A Problem of Proportions in OCT-Based Morphometry and a Proposed Solution

Advances in optical coherence tomography (OCT) have dramatically improved the ability to visualize the optic nerve head (ONH) in vivo. In recent years there has been an increase in the number of articles reporting OCT investigations of the morphology and biomechanics of the ONH, and in particular of the lamina cribrosa. Although many of these studies have resulted in important advances in understanding of the ONH, the relative simplicity of imaging and morphometry also increases the potential for mistakes. Herein, we alert readers to a common and potentially critical error made in OCT image analysis, and describe a simple solution.

The error occurs when measuring lengths and angles in OCT images with spatial aspect ratios other than 1:1. An anterior-posterior "stretching" of OCT images was introduced in the original prototype OCT to aid in the visualization of the details of the thin layers of the retina (Fig.), and continues to be used by many current commercial systems. The Spectralis SD-OCT (Heidelberg GmbH, Heidelberg, Germany), for example, presents images stretched 3-fold in the axial scan direction by default. This is indicated on the display and device output by scale bars. Image stretching also can occur because OCT sampling density is higher in the axial direction versus the transverse. Hence, an image presented in a 1:1 *pixel* aspect ratio is stretched axially. This is how most image-manipulation software presents images. Measurements using such images are likely to result in erroneous quantification of ocular structure.

For ONH morphometry, a typical measure of interest is the depth of the lamina cribrosa relative to Bruch's membrane opening. This depth can be measured by first drawing a straight line connecting Bruch's membrane openings in a longitudinal view of the ONH, typically a B-scan or a radial scan. The depth of a point in the lamina is then determined by the length of a line that passes through this point and is *perpendicular* to the Bruch's membrane reference line. Failing to consider that the images are stretched will lead to incorrect lamina depth measurements, for the following two reasons. First, computing the length of the depth line must account for differences in the horizontal and vertical scales: n pixels in the horizontal direction mean a different length than the same n pixels in the vertical direction. This is not difficult, but most popular image-manipulation software do not make this consideration, and the measurements obtained without correction are wrong. A second, less conspicuous but just as serious problem, is that lines that are perpendicular in a stretched image (Fig.) are likely not perpendicular in the 1:1 nonstretched, correct, view (Fig.). Similarly, angles used for morphometry, for example, to

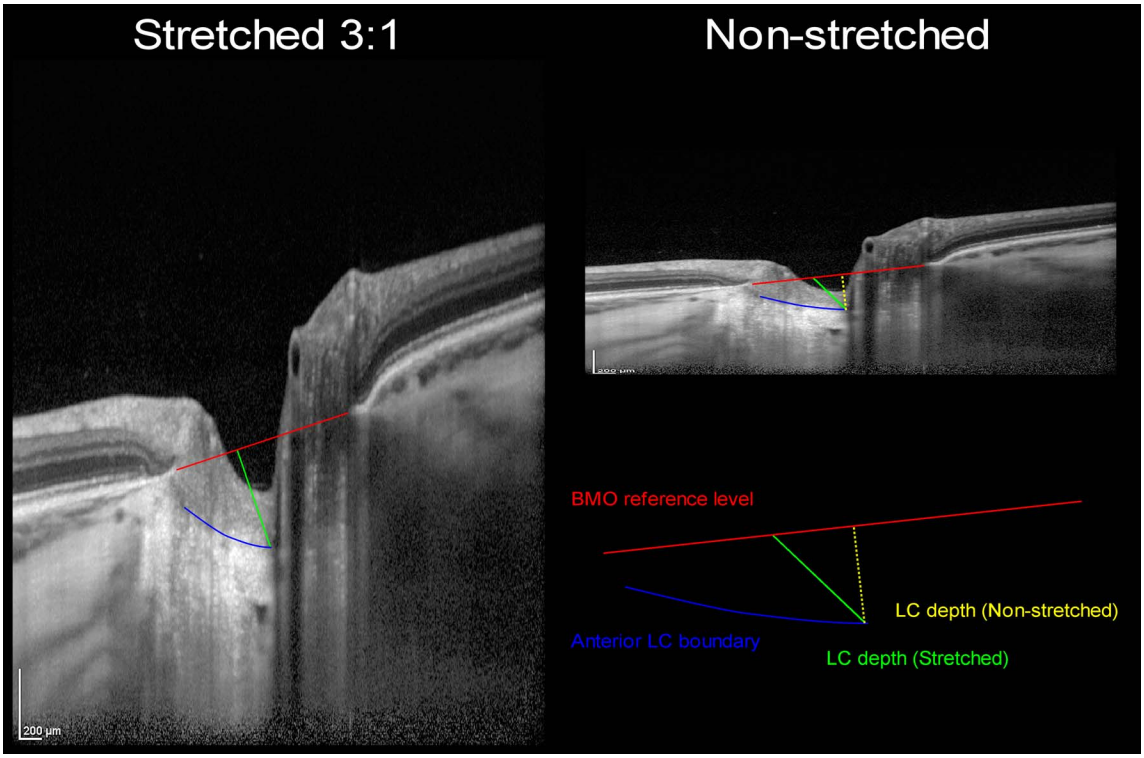

Figure. Illustrating the error of measuring lamina cribrosa depth on stretched images. On the *left side*, a B-scan through the ONH stretched 3:1 in the axial direction, as presented by Spectralis. On the *top right*, the same B-scan, corrected to a 1:1 spatial aspect ratio. Overlaid on both images are *lines* corresponding to the BMO reference level (*red*), anterior lamina cribrosa boundary (*blue*), and lamina depth (*green* in the stretched image, *yellow* and *dashed* in the nonstretched). On the *bottom right* are shown only the *lines*, magnified to ease visualization. Whereas the *green* and *red lines* are perpendicular in the stretched image, this is not the case in the nonstretched image. Hence, the *green line* does not represent the correct lamina depth relative to the BMO plane. This difference can be substantial. In this case, the *yellow line* is approximately 30% shorter than the *green line*.

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measure peripapillary sclera bowing, will be incorrect if measured in stretched images. The magnitude of the error varies with the amount that an image is stretched, and the orientation of the measurements. Note that ONH tilt can vary between scans of a patient, and therefore even analysis of relative change in the same patient, such as before versus after an intervention, can be subject to error.

The most straightforward solution is to do all marking and morphometry on unstretched images. If the images were saved stretched, unstretching requires knowledge of the stretch applied or the OCT's native image aspect ratio. This is not always easy, because these values can change from one OCT vendor to another, between software versions, and even with the viewing mode. Depending on how it is done, removing the stretch may downgrade the image, due to resampling, and may still require using measurement software that can deal with pixels that are not square.

Alternatively, it is possible to mathematically "correct" post hoc measurements done on stretched images, but this again requires knowledge of the stretching factor as well as the angles of the measured and reference lines.

Unfortunately, this potential error is difficult or impossible for a journal reviewer or reader to detect. In our experience, the vast majority of articles never mention consideration of the image aspect ratio. This may contribute to the low visibility of the problem, and likely to increase prevalence. It is impossible to know if authors of articles that show stretched OCT images carried out the measurements using correct aspect ratios. However, illustrations displaying "orthogonal" lines on stretched images, and use of image-manipulation software that does not account for stretched images or nonsquare pixels, suggest errant data.

Our recommendation is for authors to include in the article details about whether the image aspect ratio was considered, and how. This could include showing the marking and measurement example illustrations using unstretched 1:1 images.

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