PERSPECTIVE
From Clinical Examination of the Optic Disc to Clinical Assessment of the Optic Nerve Head: A Paradigm Change

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• PURPOSE: To review and interpret the anatomy of the optic nerve head (ONH) detected with spectral-domain optical coherence tomography (SD OCT) pertaining to the clinical examination of the optic disc and to propose that a paradigm change for clinical assessment of the ONH is necessary.

• DESIGN: Perspective.

• METHODS: Presently, the clinician evaluates neuroretinal rim health according to the appearance of the optic disc, the clinically visible surface of the ONH. Recent anatomic findings with SD OCT have challenged the basis and accuracy of current rim evaluation. We demonstrate why incorporation of SD OCT imaging of the ONH into the clinical examination of the disc is required.

• RESULTS: Disc margin-based rim evaluation lacks a solid anatomic basis and results in variably inaccurate measurements for 2 reasons. First, the clinically visible disc margin is an unreliable outer border of rim tissue because of clinically and photographically invisible extensions of Bruch’s membrane. Second, rim tissue orientation is not considered in width measurements. We propose alternative anatomically and geometrically accurate SD OCT-based approaches for rim assessment that have enhanced detection of glaucoma. We also argue for new data acquisition and analysis strategies with SD OCT that account for the large interindividual variability in the angle between the fovea and ONH.

• CONCLUSIONS: We propose a 4-point paradigm change for clinical assessment of the ONH that is anchored to the eye-specific anatomy and geometry of the ONH and fovea. Our approach is designed to enhance the accuracy and consistency of rim width, as well as of peripapillary and macular intraretinal thickness measurements. (Am J Ophthalmol 2013;■:■–■. © 2013 by Elsevier Inc. All rights reserved.)

Since Von Helmholtz’s description of the direct ophthalmoscope in 1851, clinical examination of the optic disc has been a cornerstone of ophthalmic practice.1 The optic disc constitutes the clinically visible surface of the neural and connective tissues of the optic nerve head (ONH). By current convention, clinical disc examination requires identification of the outer and inner borders of the neuroretinal rim, respectively, the optic disc margin, and the optic disc cup. The amount of rim tissue then is estimated within the apparent plane of the disc margin as either the ratio of the size of the cup to the size of the disc2 or the rim area.3 These concepts are applied whether the examination is performed with direct ophthalmoscopy, slit-lamp biomicroscopy, optic disc photography, or a growing number of quantitative imaging methods.

Advances in spectral-domain optical coherence tomography (SD OCT) for the first time have permitted imaging of ONH anatomic features. Structures such as the anterior4–6 and posterior7,8 lamina cribrosa surfaces, Bruch’s membrane–retinal pigment epithelium complex and its termination within the ONH6,9,10 border tissue of Elschnig,5 and the scleral canal opening9 now can be visualized readily. Accurately colocalizing fundus photographs to SD OCT image data has allowed clinicians to identify structures that correspond to common clinical landmarks, for example, the optic disc margin.9,10

In this article, we explain how recent SD OCT findings undermine the current concepts of the clinical disc margin and rim quantification from both anatomic10 and geometric11–13 perspectives. In light of these findings, we propose a 4-part paradigm for incorporating new insights provided by SD OCT imaging of ONH anatomic features into the clinical examination of the optic disc to achieve a clinical assessment of the ONH. The paradigm recognizes the variable relationship between the fovea, the path of the retinal nerve fiber bundles, and the ONH14 among individuals. Its logic links the evaluation of the neuroretinal rim and peripapillary and macular retinal nerve fiber layer (RNFL) to the specific anatomy and geometry of each individual ONH and its relative orientation with the fovea.
ANATOMIC ASSUMPTIONS UNDERLYING THE CLINICALLY VISIBLE OPTIC DISC MARGIN

The optic disc margin is a clinical landmark that traditionally is defined to be the inner edge of the scleral lip or crescent (Figure 1).13 Within this conceptual framework, the disc margin is assumed to be a single and consistent anatomic structure around the entire ONH and a true outer border of the neuroretinal rim, and therefore the landmark from which the width of the rim can be measured. Current examination methods require identification of the disc margin, whether the examination is performed clinically, photographically, or with confocal scanning laser tomography, an imaging technique that maps the surface topography of the ONH.16

ANATOMIC ERRORS IN THE CURRENT EVALUATION OF THE NEURORETINAL RIM

Recent histologic findings in monkey eyes9 and SD OCT findings in human eyes10 (in each case, colocalized to optic disc stereophotographs with the disc margin traced by a glaucomatologist) have revealed 2 new findings that challenge the anatomic assumptions that underlie optic disc margin-based neuroretinal rim evaluation. First, the clinical disc margin rarely is a single anatomic entity, nor are the structures that underlie it consistent in an individual eye. Hence, the structure corresponding to the disc margin at the 3-o’clock position may be different to that at the 9-o’clock position. Similarly, the structure corresponding to it at the 3-o’clock position in 2 eyes also may be different.10 Second, what the clinician perceives as the disc margin in clinical examination or with photographs frequently is not a true anatomic outer border of the neuroretinal rim because of regionally variable and invisible extensions of Bruch’s membrane that have not been appreciated previously (Figure 2). In such cases, there can be a serious overestimation of the remaining rim tissue.13

Separate from these new issues regarding the anatomic outer border of the neuroretinal rim, its inner border, which constitutes the cup margin, is evaluated clinically with a stereoscopic evaluation of the rim width within the perceived plane of the disc margin. However, the rationale to support the existence of an anatomically defensible junction between the neuroretinal rim and cup is weak. Current imaging techniques similarly divide the rim and cup on the basis of an arbitrary depth below a fixed plane.

The consequence of these findings is that current parameters, including cup-to-disc ratio and neuroretinal rim area, are unlikely to estimate accurately the amount of remaining neural tissue in the ONH.13

ANATOMIC RATIONALE FOR BRUCH’S MEMBRANE OPENING AS THE OUTER BORDER OF THE NEURORETINAL RIM

The termination of Bruch’s membrane at the ONH represents the opening through which retinal ganglion cell axons exit the eye to form the choroidal and scleral portions of the neural canal. As such, this anatomic opening, termed Bruch’s membrane opening (BMO), is a true outer border of the neural tissues because axons cannot pass through an intact Bruch’s membrane to exit the eye. Whether BMO is clinically visible, it is an
anatomically accurate landmark from which neuroretinal rim measurements can be made. It is also a structure that is identified consistently with SD OCT.9,13,17

The stability of BMO under a variety of conditions provides another rationale for its usefulness as a landmark. BMO is unaltered in the face of large changes in intraocular pressure induced by glaucoma surgery.18 The 2-dimensional plane that best fits BMO also is axially stable with surgical reduction of intraocular pressure.18 There is no published evidence yet on the stability of BMO with glaucoma progression; however, in experimental glaucoma in monkeys, BMO position in 3-dimensional histomorphometry of the ONH seems to be unaltered despite changes in the neural component of the ONH and in the positions of the anterior and posterior scleral canal opening.19

GEOMETRIC ERRORS IN THE CURRENT EVALUATION OF THE NEURORETINAL RIM

NEURORETINAL RIM MEASUREMENT WITH CLINICAL, photographic, or confocal scanning laser tomographic techniques is made along the 2-dimensional plane of the perceived optic disc margin. However, in a single eye, the orientation of rim tissue varies around the ONH. At one extreme, axons may exit the eye almost parallel to the visual axis, whereas at the other extreme, they may exit the eye almost perpendicular to it, typically in the temporal sector, which can have a shallow sloping rim.20 Hence, potentially significant errors in rim width can occur if the measurement plane is fixed.13 For example, for the same number of axons, the conventional rim width will be larger when its orientation is more horizontal compared with when it is more perpendicular to the fixed plane of measurement (Figure 3). Even if a rim measurement is made from an anatomically accurate location, that is, BMO, its width along the approximately horizontal fixed plane of BMO will be influenced by the orientation of the overlying rim tissue (Figure 3).

GEOMETRIC RATIONALE FOR FORMULATING A MINIMUM RIM WIDTH MEASUREMENT

BECAUSE OF THE VARYING ORIENTATION OF THE NEURORETINAL rim relative to BMO, Chen and Povazay and associates and first proposed that the minimum distance from BMO to the internal limiting membrane represents the most geometrically accurate measurement of neuroretinal rim width.11,12 We subsequently characterized the
difference between this rim measurement, termed BMO-
minimum rim width (BMO-MRW), and conventional
ones13 and its usefulness in the detection of progressive
ONH change in experimental primate glaucoma. Most
recently, we showed that BMO-MRW significantly
enhanced the ability to detect glaucomatous optic neurop-
athy compared with current confocal scanning laser tomog-
raphy and current SD OCT analyses.22

Automated algorithms for identifying (segmenting) BMO
in B-scans of SD OCT images have been described and incor-
porated into commercial software.17,23–25 However, to date,
the primary rationale for this implementation has been for
automated detection of the optic disc margin and derivation
of a rim width measurement along a single fixed plane,23,25
akin to current clinical methods. Hence, although SD OCT
technology is providing unprecedented detail on the
anatomy of the ONH, which heretofore has not been
possible, its use has been limited to mimicking the manner
in which the optic disc is examined clinically, rather than
incorporating the anatomic insights that clinicians have not
been able to appreciate before into clinical practice.

CLINICAL EXAMPLES

THE OPTIC DISC PHOTOGRAPH AND 24 COLOCALIZED SD OCT
radial B-scans around the ONH of each of 30 glaucoma
patients and 10 control subjects illustrating (1) that the clinical
disc margin is not a single anatomic location, (2) that clinically invisible extensions of Bruch’s membrane internal
to the disc margin are regionally present in most eyes,
and (3) that the dependence of rim width measurement
on rim tissue orientation are available online (http://
ophthalmology.medicine.dal.ca/research/onh.html).

FIGURE 3. Influence of neuroretinal rim orientation on rim width measurement. Portions of B-scans from the same eye with
spectral-domain optical coherence tomography: (Top left) one in which the rim orientation is relatively flat and (Top right) in another
where it is relatively steep. (Bottom) Measurement of rim width along the fixed Bruch’s membrane opening (BMO) plane, termed
BMO-horizontal rim width (BMO-HRW), and along the axis resulting in the minimum rim width from BMO, termed BMO-
minimum rim width (BMO-MRW). The actual amount of rim tissue represented by BMO-MRW is identical in these 2 sections;
however, BMO-HRW is more than 60% wider in the section shown to the left compared with the one on the right.

ANATOMIC VARIATION IN FOVEA
POSITION RELATIVE TO THE OPTIC
NERVE HEAD

IN CLINICAL FUNDUS IMAGES, THE FOVEA IS LOCATED
below the level of the center of the ONH in most individu-
als. A recent study on the angle between the fovea and
BMO center relative to the horizontal axis defined by the
fundus image, termed the fovea-BMO center axis, in 222
patients with ocular hypertension or glaucoma showed
that although the mean angle of this axis was −7 degrees
(the fovea being 7 degrees below), the range was
from −17 degrees to +6 degrees, or 23 degrees (Demirel
S, written communication, January 25, 2013; Figure 4).
Although the positions of these 2 structures relative to
the fundus image vary considerably between subjects, the
anatomic path of RNFL bundles is governed primarily by
these 2 structures as the bundles approach the ONH and

FIGURE 3.
exit the eye. In fundus images, the positions of the fovea and ONH also may vary slightly within the same individual from day to day because of cyclotorsion; however, the path of RNFL bundles remains constant relative to the fovea-BMO center axis.

RATIONALE FOR REGIONALIZATION OF THE NEURORETINAL RIM AND PERIPAPILLARY AND MACULAR NERVE FIBER LAYER RELATIVE TO THE FOVEA-BMOS MEMBRANE OPENING CENTER AXIS

Currently, image acquisition and data analysis algorithms report regional data according to the temporal, superior, nasal, and inferior sector positions that are established relative to the fixed horizontal and vertical axes of the image. Hence, for example, the neuroretinal rim width or peripapillary RNFL thickness in a given sector is assumed to refer to precisely the same anatomic location among different persons. However, because the fovea-BMO center axis can vary by as much as 23 degrees, the anatomic difference between 2 eyes of an individual geometric sector position also may be as large as 23 degrees (Figure 5).

Because sector positions refer to measurements from different anatomic locations, artificially large interindividual differences in sectoral neuroretinal rim width and peripapillary and macular RNFL thickness likely occur. As a result, the limits of normal variation in these measurements, as reflected in normative databases, are probably artificially increased, decreasing the diagnostic precision of imaging devices. Errors in mapping ocular structures to the visual field also may be induced and contribute to the poor observed correlation between measures of structure and function in glaucoma.

RATIONALE FOR IMAGE ACQUISITION RELATIVE TO THE FOVEA-BMOS MEMBRANE OPENING CENTER AXIS

Because it is important to regionalize neuroretinal rim width and peripapillary and macular RNFL thickness according to the fovea-BMO center axis, it is reasonable to extend the same logic also to data acquisition. Currently, data acquisition by imaging devices occurs invariably

FIGURE 4. Interindividual variability in the axis connecting the fovea and Bruch’s membrane opening (BMO) center (fovea-BMO center axis) in 222 patients with ocular hypertension or glaucoma. (Left) Schematic demonstrating the range of the fovea-BMO center axis (solid line), from (Top left) + 6 degrees above to (Bottom left) − 17 degrees below the horizontal in the image frame (dashed line). (Right) Frequency histogram with a mean value of − 7 degrees (center left). Dots = BMO; filled circle = fovea; filled square = BMO center. Data courtesy of Dr Shaban Demirel, Devers Eye Institute, Portland, Oregon.
according to a fixed coordinate system for sectors preset in the device.

It is logical, therefore, that the fovea-BMO center axis be determined first in each eye, followed by data acquisition relative to this axis, to ensure that measurements are distributed according to the pertinent anatomy of the individual eye. Such an approach will allow the most robust sampling of the constituent anatomy and the most meaningful comparison between individuals. Furthermore, because of image registration software, follow-up images then can be acquired at the same anatomic positions in each eye.

FIGURE 5. Impact of regionalization of neuroretinal rim width and peripapillary retinal nerve fiber layer thickness measurements based on the axis connecting the fovea and Bruch’s membrane opening (BMO) center (fovea-BMO center axis). (Top center) Eye with fovea-BMO center axis of +6 degrees. (Top right) Eye with fovea-BMO center axis of −17 degrees. (Middle left) Sector regionalization according to positions that are fixed relative to the imaging frame of the imaging device, currently applied to all eyes in the analyses of rim width and retinal nerve fiber layer thickness. (Middle center and Middle right) Current regionalization with fixed sector orientation leads to measurements from variably different anatomic locations. (Bottom center and Bottom right) Regionalization relative to fovea-BMO center axis. In this case, rotating the sector orientation according to the fovea-BMO center axis ensures that sectors contain measurements from the same anatomic locations. IN = inferonasal; IT = inferotemporal; N = nasal; SN = superonasal; ST = superotemporal; T = temporal.

PROPOSED PARADIGM CHANGE FOR CLINICAL ASSESSMENT OF THE OPTIC NERVE HEAD

Below, we propose a 4-point paradigm change that incorporates the new anatomic insights provided by SD OCT imaging of the ONH into the clinical examination of the optic disc for clinical assessment of the ONH (Figure 6).

1. Optical Coherence Tomography Imaging of the Optic Nerve Head Should not Mimic the Clinical Examination of the Optic Disc.
Because of the fundamental differences between the clinical examination of the optic disc and SD OCT imaging of the ONH, we believe that constraining SD OCT analyses to mimic the disc examination is erroneous. Instead, we propose that clinical practice should incorporate knowledge of ONH anatomy detected by SD OCT into the clinical disc examination in the same manner that diagnostic imaging techniques in other areas of medicine have advanced their fields. For example, pulmonologists are trained to review imaging studies (x-ray, computed tomography, and magnetic resonance images) to enhance their clinical chest examination (palpation, percussion, and auscultation). In this regard, the practice of referring to the SD OCT-detected BMO as the optic disc margin is inaccurate and potentially misleading. Incorporating the anatomic insights provided by SD OCT into the clinical examination will be informative and should enable clinicians to make more accurate diagnoses. Constraining SD OCT to conventional concepts of disc anatomy and terminology will inhibit its clinical potential.


Quantifying neuroretinal rim width requires identification of its inner border relative to anatomic landmarks that is a true outer border of the rim. Currently, BMO is the most consistent SD OCT-detected outer border of the neuroretinal rim and a stable landmark that is visible readily in all but a few exceptional B-scans. The minimum distance from BMO to the internal limiting membrane represents the geometrically correct width of the neuroretinal rim. Automated algorithms that detect BMO and the internal limiting membrane with SD OCT images are now available. Those that quantify BMO-MRW regionally and determine its probability of being within age-specific norms could be developed and be available for clinical use.

3. Acquisition and Regionalization of Data Based on Fovea-Bruch’s Membrane Opening Center Axis.

Acquisition and regionalization of ONH and retinal imaging data should respect the anatomic relationship between the fovea and the ONH. In doing so, regional estimates of the neuroretinal rim and the peripapillary and macular RNFL layer thickness will be correct anatomically and consistently will be comparable among individuals. The practical effect of correct regionalization should be reduced interindividual variation, leading to potentially more accurate and sensitive identification of early damage because of statistically narrower limits of variability. Correct regionalization also may increase the correspondence between structural and visual field measures. Such regionalization strategies will not impact global measurements, because the latter represent sums or averages around the entire ONH or macula.

4. Optical Coherence Tomography Imaging of ONH Anatomic Features Should Enhance, Rather Than Replace, the Clinical Optic Disc Examination.

One of the key goals of the clinical optic disc examination is to assess the amount and health of the neuroretinal rim. In the clinical examination of the optic disc, the amount of rim tissue should be estimated based on the assumption that the disc margin represents the outer border of rim tissue. The examination should continue to characterize the color and health of the rim regionally, or by clock hour, around the optic disc and to check for the presence of pallor, bowing, or excavation of the ONH surface; optic disc hemorrhages; and peripapillary RNFL defects. The clinical examination is essential even if SD OCT imaging is available because many of the qualitative aspects of the examination, such as the color of the rim and the presence of hemorrhages, cannot be detected readily with SD OCT or other imaging devices.

However, the clinician should be cognizant of the limitations of current methods of rim width measurement and be aware that potentially serious errors in rim evaluation can occur because of the reasons discussed above. For pragmatic reasons, it is unrealistic to expect or require that each clinical optic disc examination by all physicians in all environments be accompanied by SD OCT imaging. When the clinical disc examination is unequivocally normal, SD OCT imaging is unlikely to be additionally informative (Figure 7). However, when there is suspicion of abnormality, SD OCT will provide an anatomically accurate assessment of the neuroretinal rim (Figure 8).

Finally, we believe that SD OCT-detected anatomic features of the ONH should be displayed relative to a clinical photograph or infrared image of the disc by sectors or clock-hour positions according to the fovea-BMO center axis (Figures 7 and 8). Hence, clinicians can incorporate knowledge of this anatomy into their clinical disc examination and formulate a clinical assessment of the ONH at the time imaging is performed. In the future, segmental rim widths in a given image may be compared.

FIGURE 6. Schematic of incorporating spectral-domain optical coherence tomography (SD OCT) imaging that includes quantitative analyses and an understanding of optic nerve head (ONH) anatomic features into a clinical examination of the optic disc with ophthalmoscopy, slit-lamp biomicroscopy, or photography to yield a clinically informed assessment of the ONH.
with normative databases in an anatomically and geometrically accurate manner.

**SUMMARY**

**FROM RECENT FINDINGS ON ONH ANATOMY DETECTED** with SD OCT, we have argued that the foundation of current clinical optic disc margin-based evaluation of the neuroretinal rim is inaccurate because it lacks a solid anatomic and geometric foundation. We propose a paradigm change from the current clinical examination of the optic disc to the clinical assessment of the ONH that includes SD OCT imaging (Figure 6). The immediate consequence of the new quantitative measures proposed is that our ability to detect glaucoma is enhanced. We anticipate that as data acquisition and analysis takes place according to the specific fovea-BMO center axis of an individual eye, interindividual variation in several important quantitative measures, including thickness of the peripapillary and macular RNFL and other segmented layers of the retina, will decrease and further will enhance detection of glaucoma. Finally, as longitudinal data are acquired, our ability to detect earlier and clinically meaningful change similarly may also be improved.

**FIGURE 7.** Incorporation of spectral-domain optical coherence tomography (SD OCT) into a clinical examination of the optic disc in a normal left eye. In this case, where the clinical appearance (Top) seems unequivocally normal, SD OCT with analysis of Bruch’s membrane opening minimum rim width (BMO-MRW) by clock hour (Bottom) is unlikely to be additionally informative. There is a minor mismatch between the clinically visible disc margin (green dots) and BMO (red dots), indicating that disc margin or BMO-based rim values are similar. At most clock hour positions, BMO-MRW appears wide. Future algorithms that indicate whether individual BMO-MRW values lie within or outside age-specific normal values could be clinically valuable.
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FIGURE 8. Incorporation of spectral-domain optical coherence tomography (SD OCT) into a clinical examination of the optic disc (Top) in a right eye suspected of glaucoma. In this case, SD OCT with analysis of Bruch’s membrane opening minimum rim width (BMO-MRW) by clock hour (Bottom) provides valuable additional information. There is a considerable mismatch between the clinically visible disc margin (green dots) and BMO (red dots), indicating a clinically invisible extension of Bruch’s membrane, especially inferiorly and nasally. In these locations as well as the superior sector, which is the most suspicious, the neuroretinal rim is considerably thinner than the clinician would estimate from a disc margin-based evaluation. Future algorithms that indicate whether individual BMO-MRW values lie within or outside age-specific normal values could be clinically valuable.
REFERENCES


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