Foveal Photoreceptor Deformation as a Significant Predictor of Postoperative Visual Outcome in Idiopathic Epiretinal Membrane Surgery

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PURPOSE. The purpose of this study was to determine whether the outer nuclear layer (ONL) deformation detected by spectral-domain optical coherence tomography (SD-OCT) is correlated with visual acuity before and after surgery in patients with idiopathic epiretinal membrane (ERM).

METHODS. Forty-four eyes of 44 patients who underwent vitreous surgery for treatment of ERM were included. All patients underwent comprehensive ophthalmologic evaluations including measurement of best corrected visual acuity (BCVA) and SD-OCT before and after surgery. The central foveal thickness (CFT), foveal ONL thickness, juxtafoveal ONL plus outer plexiform layer (OPL) thickness, photoreceptor outer segment thickness, and size of the disrupted interdigitation zone (IZ) line were measured. We defined the “photoreceptor deformation index” (PDI) as the ratio of foveal ONL thickness to the juxtafoveal ONL plus OPL thickness.

RESULTS. Multiple regression analysis showed that the only significant predictor of preoperative mean logarithm of the minimum angle of resolution (logMAR) BCVA was preoperative CFT (P < 0.0001). Preoperative PDI (P < 0.0001) and disrupted IZ diameter (P = 0.0242) were positively correlated with logMAR at 3 months after surgery. PDI (P < 0.0001) and disrupted IZ diameter (P = 0.0351) were also positively correlated with logMAR BCVA at 6 months after surgery. The only significant predictor of logMAR at 12 months after surgery was preoperative PDI (P < 0.0001).

CONCLUSIONS. Preoperative PDI was most significantly correlated with postoperative BCVA. These results suggest that PDI is a novel parameter predicting visual outcome after surgery in eyes with ERM.

Keywords: epiretinal membrane, optical coherence tomography, vitreoretinal surgery
Participants

Candidates in this retrospective interventional case study were consecutive patients with idiopathic ERM but without any other macular abnormality such as age-related macular degeneration or glaucoma, who underwent vitrectomy at the Kyoto University Hospital from December 2008 through March 2013, and were followed for at least 1 year. Glaucomatous eyes were defined by the presence of evident diffuse or localized rim thinning on stereo disc photography regardless of the presence or absence of glaucomatous visual field defects. Eyes with high myopia (axial length > 26.5 mm) were excluded. Eyes with secondary ERM (e.g., due to retinal detachment, diabetic retinopathy, venous occlusion, uveitis, or trauma) were excluded from this study. Eyes with other ocular pathologies that could have interfered with the functional results, such as dense cataract, also were excluded.

The medical records of healthy eyes of the unilateral ERM cases were also reviewed as controls.

At baseline, all patients underwent comprehensive ophthalmologic evaluations including standardized refraction and measurement of BCVA, assessed using the Landolt chart and expressed as the logarithm of the minimum angle of resolution (logMAR), slit-lamp biomicroscopy, color fundus photography, and SD-OCT. All patients were asked how long they had had symptoms. At postoperative evaluation examinations, we routinely made BCVA and SD-OCT measurements.

The ERM was removed in each case by using standard 3-port 23- or 25-gauge pars plana vitrectomy. Before vitrectomy, all phakic eyes underwent phacoemulsification and implantation of a posterior chamber intraocular lens. After core vitrectomy with intravitreal injection of triamcinolone acetonide to visualize the vitreous gel, we detached the posterior vitreous if detachment had not yet occurred. ERM peeling was carried out using end-gripping forceps. The internal limiting membrane (ILM) was subsequently peeled at the surgeon’s discretion using 0.05% indocyanine green (ICG) dye.

SD-OCT Evaluation of Photoreceptor Features

SD-OCT was performed 3, 6, and 12 months after surgery. Horizontal and vertical line scans through the center of the fovea were obtained at a 30° angle, after which we obtained volume scans (10° × 30°). In this study, we used horizontal and vertical B-scan images through the fovea for analysis. Eyes with poor image quality or no central foveal scans were excluded. If both images were eligible, we selected one image at random. Using preoperative images, we measured the central foveal thickness (CFT), foveal ONL thickness, juxtafoveal ONL plus outer plexiform layer (OPL) thickness, OS thickness, diameter of the disrupted IZ line and EZ line by using the digital caliper tool built into the SD-OCT system (Figs. 1–3). The border of EZ or IZ disruption was defined as the line on the grayscale image along which EZ or IZ reflectivity had diminished by 2 standard deviations from the reflectivity of the EZ or IZ in the unaffected peripheral macula.21
measurements. OS thickness was defined as the distance between the outer border of the EZ and the inner border of the RPE. We defined the “photoreceptor deformation index” as $a/b$.

Schematics of photoreceptor deformation indexes in eyes with ERM and normal eyes are presented in Figure 2. Inner border of juxtafoveal OPL may be sometimes unclear. In such cases, several points where the border of OPL could be identified were chosen and connected to create a segmentation line, and then OPL+ONL thickness was measured.

### Statistical Analysis

Comparisons between preoperative and postoperative BCVA values and photoreceptor deformation indexes were evaluated by Mann-Whitney $U$ test. Correlations among CFT, ONL thickness, OS thickness, diameter of disrupted EZ and IZ lines, photoreceptor deformation indexes, and BCVA values were evaluated using Spearman rank correlation coefficient. Independent variables for multiple regression analysis were determined using stepwise selection. A $P$ value of $<0.05$ was considered statistically significant. All analyses were performed using a commercial software program (SPSS software version 20.0; SPSS, Inc., Chicago, IL, USA).

### RESULTS

#### Preoperative and Intraoperative Characteristics

Images obtained from 44 eyes from 44 patients (16 men and 28 women; mean age: 67.7 ± 7.6 years) and 35 normal eyes of 35 subjects (13 men and 22 women; mean age: 69.8 ± 8.1 years) were suitable for analysis in this study. Table 1 summarizes patients’ characteristics prior to surgery. Mean preoperative logMAR BCVA was 0.278 ± 0.204, and mean symptom duration was 20.6 months. In eyes with ERM, mean ONL thickness of the fovea was 368 ± 88 μm, and mean OS thickness was 59 ± 10 μm, both of which were significantly greater than in normal eyes ($P < 0.0001$ and $P = 0.0441$, respectively). In six eyes, inner retinal layers were included in foveal ONL measurements because of structural continuum of the inner retinal layers.²² Mean disrupted IZ diameter was 357 ± 176 μm. Mean photoreceptor deformation index was significantly higher in eyes with ERM than in normal eyes (2.66 vs. 0.95, respectively; $P < 0.0001$). Photoreceptor deformation index did not significantly correlate with age ($P = 0.6226$) and had no association with sex ($P = 0.4366$) in normal eyes. Half of the eyes (22 eyes) had cotton-ball sign, a highly reflective foveal region reported by Tsunoda et al.²³ before surgery. The ILM was peeled in 26 eyes, and 0.05% ICG was used to dye ILM in 25 eyes.

#### Postoperative Changes of BCVA and Foveal Deformation Index

Mean logMAR BCVA values at 3, 6, and 12 months after surgery were 0.136 ± 0.188, 0.075 ± 0.193, and 0.057 ± 0.209, respectively. Mean logMAR BCVA values at 3, 6, and 12 months postoperatively were improved significantly compared with mean preoperative logMAR BCVA values ($P < 0.0001$ for all) (Figs. 3, 4). Mean photoreceptor deformation indexes at 3, 6, and 12 months after surgery were 1.99, 1.87, and 1.72, respectively. Mean photoreceptor deformation indexes at 3, 6, and 12 months postoperatively decreased significantly compared with mean preoperative photoreceptor deformation indexes ($P = 0.0020$, $<0.0001$, and $<0.0001$, respectively) (Fig. 4).
Relationship Between Preoperative OCT Parameters and BCVA

Table 2 shows correlations between preoperative OCT parameters and logMAR BCVA before and after surgery. Preoperative logMAR BCVA was positively correlated with CFT ($P < 0.0001$), foveal ONL thickness ($P < 0.0001$), and photoreceptor deformation index ($P < 0.0001$). Preoperative logMAR BCVA was negatively correlated with OS thickness ($P = 0.0066$). Preoperative photoreceptor deformation index positively correlated with logMAR BCVA at all time points after surgery ($P < 0.0001$ for all) (Fig. 5). However, preoperative photoreceptor deformation index showed no significant correlation with improvement of BCVA at 12 months after surgery ($P = 0.1850$). Preoperative logMAR BCVA and foveal ONL thickness also showed positive correlation with logMAR BCVA at each time point examined. Disrupted IZ diameter was positively correlated with BCVA postoperatively but not preoperatively. Disrupted EZ diameter did not correlate with BCVA at each time point. There were no relationships between cotton-ball sign and preoperative/postoperative logMAR BCVA. Symptom duration showed no significant correlation with OCT parameters and logMAR BCVA at each time point.
Table 2. Relationship Among Optical Coherence Tomography Parameters and Visual Acuity Before and After Epiretinal Membrane Surgery*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BCVA Before Surgery</th>
<th>BCVA 3 Months After Surgery</th>
<th>BCVA 6 Months After Surgery</th>
<th>BCVA 12 Months After Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCVA before surgery</td>
<td>-</td>
<td>P &lt; 0.0001</td>
<td>P = 0.0008</td>
<td>P = 0.0048</td>
</tr>
<tr>
<td>CFT</td>
<td>P &lt; 0.0001</td>
<td>r = 0.593</td>
<td>r = 0.486</td>
<td>r = 0.417</td>
</tr>
<tr>
<td>Foveal ONL thickness</td>
<td>P &lt; 0.0001</td>
<td>r = 0.338</td>
<td>r = 0.263</td>
<td>r = 0.150</td>
</tr>
<tr>
<td>Juxtafoveal ONL plus OPL thickness</td>
<td>P = 0.3823</td>
<td>r = 0.372</td>
<td>r = 0.544</td>
<td>r = 0.228</td>
</tr>
<tr>
<td>Photoreceptor deformation index</td>
<td>P &lt; 0.0001</td>
<td>r = 0.595</td>
<td>r = 0.521</td>
<td>r = 0.506</td>
</tr>
<tr>
<td>Diameter of disrupted IZ line</td>
<td>P = 0.0802</td>
<td>r = 0.267</td>
<td>r = 0.415</td>
<td>r = 0.411</td>
</tr>
<tr>
<td>Diameter of disrupted EZ line</td>
<td>P = 0.1483</td>
<td>r = 0.1342</td>
<td>r = 0.383</td>
<td>r = 0.411</td>
</tr>
<tr>
<td>OS thickness</td>
<td>P = 0.0221</td>
<td>r = –0.222</td>
<td>r = –0.134</td>
<td>r = –0.158</td>
</tr>
</tbody>
</table>

BCVA, best-corrected visual acuity; EZ, ellipsoid zone; IZ, interdigitation zone; OS, outer segment; r, correlation coefficient. Other abbreviations are as in Table 1.

* Values in boldface are statistically significant.

Predictors of Preoperative/Postoperative BCVA by Using Multiple Regression Analysis

Table 3 shows results of multiple regression analysis of preoperative and intraoperative parameters (BCVA before surgery, CFT, foveal ONL thickness, photoreceptor deformation index, diameter of disrupted IZ line, OS thickness, ICG staining, and ILM peeling) and preoperative/postoperative logMAR BCVA values. Multiple regression analysis showed that the only significant predictor of preoperative logMAR BCVA was preoperative CFT (P < 0.0001; standard regression coefficient = 0.706). Model R² for this analysis was 0.499. Preoperative photoreceptor deformation index (P < 0.0001) and disrupted IZ diameter (P = 0.0242) were positively correlated with logMAR BCVA at 3 months after surgery. Photoreceptor deformation index (P < 0.0001) and disrupted IZ diameter (P = 0.0351) were also positively correlated with logMAR BCVA at 6 months after surgery. The only significant predictor of logMAR BCVA at 12 months after surgery was preoperative photoreceptor deformation index (P < 0.0001; standard regression coefficient = 0.468). Model R² for this analysis was 0.336.

DISCUSSION

Results of this study showed that photoreceptor deformation index, a new parameter that provides a quantitative method for evaluating deformation of the foveal ONL, was significantly correlated with BCVA at each time point before and after surgery. Most importantly, multiple regression analysis showed that preoperative photoreceptor deformation index was most significantly correlated with BCVA postoperatively. These results suggest that photoreceptor deformation index is a novel parameter predicting visual outcome after surgery in eyes with ERM.

We propose photoreceptor deformation index represents the degree of photoreceptor deformation in eyes with ERM. ONL contains the photoreceptor cell bodies of both rods and cones. In eyes with ERM, thickening of the ONL is greatest at the center of the fovea (Figs. 1–3), suggesting that the centripetal force toward the foveal center is transmitted from the ERM to the foveal photoreceptor cell bodies. Thus, photoreceptor deformation index appears to reflect how shrinkage of the ERM causes disarrangement to the photoreceptor cell bodies. In support of this proposal, we previously reported that the regularity of the spatial arrangement of the cone mosaic is disrupted in eyes with ERM by using adaptive optics scanning laser ophthalmoscopy.

Preoperative BCVA and the CFT have been reported to be correlated with postoperative BCVA after ERM surgery. Consistent with those results, our study showed that preoperative logMAR BCVA and CFT were significantly correlated with postoperative BCVA. However, multiple regression analysis revealed that preoperative BCVA and CFT were not
significant predictors of postoperative BCVA. These results suggest that preoperative BCVA and CFT are not strong prognostic factors.

Shiono et al.\textsuperscript{15} reported that preoperative OS thickness yielded the highest regression coefficient with postoperative BCVA. Consistent with these reports, we also found that the correlation between preoperative OS thickness and postoperative BCVA was marginal. Although these opposing results may be due to different study populations, OS thickness does not appear to be a major prognostic factor compared with photoreceptor deformation index. It is possible that the correlation between OS thickness and postoperative BCVA is due to different study populations, and OS thickness does not appear to be a major prognostic factor compared with photoreceptor deformation index.

Multiple regression analysis showed that the disrupted IZ line defect can predict BCVA after ERM surgery.\textsuperscript{18,19} Consistent with those reports, we also found a significant correlation with preoperative OS thickness. However, we found that the correlation between preoperative OS thickness and postoperative BCVA was marginal. Although these opposing results may be due to different study populations, OS thickness does not appear to be a major prognostic factor compared with photoreceptor deformation index. It is possible that the correlation between OS thickness and postoperative BCVA is due to different study populations, and OS thickness does not appear to be a major prognostic factor compared with photoreceptor deformation index.

Multiple regression analysis showed that preoperative photoreceptor deformation index was more significantly correlated with postoperative BCVA than previously reported prognostic factors such as preoperative BCVA, CFT, OS thickness, and disrupted IZ diameter. In addition, preoperative photoreceptor deformation index was the only significant predictor of logMAR BCVA at 12 months after surgery, and patients with lower photoreceptor deformation index exhibited better visual outcome. These results suggest that photoreceptor deformation index is useful to predict visual outcome of ERM surgery and that foveal photoreceptor cell bodies play one of the most important roles in the improvement of visual function in eyes with ERM. Contraction or shrinkage of an ERM may cause not only retinal thickening but also various degrees of distortional force in the photoreceptor cell bodies, leading to irreversible functional impairment. However, it also should be stated that preoperative photoreceptor deformation index showed no significant correlation with improvement of BCVA. It implies that photoreceptor deformation index may fail to identify the patients who would benefit most from surgery and is rather a useful measure for severity of retinal distortion and subsequent limited visual prognosis of patients.

This study has several limitations. First, this was a retrospective study and the ILM was peeled at the surgeon’s discretion. However, multiple regression analyses have revealed that neither ILM peeling nor ICG staining were significant predictors of postoperative BCVA. Second, we did not evaluate ONL thickness alone at 500 μm from the center of the fovea; instead, we measured the combined thicknesses of the OPL and ONL. This is because standard SD-OCT images acquired along the optical axis typically do not show axons of the photoreceptor nuclei or Henle’s fiber layer; thus, accurate measurement of ONL thickness is challenging except at the center of the fovea.\textsuperscript{25} Further studies are necessary to evaluate “pure ONL” deformation by using a method reported by Lujan et al.\textsuperscript{25} Despite these limitations, the current study revealed highly significant correlations between the photoreceptor deformation index and visual acuity before and after ERM surgery. Considering the strength of these results, we believe that the photoreceptor deformation index is a strong indicator of mechanical stress on foveal structures and a prognostic factor for postoperative BCVA in patients with idiopathic ERM.

**Acknowledgments**

Authors Masanori Hangai and Nagahisa Yoshimura are paid members of the advisory boards of Topcon (Tokyo, Japan) and NIDEK (Gamagori, Japan).

Disclosure: **Y. Hosoda.** None; **S. Ooto.** None; **M. Hangai.** Topcon (C), NIDEK (C); **A. Oishi.** None; **N. Yoshimura.** Topcon (C), NIDEK (C)

**References**


