Ophthalmoscopic-Perspectively Distorted Optic Disc Diameters and Real Disc Diameters

Yi Dai,1,2 Jost B. Jonas,3 Zhihong Ling,1,2 and Xinghuai Sun1,2,4

1Department of Ophthalmology and Vision Science, Eye & ENT Hospital, Shanghai Medical College, Fudan University, Shanghai, China
2Key Laboratory of Myopia of State Health Ministry and Key Laboratory of Visual Impairment and Restoration of Shanghai, Shanghai, China
3Department of Ophthalmology, Medical Faculty Mannheim of the Ruprecht-Karls-University, Heidelberg, Germany
4State Key Laboratory of Medical Neurobiology, Institutes of Brain Science, Fudan University

Correspondence: Xinghuai Sun, Department of Ophthalmology, Shanghai Eye, Ear, Nose and Throat Hospital, School of Shanghai Medicine, Fudan University, 83 Fenyang Road, Shanghai 200031, China; xhsun@shmu.edu.cn.

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Purpose. To investigate the difference between two-dimensionally measured disc diameters (DDs) based on fundus images and three-dimensionally measured DDs based on enhanced depth imaging optical coherence tomography (EDI-OCT).

Methods. The DDs were three-dimensionally measured on EDI-OCT images of optic nerve heads and two-dimensionally measured on near-infrared reflectance fundus images in 90 normal eyes of 90 subjects. Disc rotation around sagittal axis was defined as the angle between maximal DD and vertical axis. Disc rotation around horizontal and vertical axes was defined as cosine of DD on fundus images divided by DD on EDI-OCT images.

Results. Mean optic disc rotation around vertical axis was 14.4 ± 9.3°, rotation around sagittal axis was 23.0 ± 21.3°, and rotation around horizontal axis was 4.7 ± 6.6°. Horizontal, vertical, minimal, and maximal DDs as measured three-dimensionally were significantly (P < 0.001) higher than those measured two-dimensionally. Difference between three-dimensional and two-dimensional measurement of horizontal DD and vertical DD was associated with axial length (r = 0.38; P < 0.001, and r = 0.23; P = 0.03, respectively). Difference between three-dimensional and two-dimensional measurements was larger (P < 0.001) for horizontal DD (69.6 ± 21.3 μm) than for vertical DD (14.8 ± 25.6 μm). Correspondingly, the ratio of maximal-to-minimal DD (ovality index) was significantly larger (P < 0.001) for two-dimensional (1.33 ± 0.21) than for three-dimensional (1.27 ± 0.16) measurements.

Conclusions. Two-dimensional measurement of DDs leads to falsely low results, more for horizontal DD than for vertical DD. The discrepancy between low two-dimensional compared to three-dimensional disc measurements increases with longer axial length. The angle of disc rotation around vertical and horizontal axes can be measured with EDI-OCT imaging.

Keywords: optic disc, disc rotation, disc diameter, myopia, OCT

The optic disc has been defined as all the area within the peripapillary ring.1 The peripapillary ring is the continuation of the optic nerve pia mater into the border tissue of Eslchung and Jacoby, which separates the retinal ganglion cell axons from the choroid within the prelaminar space of the optic nerve head.2 The peripapillary ring usually is covered by Bruch’s membrane, which can protrude into the prelaminar space of the optic nerve head (in particular in the nasal region of the optic disc), or which in some myopic eyes may not reach the peripapillary ring leaving a parapapillary region without cover of Bruch’s membrane.3–5 Previous studies addressing size and shape of the optic nerve head usually have measured the image of the optic disc on fundus photographs.7 If stereoscopic fundus photographs were available, the optic cup and border between the optic cup and neuroretinal rim were determined in a three-dimensional manner, while the delineation of the border of the optic disc was based on a two-dimensional video screen.8 Most of these studies reported that the optic disc shape was slightly vertical oval with the vertical optic disc diameter being approximately 10% longer than the horizontal disc diameter.5 Studies on highly myopic eyes revealed that the ophthalmoscopic image of highly myopic optic discs showed a markedly oval shape and the longest diameter often was obliquely orientated.9,10

A two-dimensional assessment of an imaged structure will only reveal the real dimensions of the structure if the view onto the structure occurs in a perpendicular manner. If the structure is imaged at an oblique angle, the two-dimensional assessment of the image will lead to an underestimation of the real size in the meridian, which is oriented perpendicular to the axis around which the structure was rotated before it was imaged. Since the optic nerve head is not located exactly at the posterior pole of the eye globe, but positioned at the intermediate region between the posterior pole and the nasal eye globe wall, the ophthalmoscopic view onto the optic disc occurs at a slightly oblique angle. This angle gets more oblique...
(i.e., geometrically speaking, smaller) the more the optic nerve head is positioned more distant from the posterior pole. This is the case in eyes with axial myopia, in particular in eyes with axial high myopia. The hypothesis, therefore, is that the two-dimensional assessment of the optic disc borders on ophthalmoscopic images can lead to an underestimation of the optic disc diameters, in particular of the horizontal disc diameters. An underestimation of the optic disc size can lead to problems in the clinical diagnosis, in the sense of falsely low measurements of the neuroretinal rim, in particular in eyes with a vertical rotation of the optic disc. The neuroretinal rim size depends on the optic disc size and is the main intrapapillary target of the quantitative assessment of the optic nerve in glaucoma. Another clinical implication of an underestimation of the optic disc size is that the prevalences of some optic disc anomalies and diseases depend on the optic disc size. Optic disc drusen, pseudopapilledema and non-arteritic anterior ischemic optic neuropathy usually occur in small optic discs, while the prevalence of true papilledema and arteritic anterior ischemic optic neuropathy is independent of the optic disc size. Assessment of the optic disc, thus, can be helpful in the differential diagnosis of optic nerve head diseases. Any underestimation of the disc size, thus, may have a direct clinical impact.

The recently developed enhanced depth imaging technique of optical coherence tomography (EDI-OCT) has enabled the detection of the end of Bruch’s membrane in the region of the optic disc. Using the level of Bruch’s membrane as orientation level for the determination of the optic disc border, the EDI-OCT allows the three-dimensional assessment of the optic disc diameters and shape. Therefore, we conducted this study to examine whether the three-dimensional measurement of the disc diameters and shape of the optic disc differs from the two-dimensional measurements, and, if a difference exists, on which parameters such a difference is associated with. The results may be of clinical interest, since an assessment of an ophthalmoscopic-perspectively distorted optic disc image leads to falsely small disc measurements and an overestimated oval disc shape.

**Methods**

The cross-sectional clinical observational study included normal eyes of individuals who were consecutively examined. The study protocol was approved by the Institutional Review Board and written informed consent was obtained from all participants. All investigations adhered to the tenets of the Declaration of Helsinki. All study participants underwent a complete ophthalmological examination, including refractionmetry and assessment of visual acuity, slit-lamp assisted biomicroscopy of the anterior and posterior segment of the eye, gonioscopy, applanation tonometry, biometry with measurement of the axial length (IOL Master; Carl Zeiss Meditec, Jena, Germany), color photography of the optic nerve head (CR-DGI; Canon, Inc., Tokyo, Japan), perimetry (Humphrey Visual Field Analyzer; Zeiss, Inc., Oberkochen, Germany), and EDI-OCT imaging of the optic nerve head (Spectralis HRA-OCT; Heidelberg Engineering GmbH, Heidelberg, Germany).

The EDI-OCT scan was obtained using a 24 radial line B-scan centered on the optic disc, each at an angle of 7.5°. In a rectangle of $20^\circ \times 20^\circ$, we additionally obtained horizontal scans that included the parapapillary region and the optic disc. The number of these automatic real-time repeat scans was set to an average of 23 images. Additional single scans with 100 OCT frames averaged were performed if necessary. As imaged by the OCT, the parapapillary region was differentiated into α zone, β zone and γ zone. The α zone was defined as presence of Bruch’s membrane with irregular RPE, the β zone was characterized by the presence of Bruch’s membrane without RPE, and the γ zone was defined by the absence of Bruch’s membrane. The peripapillary region around optic disc was divided by clock hours and the location of the β zone around optic disc was centered on the optic disc, each at an angle of 7.5° by the OCT, the parapapillary region was differentiated into α zone, β zone and γ zone. As described previously in detail (Fig. 1). The optic disc diameter was defined as the length between the two borders marked on Bruch’s membrane in eyes without a parapapillary zone, that is, in eyes in which the peripapillary ring was covered by Bruch’s membrane. In eyes with a γ zone (i.e., eyes in which Bruch’s membrane did not extend to the border of the peripapillary ring), the peripapillary ring was defined to be the optic disc border. On the EDI-OCT images and on the near-infrared reflectance fundus images, we measured the horizontal, vertical, minimal, and maximal disc diameters using the built-in measurement tools. The ratio of the maximal-to-minimal disc diameter was calculated as the ovality index.

As described in detail recently, we differentiated between a rotation of the optic disc around the vertical axis (“vertical rotation”), the sagittal axis (“sagittal rotation”), and/or the horizontal axis (“horizontal rotation”). Based on geometry, a rotation around the vertical disc axis leads to a horizontally shortened, or seemingly vertically elongated, image of the optic disc. If measured by a two-dimensional method, the horizontal disc diameter measurements get falsely low, while the vertical disc diameter measurements remain unaffected. Using trigonometrical calculations, a disc rotation around the vertical axis was calculated as the cosine of the ratio of the horizontal disc diameter measured on the two-dimensional reflectance fundus images divided by the horizontal disc diameter as measured on the EDI-OCT images. A disc rotation around the sagittal disc axis, usually moving the superior disc pole into the temporal direction, is not associated with a change in the perspective ophthalmoscopic image of the optic nerve head since the en face view remains unchanged. Since the ophthalmoscopic image is not affected, neither are the measurements of any disc diameter or the disc area. A disc rotation around the sagittal axis was measured on the near-infrared reflectance fundus images by the angle between the maximal disc diameter and the vertical axis. If the optic disc is rotated around the horizontal disc axis, a typically “tilted” disc would occur with a retinal vessel exit at the superior disc pole, a prominent and slightly unsharp disc border in the superior disc region, and often a so-called inferior scleral crescent. As a corollary to discs rotated around the vertical disc axis, discs rotated around the horizontal disc axis show a perspective shortening of the vertical disc diameter, while the image of the horizontal disc diameter remains unaffected. A disc rotation around the horizontal axis was calculated as the cosine of the ratio of the vertical disc diameter measured on the two-dimensional reflectance fundus images divided by the vertical disc diameter as measured on the EDI-OCT images.

The statistical analysis was performed using a commercially available statistical software package (SPSS for Windows, version 22.0; IBM-SPSS, Inc., Chicago, IL, USA). Means and standard, and medians and ranges were presented. The paired sample $t$-test and Pearson correlation analysis were used to investigate the difference between parameters measured on the EDI-OCT and near-infrared reflectance fundus images. All $P$ values were 2-sided and considered statistically significant when they were less than 0.05.
RESULTS

The study included 90 eyes of 90 patients (46 women). Mean age was 38.4 ± 11.6 years (median, 37 years; range, 20–70 years), mean axial length was 26.42 ± 2.60 mm (median, 26.55 mm; range, 21.91–32.30 mm), and mean refractive error was −7.68 ± 5.58 diopters (median, −7.50 diopters; range, −20.50 to +3.25 diopters).

The mean vertical rotation was 14.4 ± 9.3º, the mean sagittal rotation was 23.0 ± 21.3º, and the mean horizontal rotation was 4.7 ± 6.6º. The rotation around all three axes was significantly and positively associated with increasing axial length, with the association being stronger for the vertical rotation ($r = 0.44$, $P < 0.001$), followed by the sagittal rotation ($r = 0.29$, $P = 0.007$), and finally by the horizontal rotation ($r = 0.24$, $P = 0.02$, Figs. 2–4).

The horizontal, vertical, minimal, and maximal disc diameter as measured on EDI-OCT images all were significantly higher than those measured on the near-infrared reflectance fundus images ($P < 0.001$, Fig. 5; Table). In univariate analysis, the difference with respect to the horizontal disc diameter between the three-dimensional measurement and the two-dimensional measurement, and the ratio of this difference divided by the disc three-dimensional measurement and the two-dimensional measurement was significantly associated with axial length ($r = 0.38$, $P < 0.001$ and $r = 0.38$, $P < 0.001$, respectively) and vertical rotation ($r = 0.94$, $P < 0.001$ and $r = 0.94$, $P < 0.001$, respectively, Fig. 6). It was not significantly associated with the horizontal rotation ($P = 0.75$ and $P = 0.88$, respectively) or sagittal rotation ($P = 0.94$ and $P = 0.77$, respectively). In univariate analysis, the difference with respect to the vertical disc diameter between the three-dimensional measurement and the two-dimensional measurement, and the ratio of this difference divided by the disc three-dimensional diameter of the vertical disc diameter was significantly associated with axial length ($r = 0.25$, $P = 0.03$ and $r = 0.18$, $P = 0.18$, respectively), horizontal rotation ($r = 0.90$, $P < 0.001$ and $r = 0.87$, $P < 0.001$, respectively), and sagittal rotation ($r = 0.44$, $P < 0.001$ and $r = 0.44$, $P < 0.001$, respectively). It was not significantly associated with the vertical rotation ($P = 0.58$ and $P = 0.69$, respectively).

The difference between three-dimensional and two-dimensional measurements was significantly ($P < 0.001$) larger for the minimal disc diameters (75.4 ± 69.6 μm) than for the maximal disc diameters (9.2 ± 21.7 μm). In a similar manner, the difference between three-dimensional and two-dimensional measurements was significantly ($P < 0.001$) larger for the horizontal (69.6 ± 68.1 μm) than for the vertical (14.8 ± 25.6 μm) disc diameters. The ratio of maximal-to-minimal disc diameter (ovality index) was significantly larger ($P < 0.001$) for the two-dimensional (1.33 ± 0.21) than for the three-dimensional (1.27 ± 0.16) measurements.

The ratio of the three-dimensional maximal-to-minimal disc diameter increased with increasing axial length ($r = 0.47$, $P < 0.001$). The ratio of two-dimensional maximal-to-minimal disc diameter was slightly stronger associated with increasing axial length ($r = 0.49$, $P < 0.001$). The ratio of three-dimensional vertical-to-horizontal disc diameter increased with increasing axial length ($r = 0.20$, $P = 0.058$). The ratio of two-dimensional
vertical-to-horizontal disc diameter was slightly stronger associated with increasing axial length ($r = 0.26$, $P = 0.01$, Fig. 7).

**DISCUSSION**

Our clinical observational study showed that the optic disc as measured three-dimensionally can be rotated around the vertical, sagittal, and horizontal axes. If measured two-dimensionally on fundus photographs, the horizontal disc diameter is determined falsely low in the case of a disc rotation around the vertical axis, and the vertical disc diameter is determined falsely low in the case of a rotation around the horizontal axis. The amount of falsely low measurements, corresponding to an increasing rotation of the optic disc,
increased with longer axial length. The association of disc rotation with longer axial length was stronger for the vertical disc rotation than for the sagittal or horizontal disc rotation. As a whole, the difference between two-dimensional and three-dimensional measurements was more marked for the horizontal than for the vertical disc diameter. Thus, two-dimensional measurements on fundus photographs led to a falsely oval disc shape, while in three-dimensional assessment, the disc shape was more circular.

These findings agreed with a previous study in which the optic nerve was directly measured in 107 freshly enucleated unfixed human donor eyes after removal of cornea, lens, vitreous body, choroid, and retina. In that study, the ratio of minimal-to-maximal disc diameter was 0.86 ± 0.11, indicating a slightly oval nearly round form. In our study, the ratio of minimal-to-maximal disc diameter was 0.80 ± 0.10, which was slightly lower than in the previous study. The difference may be due to a higher prevalence of highly myopic axially elongated eyes in our study, with highly myopic eyes compared to nonhighly myopic eyes having a more ovaly configured optic disc.

The results of our study have clinical importance, in particular for eyes with so called tilted discs and for highly myopic eyes. Tilted discs usually have been defined as optic nerve heads in which the longest disc diameter is orientated horizontally or obliquely, while in normal eyes, the vertical disc diameter is approximately 5% to 10% longer than the horizontal disc diameter. In these tilted discs, the superior disc pole usually is leaned forward, corresponding to a disc rotation around the horizontal disc axis. Since a disc rotation around the horizontal axis leads to falsely low measurements of the vertical disc diameter, the two-dimensional image of a tilted disc will be falsely oval.

**Figure 4.** Scattergram showing the distribution of axial length and optic disc rotation around the horizontal axis ($P = 0.02$; correlation coefficient, $R^2 = 0.06$).

**Figure 5.** Optical coherence tomography of the optic disc showing the difference between 2-dimensional near-infrared reflectance fundus image and 3-dimensional EDI-OCT images. (B) A B-scan EDI-OCT image corresponding to (A). Serial B-scan of the optic disc led to the 3-dimensional reconstruction. (C) A 3-dimensional reconstruction of the optic disc at the same scale of (A). The angle of view was rotated along the horizontal and vertical axes.
disc on a fundus photograph gives a falsely low vertical dimension of this optic nerve head. In highly myopic axially elongated eyes, the posterior pole of the globe gets enlarged, so that the optic nerve head may move from a paracentral position to a location closer to the nasal eye globe wall. It leads to a rotation of the optic disc around the vertical axis with a secondary perspective shortening of the horizontal disc diameter on two-dimensional fundus photographs. Another importance of the perspectively shortening of the disc diameters in the two-dimensional assessment of optic nerve heads on fundus photographs is that similar changes could occur for the determination of the neuroretinal rim width. The neuroretinal rim is one of the most important parameters in the assessment of the optic nerve.

We described a new method for measuring the angle of disc rotation with EDI-OCT imaging by using the fundus photograph as surrogate for the horizontal/vertical line and calculated the angle as the cosine of the ratio of the two-dimensionally determined disc diameter and the three-dimensionally determined disc diameter. The ovality of the optic disk has been traditionally assumed to be an index of disc tilt.16,17 In recent years, several different ways of measuring the disc tilt and rotation quantitatively have been reported.18–21 Lamparter et al.18 draw a line between the retinal pigment epithelium border/Bruch’s membrane opening and an additional line connecting two points in an arbitrarily chosen distance of 2000 μm from the retinal pigment epithelium border on OCT images. While Hosseini et al.19 used the same line between the RPE border and draw a second line connecting the two points marking the clinical disc margin on the OCT image and measured the vertical tilt angle between both lines. All these OCT-based methods are helping to define the various optic disc morphologies that have been collectively called tilted discs.22

Potential limitations of our study should be mentioned. First, it was a hospital-based investigation so that the values found for the mean disc rotation may not be taken to be representative for the whole population. Such information is best obtained in a population-based study. Second, our study did not include very many highly myopic eyes so that the difference between the two-dimensional optic disc assessment on fundus photographs and the three-dimensional assessment on OCT images may not have been fully explored for this subgroup. The same holds true for so called tilted discs. Third, our study did not include children. Previous studies have

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**Table.** Optic Disc Dimensions in 90 Normal Human Eyes Measured on Three-Dimensional Enhanced-Depth Imaging OCT Images and on Two-Dimensional Near-Infrared Reflectance Fundus Images

<table>
<thead>
<tr>
<th>Metric</th>
<th>3-Dimensional OCT Images</th>
<th>2-Dimensional Fundus Images</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Minimum</td>
</tr>
<tr>
<td>Horizontal diameter, mm</td>
<td>1.62 ± 0.25</td>
<td>1.14</td>
</tr>
<tr>
<td>Vertical diameter, mm</td>
<td>1.85 ± 0.26</td>
<td>1.28</td>
</tr>
<tr>
<td>Minimal diameter, mm</td>
<td>1.56 ± 0.22</td>
<td>1.14</td>
</tr>
<tr>
<td>Maximal diameter, mm</td>
<td>1.95 ± 0.28</td>
<td>1.37</td>
</tr>
<tr>
<td>Horizontal/vertical diameter</td>
<td>0.88 ± 0.12</td>
<td>0.60</td>
</tr>
<tr>
<td>Minimal/maximal diameter</td>
<td>0.80 ± 0.10</td>
<td>0.57</td>
</tr>
</tbody>
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P value; statistical significance of the difference in the mean value between both groups.
shown the change in the orientation of the optic nerve head with increasing age in myopic children. Future studies may specifically address the change in the rotation of the optic nerve head in children in dependence on the refractive error.

In conclusion, the two-dimensional measurements of disc diameters on fundus photographs leads to falsely low results, more for the horizontal and maximal disc diameter than for the vertical and minimal diameter. The discrepancy between falsely low disc measurements by two-dimensional assessment as compared to three-dimensional measurements increases with longer axial length. The real shape of optic disc is more circular than it appears upon ophthalmoscopically, in particular in myopic eyes.

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References


FIGURE 7. Scattergram showing the distribution of axial length and the ratio of vertical optic disc diameter (2-dimensional) divided by the horizontal optic disc diameter (2-dimensional), stratified by the amount of optic disc rotation around the vertical axis ($P = 0.01$; correlation coefficient, $R^2 = 0.07$).


