findings, identifying six different phenotypes of Henle's layer variable thickness and reflectivity: bright, columnar, dentate, delimited, indistinct and dark.[4] The delimited variant was shown in their figure Id, where Henle's layer was iso-hyporeflective with the ONL with a hyperreflective outer boundary.

We recently noticed this delimited OPL appearance, which we call the "bifurcation sign", in many of the OCTs of our patients with CSC (Figure I). We also noticed that many of our eyes also contained a thickening of the OPL at the inflection from attached to detached retina, which we call the "bump sign".

We therefore searched through our practice's retinal image and journal article portable document format (PDF) teaching collection to look for similar cases to try to better characterize these findings. We then synthesized our findings with the current literature to help elucidate what this could teach us about current OCT nomenclature for the OPL and ONL anatomy.

Methods

Our practice maintains Retina Rocks, an open-source online collection of over 28,000 multimodal retinal images (www.retinarocks.org). We browsed through this collection, looking for high-quality OCT line scans exhibiting splitting of the OPL overlying macular detachment from various disorders, including rhegmatogenous retinal detachment, CSC, uveal malignant melanoma choroidal metastases, choroidal nevus, choroidal hemangioma, retinal capillary hemangioma, posterior scleritis, and uveal effusion syndrome. Disorders that routinely alter the neurosensory retinal anatomy, such as optic nerve pit maculopathy, Vogt-Koyanagi-Harada syndrome, and diabetic traction detachment, were excluded since this would have confounded our evaluation of the OPL. No attempt was made to include every such example in our collection. From this review of approximately 1700 images, we selected 12 representative eyes (12 patients) with macular detachment from various causes, including CSC (cases 1, 2, 4, 5, 7, 8, 9, 10 and 12), choroidal nevus (case 11), uveal malignant melanoma (case 3) and loculated fluid following retinal reattachment surgery (case 6). For cases 1, 2, 3, 4, 5, 6, 8, 10 and 11 we reviewed our practice's retinal image teaching collection. Cases 7, 9 and 12 were donated by Dr. Richard Spaide with similar selection criteria. Most reviewed and selected images were from eyes with CSC since this was by far the most common entity in our collection that met our selection criteria. All patients gave written permission to use their images for educational purposes.

Scans were performed using either the Cirrus spectral domain (Carl Zeiss Meditech, Dublin, CA), the Heidelberg Spectralis (Heidelberg Engineering, Heidelberg, Germany) or the Triton Plus swept source (Topcon Medical Systems, Incorporated, Oakland, NJ) OCT units. Axial resolutions were 5 μm, 3.5 μm, and 2.6 μm for the Cirrus, Spectralis, and Triton Plus units, respectively. Images were selected for relevant anatomic detail using either enhanced depth imaging B-scans (cases 1, 3, 4, 5, 6, 8, 10, 11 and 12) or by scrolling through volume scans (cases 2, 7 and 9).

Each of the 12 patient B-scans was analyzed for the following: angle of detached retina with respect to the retinal pigment epithelium (RPE) at the transition from attached to detached retina (retinal plane at the level of the OPL, RPE plane at the RPE apex), nasal versus temporal location of the OPL splitting, whether the OPL splitting was located on the steeper or shallower slope of the detachment, and the presence of an OPL bump. If the area of transition from attached to detached retina was outside the field of view of the OCT, this was estimated by extrapolating the planes of visible RPE and neurosensory retina until they intersected at the presumed transition point.

As part of the Retina Rocks collection, our practice also maintains a database of over 4,500 key retina-related journal article PDFs filed by disease state. We browsed through publications dealing with exudative or rhegmatogenous retinal detachment looking for OCT images showing OPL splitting within the detachment.

Case Reports

Figures for all cases were labelled to illustrate the various OPL and ONL details of interest, including a single OPL in attached retina (red arrow), a thickened OPL bump at the inflection from attached to detached retina (yellow arrow), a split hyperreflective OPL surrounding a hyporeflective OPL region (white arrows), and a single OPL band overlying detachment (orange arrow).

Case I (Figure II): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina. There is a thickened bump in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the steeper ascending portion of the detachment and fuses into a single layer along the shallower descending portion of the detachment.

Case 2 (Figure III): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina. There is a thickened bump in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the steeper ascending portion of the detachment and fuses into a single layer along the shallower descending portion of the detachment.

Case 3 (Figure IV): Uveal malignant melanoma.

The serous detachment is over 6mm in length and therefore occupies the entire OCT scan. The OPL is a single layer on the far nasal and entire temporal edges of the serous detachment but splits into 2 layers towards the nasal fovea.

Case 4 (Figure V): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. The OPL then bifurcates along the steeper ascending portion of the detachment and fuses into a single layer along the shallower descending portion of the detachment.

Case 5 (Figure VI): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. There is a thickened bump in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the steeper ascending portion of the detachment and fuses into a single layer along the shallower descending portion of the detachment.

Case 6 (Figure VII): Loculated fluid following pars plana vitrectomy for rhegmatogenous retinal detachment.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. There is a thickened bump in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the shallower ascending portion of the detachment and fuses into a single layer along the steeper descending portion of the detachment.

Case 7 (Figure VIII): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina. The serous detachment is shallowly elevated throughout. The OPL is bifurcated along the temporal portion of the detachment but fuses into a single layer throughout the nasal portion of the detachment.

Case 8 (Figure IX): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina. The serous detachment is shallowly elevated throughout. The OPL is bifurcated along the nasal portion of the detachment but fuses into a single layer throughout the temporal portion of the detachment.

Case 9 (Figure X): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. The serous detachment is shallowly elevated throughout. The OPL is bifurcated along both the nasal and temporal portions of the detachment.

Case 10 (Figure XI): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. There is a thickened bump in the OPL at the inflections from attached to detached retina. The OPL is bifurcated along both the nasal and temporal portions of the detachment.

Case 11 (Figure XII): Choroidal nevus.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. There is a thickened bump in the OPL at the inflections from attached to detached retina. The OPL is bifurcated along both the nasal and temporal portions of the detachment and diffusely thickened compared to its appearance in attached retina. The central region between the OPL hyperreflective splitting is variably hyperreflective compared to our other cases.

Case 12 (Figure XIII): CSC.

The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina. The OPL is bifurcated more centrally and fused more distally along both the nasal and temporal portions of the detachment.

Results

The Table summarizes the major OCT findings for each case.

We selected 12 representative eyes (12 patients) from our practice's retinal image teaching collection that exhibited a hyperreflective bifurcation of the OPL sandwiching a band of variable reflectivity associated with macular detachment due to CSC, choroidal nevus, uveal malignant melanoma, and loculated fluid following successful retinal reattachment surgery. Within the area of detachment where the OPL was not bifurcated, most of these eyes had a thickened, diffusely hyperreflective OPL approximating the same height as the bifurcation.

We noticed the OPL splitting nasally (cases 1, 2, 3, and 8), temporally (cases 4, 5, 6, 7) and on both sides of the detachment (cases 9, 10, 11 and 12). OPL splitting was noted within both the steeper side (cases 1 through 5), shallower side (cases 6 and 8) and on both sides of fairly symmetrically elevated retina (cases 9 through 12).

Splitting of the OPL layer occurred with an angle of detachment between 10 (case 8) and 57 (case 2) degrees. But we also found that the OPL was a single layer with an angle of detachment between 12 (case 4) and 38 (case 6) degrees.

In half of our cases (6 eyes, 6 patients), the OPL had a thickened hyperreflective bump overlying the inflection from attached to detached retina. The OPL then more or less maintained this increased thickness compared to that seen in attached retina. When visualized, this bump appeared at the junction of the steeper detached edge (cases 1, 2, 5, 6) as well as on both sides of shallowly detached retina (cases 10 and 11).

We then browsed through our practice's PDF retina journal database looking for references dealing with retinal detachment and subretinal fluid. We found numerous instances of the OCT bump and splitting, although the bump was explicitly described only once[1] and the splitting explicitly described only twice.[1,4] Bifurcation of the OPL was found with CSC,[5,6,3,7] CSC with type 1 macular neovascularization,[8] drusen with overlying subretinal fluid,[9] unilateral acute idiopathic maculopathy,[10] rhegmatogenous retinal detachment,[11] loculated fluid following retinal detachment repair,[12,13] and subretinal fluid associated with choroidal nevus,[4] dome macula,[14] retinal vein occlusion,[15] Kearns-Sayre Syndrome,[16] deferoxamine toxicity,[17] and monoclonal immunoglobulin light chain deposition disease.[18] A localized thickening of the OPL at the inflection from attached to detached retina was also seen in the majority of these published cases.[6-16,4]

Discussion

The histologic definition for what constitutes the OPL is well established. Stephen Polyak, the renowned twentieth century neuroanatomist, defined the OPL as a trilaminar structure consisting of Henle's layer ("fibrous expansions of rod and cone cells"), "rod spherules and larger cone pedicles," and "outer expansions of bipolars and all expansions of horizontal cells..."[19] Curcio et al, in the first graphic representation and thickness database of normal macular and chorioretinal layers, defined the OPL layers as the OPL Henle, OPL pedicles, and OPL synaptic,[20] now felt to be better described as the OPL Henle, OPL terminal (spherules and pedicles), and OPL dendritic (processes of bipolar and horizontal cells) layers (written communication July 16, 2020).

Correlating OPL histology with OCT findings remains a work in progress since current OCT technology does not allow for routine separation of the OPL layers from the ONL. In 2014, The International Nomenclature for Optical Coherence Tomography Panel (IN•OCT) suggested the current widely accepted terminology for OCT retinal anatomic landmarks.[21] Their hyperreflective band 7 was defined as the "dendritic outer plexiform layer." The inner half of their hyporeflective band 8 was felt to represent Henle's nerve fiber layer and the outer half the ONL. Implied but not explicitly mentioned in this publication, is that Henle's layer is the non-dendritic portion of the OPL. The nuanced description of their hyperreflective band 7 representing the synaptic portions of the photoreceptors with the horizontal and bipolar cells, is generally lost in clinical use since their Figures 1 and 2 called this the "Outer Plexiform Layer."

Most of our eyes exhibited the well-known phenomenon of a thickened, diffusely hyperreflective OPL, what Ouyang et all termed the bright OPL phenotype. We also noticed a common, but rarely previously discussed, OPL bifurcation overlying retinal detachment. We found that the OPL split along the steeper, shallower and within both portions of equally shallowly detached retina. Splitting was noted with an angle of detachment as low as 10 degrees (case 8) and as high as 57 degrees (case 2). Similarly, OPL splitting was absent with an angle as low as 12 degrees and as high as 38 degrees (case 6). In addition, splitting was found nasally, temporally and on both sides of the detachment. In other eyes with detachment there was no OPL splitting. We expected that the split OPL should be seen within a given angle of detachment, since others have suggested that the OPL is best visualized when the incident OCT beam is most perpendicular to it.[3,4] However, we saw this finding regardless of location (nasal vs temporal) or angle of detachment. We are not sure why this was the case.

Our cases confirmed prior observations that the height of the hyperreflective paracentral OPL in attached retina was thinner and the outer nuclear layer thicker than the region between the area of apparent OPL splitting or hyperreflectivity within detached retina. Curcio et al provided retinal and choroidal layer thicknesses for the central and parafoveal macula.[20] Mean central foveal thickness for the OPL synaptic, OPL pedicles, OPL Henle, and ONL (ONL rods plus ONL cones) were 0, 0, 22, and 34 μm, respectively. Mean thickness 1mm nasal to the macular center for the OPL synaptic, OPL pedicles, OPL Henle, and ONL (ONL rods plus ONL cones) were 6, 7, 29, and 27 μm, respectively. Mean thickness 1mm temporal to the macular center for the OPL synaptic, OPL pedicles, OPL Henle, and ONL (ONL rods plus ONL cones) were 7, 6, 55, and 32 μm, respectively. OPL Henle in the paracentral macula is thus about 70% thicker than the ONL. Current OCT technology does not allow for us to accurately measure the height of these bands into μm resolution, but the relative heights of these regions in our eyes were most consistent with Curcio's measurements within the area of detachment (Figure XIV). Each of our patients' altered OPL, whether it was a bump, bifurcation, or solid hyperreflective band, all had the same height approximating its true anatomic thickness. Thus, altering the angle of the OPL with the incident OCT laser beam, either by manipulating the beam's location within the patient's pupil or by nature presenting us with a retinal detachment, may allow for better separation of these layers and a truer correlation with anatomic measurements.

We therefore suggest a revised OCT OPL and ONL classification scheme applicable only when the normal retinal anatomy is altered either by the OCT technician or overlying retinal detachment (Figure XV). The innermost hyperreflective band, the OPL Dendritic Zone, includes the synaptic and terminal subzones of horizontal and bipolar cell processes and terminals of the rods and cones. The anatomic thickness of this region is only 13-14 μm,[20] and it is unclear what components contribute to its hyperreflectivity. The thickened hyperreflective region at the inflection from attached to detached retina, as well as the hyporeflective band within detachment, is the OPL Henle's Zone. This area may also appear as a solid hyperreflective band. The border between Henle's and the ONL is the outermost hyperreflective band, followed by the hyporeflective ONL. We prefer to call these bands, zones, to emphasize that these are heterogeneous cellular structures.

Our retina image teaching collection, built from patients seen at our practice, is composed of images selected for their quality and how well each exemplifies and teaches something about each entity. No attempt has been made over the years to include every example of every patient we have examined. Similarly, when retrospectively looking through this collection for images with OPL splitting, we made no attempt to include every example we found. Thus, we can make no conclusion regarding how often these findings are present with retinal detachment.

In summary, we expand on prior descriptions of splitting of the OPL within a macular detachment (bifurcation sign) and a thickened bump within the OPL at the inflection from attached to detached retina (bump sign). These findings were common in our practice's retinal image teaching collection and were also found unmentioned in many published references dealing with retinal detachment and subretinal fluid. As previously described, the appearance of what we currently call the OPL and ONL on OCT changes depending on the angle of the incident OCT laser with the retinal microstructures. However, contrary to prior explanations for this phenomenon, the varied OPL phenotypes inexplicably appear to be independent of the incident angle of the illuminating OCT laser. This altered appearance may give a clearer picture of the true anatomy.

Declarations

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Conflicts of interest/Competing interests: The authors have no relevant financial or non-financial interests to disclose.

Ethics approval / Consent to participate / publication: The University of Pikeville Ethics Committee confirmed that no IRB approval was required. All patients gave written permission to have their images used for educational purposes, including publication.

Availability of data and material: Not applicable

Code availability: Not applicable

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Table

Table: Summary of OCT Findings

Cause	Machine	Scan Type	OPL Bifurcation	Location		Angles of Detachment (degrees)		OPL Bump
				Nasal vs Temporal	Steeper vs Shallower Edge of RD	Nasal	Temporal	
CSC	Cirrus	5-line raster	Single	Nasal	Steeper	40	24	Yes, more acute side
CSC	Triton	Volume	Single	Nasal	Steeper	57	16	Yes, more acute side
Uveal MM	Cirrus	5-line raster	Single	Nasal	Steeper	42	32	N/A
CSC	Cirrus	5-line raster	Single	Temporal	Steeper	12	45	No
CSC	Cirrus	5-line raster	Single	Temporal	Steeper	15	25	Yes, more acute side
Loculated fluid after RRD	Cirrus	5-line raster	Single	Temporal	Shallower	38	13	Yes, more acute side
CSC	Cirrus	Volume	Single	Temporal	Steeper	13	18	No
CSC	Cirrus	5-line raster	Single	Nasal	Shallower	10	13	No
CSC	Spectralis	Volume	Double	Both	NA	18	13	No
CSC	Cirrus	5-line raster	Double	Both	NA	25	22	Yes, both sides
CN	Cirrus	5-line raster	Double	Both	NA	18	20	Yes, both sides
CSC	Spectralis	EDI	Double	Both	NA	12	16	No

: Outer plexiform layer, SRF = Subretinal fluid, CSC = Central serous chorioretinopathy, MM = Malignant oma, RRD=Retinal detachment, CN = Choroidal nevus, nhanced depth imaging

Figure Captions

Figure files are not included with this version of the manuscript.

Figure Captions.

Fig. I Enlarged region of nasal detachment from Figure II showing the defined outer plexiform and outer nuclear layers in attached retina towards the left, and the outer plexiform layer (OPL) bump at the inflection from attached to detached retina and split OPL within the area of detachment. The OPL consists of the inner dendritic outer plexiform layer and Henle's fiber layer.

Fig. II CSC. The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina (red arrow). There is a thickened bump (yellow arrow) in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the steeper ascending portion of the detachment (white arrows) and fuses into a single layer along the shallower descending portion of the detachment (orange arrow).

Fig. III CSC. The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina (red arrow). There is a thickened bump (yellow arrow) in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the steeper ascending portion of the detachment (white arrows) and fuses into a single layer along the shallower descending portion of the detachment (orange arrow).

Fig. IV Uveal malignant melanoma. The serous detachment is over 6mm in length and therefore occupies the entire OCT scan. The OPL is a single layer on the far nasal and entire temporal edges of the serous detachment (orange arrows) but splits into 2 layers towards the nasal fovea (white arrows).

Fig. V CSC. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). The OPL then bifurcates along the steeper ascending portion of the detachment (white arrows) and fuses into a single layer along the shallower descending portion of the detachment (orange arrow).

Fig. VI CSC. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). There is a thickened bump (yellow arrow) in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the steeper ascending portion of the detachment (white arrows) and fuses into a single layer along the shallower descending portion of the detachment (orange arrow).

Fig. VII Loculated fluid following pars plana vitrectomy for rhegmatogenous retinal detachment. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). There is a thickened bump (yellow arrow) in the OPL at the inflection from attached to detached retina. The OPL then bifurcates along the shallower ascending portion of the detachment (white arrows) and fuses into a single layer along the steeper descending portion of the detachment (orange arrow).

Fig. VIII CSC. The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina (red arrow). The serous detachment is shallowly elevated throughout. The OPL is bifurcated along the temporal portion of the detachment (white arrows) but fuses into a single layer throughout the nasal portion of the detachment (orange arrow).

Fig. IX CSC. The normal OPL layer is seen as a single hyperreflective line in the attached nasal retina (red arrow). The serous detachment is shallowly elevated throughout. The OPL is bifurcated along the nasal portion of the detachment (white arrows) but fuses into a single layer throughout the temporal portion of the detachment (orange arrow).

Fig. X CSC. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). The serous detachment is shallowly elevated throughout. The OPL is bifurcated along both the nasal and temporal portions of the detachment (white arrows).

Fig. XI CSC. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). There is a thickened bump (yellow arrows) in the OPL at the inflections from attached to detached retina. The OPL is bifurcated along both the nasal and temporal portions of the detachment (white arrows).

Fig. XII Choroidal nevus. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). There is a thickened bump (yellow arrows) in the OPL at the inflections from attached to detached retina. The OPL is bifurcated along both the nasal and temporal portions of the detachment (white arrows) and diffusely thickened compared to its appearance in attached retina. The central region between the OPL hyperreflective splitting is variably hyperreflective compared to our other cases.

Fig. XIII CSC. The normal OPL layer is seen as a single hyperreflective line in the attached temporal retina (red arrow). The OPL is bifurcated more centrally (white arrows) and fused more distally (orange arrows) along both the nasal and temporal portions of the detachment.

Fig. XIV Enlarged region of nasal detachment from Figure II. The thickness of the hyperreflective OPL in attached retina (red bar) appears thinner than the region demarcated by the bifurcated OPL in detached retina. Similarly, the ONL in attached retina (yellow bar) appears thinner within the area of detachment.

Fig. XV Proposed modified classification for the OCT bands with an altered angle of the incident OCT laser with the retinal microstructures. The innermost hyperreflective band, the OPL Dendritic Zone, includes the synaptic region of the rod spherules, cone pedicles, horizontal cells and bipolar cells. The thickened hyperreflective region at the inflection from attached to detached retina, as well as the hyporeflective band within detachment, is the OPL Henle's Zone. This area may also appear as a solid hyperreflective band. The border between Henle's and the ONL is the outermost hyperreflective band, followed by the hyporeflective ONL.