Quantitatively Measured Anatomic Location and Volume of Optic Disc Drusen: An Enhanced Depth Imaging Optical Coherence Tomography Study

Malmqvist, Lasse; Lindberg, Anne-Sofie Wessel; Dahl, Vedrana Andersen; Jørgensen, Thomas Martini; Hamann, Steffen

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Optic disc drusen (ODD) are bodies of extruded axonal material located in the optic nerve head. They are found in up to 2.4% of the population and are known to cause visual field defects and even complete vision loss due to complications.

Diagnosis and classification of ODD has historically been based mainly on ophthalmoscopy. With the development of new imaging techniques, the diagnosis by ophthalmoscopy is today normally confirmed by B-scan ultrasound or optical coherence tomography (OCT). However, the most frequently used classification of ODD is still based on ophthalmoscopy using none of the emerging imaging techniques. In the classification, ODD that are visible on ophthalmoscopy are termed superficial while ODD only visible by B-scan ultrasound or OCT are termed buried. Several studies have found significantly larger decreases in retinal nerve fiber layer (RNFL) thickness and automated perimetric mean deviation (MD) in patients with visible ODD when compared to patients with buried ODD. The morphologic causes for these findings are unclear, as the ODD visibility on ophthalmoscopy might be dependent on several factors such as age, ODD volume, anatomic location of ODD, and optic nerve head anatomy.

The introduction of enhanced depth imaging OCT (EDI-OCT) has made it possible to quantify ODD anatomically. The technique thereby enables us to decide to which degree ODD volume and anatomic location influence optic nerve function, which could be of importance for the pathophysiology of this condition.

A quantitative measure of ODD volume has only been described in a single case series, while a quantitative measure of ODD location in the optic nerve head, to the best of our knowledge, has never been described. In this study, we developed a new method based on a three-dimensional (3D) analysis of the optic nerve head and semiautomatic graph-based detection of Bruch’s membrane to calculate the height difference from the center of ODD mass to the defined reference surface.

The aim of this study was to investigate how volume and anatomic location of ODD influence optic nerve function using automated perimetry and multifocal visual evoked potentials (mfVEP). By including ODD visibility by ophthalmoscopy in the analysis, we assessed whether our quantitative measures were better predictors of optic nerve dysfunction than the qualitative often used classification using ODD visibility. Furthermore, we...
investigated whether RNFL and macular ganglion cell layer (GCL) thickness work as anatomic correlates to optic nerve dysfunction in ODD patients.

**Patients and Methods**

The study was a prospective observational study approved by the scientific ethics committee of the Capital Region, Denmark (H-4-2013-040).

**Patient Selection**

Patients diagnosed with ODD from January 1, 2009, to January 1, 2016, were asked to participate in the study. All patients were seen at the Department of Ophthalmology at Rigshospitalet-Glostrup, Denmark. The patient exclusion criteria were best corrected visual acuity (BCVA) >logMAR 0.2, age <18 years, and presence of systemic disease that could affect optic nerve function. Exclusion criteria for individual eyes were localized eye or optic nerve disease other than ODD (e.g., optic neuritis, glaucoma, etc.) or ODD complications (e.g., drusen-associated anterior ischemic optic neuropathy, central retinal artery, vein occlusion, etc.) that could affect optic nerve function.

Informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. All procedures adhered to the tenets of Declaration of Helsinki.

**Data Acquisition**

All examinations were performed by a single examiner (LM). All included participants were asked about medication use as well as ophthalmic and medical history. Best corrected visual acuity was determined using Early Treatment Diabetic Retinopathy Study (ETDRS) charts (4-meter original series; Precision-Vision, La Salle, IL, USA). Patients were examined using slit lamp biomicroscopy and intraocular pressure was measured by applanation tonometry. Spectral domain EDI-OCT (Spectralis HRA+OCT; Heidelberg Engineering, Heidelberg, Germany) was performed using the following protocol: (1) dense optic nerve head scan for identification and quantification of ODD with EDI-OCT in both vertical and horizontal directions with 30 μm between each B-scan (97 scans), averaging 30 B-scans; (2) peripapillary evaluation of RNFL thickness with a 12° circumferential scan; and (3) macular overview in vertical direction with 240 μm between each B-scan for evaluation of macular GCL thickness. All scans were performed in high resolution with averaging of B-scans using 18 scans and positive values referring to localization above the reference surface was thereafter calculated with negative values referring to localization above the reference surface and positive values referring to localization below the reference surface. The anatomic vertical location of each ODD was multiplied by the volume fraction of the same ODD relative to the total ODD volume in each patient to quantify the anatomic vertical center of weighted ODD mass. This means that a large deep ODD would have a greater impact on the vertical anatomic center of weighted ODD mass than a small superficial ODD, and thereby result in a deeper overall localization. On the other hand, if the superficial ODD was larger, the weighted center of mass would move toward a more superficial localization.

The agreement of ODD volume was assessed in 10 randomly selected patients with intraobserver variability using Bland-Altman plots. Intraobserver agreement in ODD volume assessment revealed a mean difference between measurements of 0.027 mm³ (SD ± 0.035), representing 9% of the mean ODD volume. Bland-Altman plots showed acceptable variability, no trend and limits of agreement between −0.062 and 0.099 mm³. Responses of mVEP were obtained by correlating visual stimuli with recorded electrical potentials using integrated software (Terra, version 1.6; VisionSearch, Sydney, Australia). Peak-to-peak (P2P) amplitude and monocular latency (second peak) was obtained using the integrated software after manual validation of the responses. Signal-to-noise ratio (SNR) amplitude was calculated in a computing environment (The MathWorks, Inc.) as described in previous work.

**Statistical Analysis**

Statistical analyses were performed using commercial software (SAS, version 9.1; SAS Institute, Cary, NC, USA). To avoid statistical bias, only one eye was included for each patient. The
eye with worst MD on automated perimetry was used in patients with bilateral ODD.

Mean and standard deviations or median and interquartile ranges (skewed distributions) were reported for continuous variables. Student’s t-test or Wilcoxon signed-rank test (skewed distribution) was used to compare patients with visible and buried ODD. We used χ² or Fisher’s exact tests (expected count < 5) for categorical data.

The assumptions of linearity, homoscedasticity, and normal distribution of residuals were tested when performing multiple regressions. The contribution of each predictor in the multiple regression analysis was found by assessing standardized parameter estimates (the change in Y, measured in units of its standard deviation, associated with a 1 standard deviation change in X). The assumptions of linearity, homoscedasticity, related pairs, and normality of variables were tested when performing correlation analysis. Adjustment for multiple testing in the correlation analyses was performed using the Holm-Bonferroni method. The predetermined level of statistical significance for the comparisons was $P \leq 0.05$.

**RESULTS**

We included 37 patients (30 women and 7 men) in this study. All included patients were Caucasian. Bilateral ODD were found in 95% of the patients. All eyes with ODD had one or more hyporeflective structures with a full or partial hyperreflective margin using OCT. Differences in clinical, mfVEP, and EDI-OCT findings were compared between patients with visible (visible by ophthalmoscopy) and buried (only visible by EDI-OCT) ODD (Table 1). Patient with buried ODD were significantly younger (median age: 21 years) than patients with visible ODD (median age: 33 years; $P = 0.015$). Significantly thinner peripapillary RNFL thickness and macular GCL thickness (3–6 mm from fovea) were found in patients with visible ODD ($P < 0.001$, $P = 0.002$). A tendency toward larger scleral canal size in patients with visible ODD was found ($P = 0.05$). A worse MD was found in patients with visible ODD ($-4.3$ dB) when compared to patients with buried ODD ($-1.9$ dB; $P = 0.025$). The quantitative measure of anatomic location was significantly different between the two groups with the center of weighted ODD mass being 172 lm below the reference level in patients with visible ODD and 306 lm below the reference level in patients with buried ODD ($P = 0.046$). Volume of ODD was larger in patients with visible ODD ($0.29$ mm³) than in patients with buried ODD ($0.01$ mm³; $P = 0.002$).

A multiple linear regression was calculated to predict MD based on ODD volume, visibility by ophthalmoscopy, anatomic ODD location, and age. A significant regression equation was found ($R^2 = 0.52$, $P < 0.0001$). Larger ODD volume was associated with worse MD ($P < 0.0001$). For every 1 mm³ increase in ODD volume, the MD decreased by 18.1 dB (CI 95% −25.6 to −10.7 dB). Anatomic ODD location, age, and visibility by ophthalmoscopy were not found significantly associated with MD when adjusted for the other variables. When looking at standardized parameter estimates, ODD volume had a higher effect on MD than age.

Another multiple linear regression was performed to estimate the relative effect of RNFL and macular GCL thickness on MD. A significant regression equation was found ($R^2 = 0.58$, $P < 0.0001$).
TABLE 1. Differences in Clinical, mVEP, and EDI-OCT Findings in Patients With Visible and Buried ODD

<table>
<thead>
<tr>
<th>Variable</th>
<th>Visible ODD (n = 32)</th>
<th>Buried ODD (n = 5)</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female sex, n</td>
<td>26</td>
<td>4</td>
<td>1.0*</td>
</tr>
<tr>
<td>Age, y</td>
<td>53 (26)</td>
<td>21 (1)</td>
<td>0.015†</td>
</tr>
<tr>
<td>Refractive error, D</td>
<td>−0.75 ± 3.1</td>
<td>0.95 ± 2.8</td>
<td>0.28‡</td>
</tr>
<tr>
<td>IOP, mm Hg (applanation tonometry)</td>
<td>15 (3)</td>
<td>13 (2)</td>
<td>0.98‡</td>
</tr>
<tr>
<td>BCVA, (ETDRS, letters)</td>
<td>88 (6)</td>
<td>87 (1)</td>
<td>0.79†</td>
</tr>
<tr>
<td>Ishihara</td>
<td>16/16</td>
<td>16/16</td>
<td>0.44‡</td>
</tr>
<tr>
<td>RAPD</td>
<td>8</td>
<td>0</td>
<td>0.56*</td>
</tr>
<tr>
<td>MD, dB</td>
<td>−4.5 (10.3)</td>
<td>−1.9 (2.6)</td>
<td>0.025†</td>
</tr>
<tr>
<td>Peak-to-peak mVEP amplitude, nV</td>
<td>122 ± 55</td>
<td>131 ± 48</td>
<td>0.74‡</td>
</tr>
<tr>
<td>Signal-to-noise ratio mVEP amplitude</td>
<td>3.8 ± 1.1</td>
<td>3.3 ± 0.6</td>
<td>0.29‡</td>
</tr>
<tr>
<td>Second peak mVEP latency, ms</td>
<td>154±9</td>
<td>153 ± 2</td>
<td>0.81‡</td>
</tr>
<tr>
<td>Peripapillary RNFL thickness, μm</td>
<td>66.6 ± 20</td>
<td>101.4 ± 6.8</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Retinal macular thickness, μm</td>
<td>277.8 ± 20.7</td>
<td>279.2 ± 10.6</td>
<td>0.83‡</td>
</tr>
<tr>
<td>Macular GCL thickness 3–6 mm, μm</td>
<td>29.5 ± 5.8</td>
<td>36.4 ± 3.0</td>
<td>0.002‡</td>
</tr>
<tr>
<td>Scleral canal diameter, μm</td>
<td>1631 (230)</td>
<td>1477 (114)</td>
<td>0.05†</td>
</tr>
<tr>
<td>ODD volume, mm³</td>
<td>0.29 (0.41)</td>
<td>0.01 (0.02)</td>
<td>0.002†</td>
</tr>
<tr>
<td>Mean anatomic location below reference level, μm</td>
<td>49 (211)</td>
<td>295 (114)</td>
<td>0.007†</td>
</tr>
</tbody>
</table>

D, diopter; IOP, intraocular pressure; RAPD, relative afferent pupillary defect.
* χ² test.
† Wilcoxon rank sum test.
‡ Student’s t test.

P < 0.0001). Worse MD was significantly associated only with GCL thickness (P = 0.025) when adjusted for the other variable. Mean deviation increased by 0.65 dB (CI 95% 0.08–1.2 dB) for every 1 μm increase in GCL thickness. When looking at standardized parameter estimates, GCL thickness had a higher effect on MD when compared to RNFL thickness.

Table 2 summarizes the correlation between anatomic and functional markers of optic nerve dysfunction. Macular GCL thickness had the highest degree of correlation when compared to MD (ρ = 0.76, P < 0.0001), while macular GCL thickness and peripapillary RNFL thickness were comparable when looking at mVEP parameters. The unadjusted correlation coefficient for the correlation between ODD volume and MD was −0.66 (Fig. 3).

DISCUSSION

Our study is, to the best of our knowledge, the first to quantitatively assess both the ODD volume and anatomic location quantitatively and applied it in a multivariate model for a better understanding of their relative contribution to optic nerve dysfunction.

We found that a larger ODD volume resulted in worse MD when adjusted for age, visibility by slit lamp, and anatomic location. Other studies have quantitatively assessed ODD size,11,12 and similar results were found in a recent case-series including five patients,12 where an excellent correlation between ODD volume and MD using automated perimetry was found. We suspect the increasing optic nerve dysfunction caused by larger ODD volume might be a result of either direct compression of adjacent ganglion cell axons, leading to ganglion cell death or secondary to compromised vascular flow.21

No association between weighted anatomic ODD location and MD was found in the current study. This is interesting as several studies have found worse MD in patients with ophthamologically visible ODD.8,22,25 Other studies have further found more abnormal visual fields in patients with visible ODD when compared to patients with buried ODD.24–26 The results from this study suggest that age, ODD volume, and ODD location all contribute to ODD visibility. This means that equating ODD visibility on ophtalmoscopy with superficial anatomic ODD location only, incorrectly leads one to believe that there is an association between superficial anatomic ODD location and worse MD. Our findings suggest that solely larger ODD volume, and not a more superficial ODD location, results in higher degrees of visual field defects.

Based on our finding that visibility by opthalmoscopy did not have an effect on MD when adjusted for age, ODD volume and ODD location, we argue that the classification using ODD visibility by opthalmoscopy is not ideal to estimate optic nerve dysfunction. Furthermore, the term “superficial”, often used in the classification, is misleading as several factors, such as age and ODD volume, influence the visibility. In this regard, the term “visible” ODD might therefore be more appropriate to use than superficial ODD.

We found differences in age, MD, RNFL, and GCL thickness that are supported by several studies when using the classification of ODD as visible or buried.8–11,23,27 Our results of the multivariate analysis suggest that GCL thickness is a better anatomic correlate to optic nerve dysfunction in ODD patients than RNFL thickness. While the macular GCL thickness has not been explored extensively in ODD literature, macular ganglion cell-inner plexiform layer thickness has proven to be a predictor of early glaucoma with the same sensitivity as RNFL thickness.28,29 It has even been suggested that individually segmented GCL thickness could be a better predictor for the presence of preperimetric glaucoma than RNFL thickness.30

Conflicting results have been published about the role of scleral canal size in ODD etiology.31–34 A larger scleral canal in patients with superficial ODD has been previously reported.5,33 and in this study, the same tendency was found. In unpublished data (Malqvist L, unpublished poster presentation, 2016), we have found smaller scleral canal in ODD children when compared to healthy children and we therefore suggest the finding of this study is due to a displacement of Bruch’s membrane caused by distending ODD. This was originally proposed as an alternative explanation for similar findings in a study by Floyd et al.34 Our proportion of patients...
with bilateral ODD (95%) is the highest reported in the literature. Most studies have reported bilateral ODD in 62% to 76% of patients.8,11,35,36 By using EDI-OCT in our study, we were able to diagnose eyes with small and deeply buried ODD overlooked by ophthalmoscopy, autofluorescence, B-scan ultrasound, and even conventional spectral-domain OCT. Based on these results, we propose that bilateral ODD are more common than previously believed.

In this study, we included mfVEP amplitude and latency as an objective measure of optic nerve function as previous studies have found significantly decreased amplitude and latency delays in patients with optic disc drusen when compared to control subjects.37,38 Hence an association between ODD volume and mfVEP parameters was expected. Parameters of mfVEP were significantly correlated with RNFL thickness, but not with ODD volume. That mfVEP amplitude was not correlated with ODD volume is likely a result of the high intersubject variability14 and in this case, we assume that the variability was too high to describe the more subtle changes in optic nerve dysfunction when only comparing ODD patients.

The major limitation of the study was the use of multiple regression analysis with the limited amount of patients. By using the covariate “visibility by ophthalmoscopy,” including only five eyes with buried ODD, the estimation was not strong. The fact that we, in multiple regression analyses, did not find an association between RNFL thickness and MD, can be ascribed to multicollinearity, as RNFL and GCL thickness were correlated. In this study, transverse magnification was not measured to account for the effect of optical magnification. However, the mean spherical equivalent refraction was not significantly different between patients with visible and buried ODD. In this study, we exclusively measured the volume of ODD defined as hyporeflective structures with a full or partial

<table>
<thead>
<tr>
<th>Variable</th>
<th>Automated Perimetry MD</th>
<th>Multifocal Visual Evoked Potentials</th>
<th>P2P</th>
<th>SNR</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODD volume</td>
<td>-0.66*</td>
<td>-0.43</td>
<td>-0.22</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>RNFL thickness</td>
<td>0.72*</td>
<td>0.51*</td>
<td>0.43*</td>
<td>-0.48*</td>
<td></td>
</tr>
<tr>
<td>GCL thickness</td>
<td>0.76*</td>
<td>0.56*</td>
<td>0.48*</td>
<td>-0.48*</td>
<td></td>
</tr>
</tbody>
</table>

Pearson’s correlation coefficient between anatomic and functional markers of optic nerve dysfunction.

* Holm-Bonferroni adjusted significant (P < 0.05). Latency was measured as second peak latency. Global RNFL thickness was measured peripapillary. Thickness of GCL was measured as the mean of a 3 to 6 mm ring around the fovea.

In this study, we included mfVEP amplitude and latency as an objective measure of optic nerve function as previous studies have found significantly decreased amplitude and latency delays in patients with optic disc drusen when compared to control subjects.37,38 Hence an association between ODD volume and mfVEP parameters was expected. Parameters of mfVEP were significantly correlated with RNFL and GCL thickness, but not with ODD volume. That mfVEP amplitude was not correlated with ODD volume is likely a result of the high intersubject variability14 and in this case, we assume that the variability was too high to describe the more subtle changes in optic nerve dysfunction when only comparing ODD patients.

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hyperreflective margin. However, other studies have reported ODD as either hyperreflective, granular, or hyporeflective when using OCT.\(^{11,39}\) The conflicting descriptions of ODD morphology are a limitation in this as well as other ODD studies, and should be addressed in future research.

In conclusion, this study suggests that ODD volume is significantly associated with optic nerve dysfunction. Even though a worse MD is often found in patients with visible ODD, a more superficial anatomic ODD location is not necessarily associated with worse MD. The current classification using visibility by ophthalmoscopy is an unspecific marker of optic nerve dysfunction compared to quantitative measurements of ODD volume using EDI-OCT.

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**References**


