EVALUATION OF CUP-TO-DISC RATIOS USING 3-DIMENSIONAL FUNDUS PHOTOGRAPHY

by

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ABSTRACT

Background: The evaluation of cup-to-disc ratios can be a daunting task for the novice optometry student. As most experienced optometrists know, perceiving the optic nerve head stereoscopically requires practice and skill which takes time to acquire. When first performing this evaluation, students often rely on color changes of the nerve head in order to evaluate cup-to-disc ratios. However, relying solely on coloration of the optic nerve head to evaluate cup-to-disc ratios can be misleading, especially in patients who are suspect for glaucoma or other optic nerve head diseases. *Methods:* Utilizing fundus photography, we asked optometry students of two different skill levels to evaluate cup-to-disc ratios using 2-dimensional and 3-dimensional images. The images were presented to students at random via two separate online quizzes during which they were asked to unknowingly evaluate the same nerve head in both 2-D and 3-D. *Results:* Twelve 2nd year students and twelve 4th year students were asked to estimate the cup-to-disc ratios (CDR) of 10 optic nerve heads. In each quiz five were presented as single 2-dimensional images while the other five were presented as stereo image pairs. The more advanced students were able to more accurately estimate the CDR compared to their less experienced peers. Overall, both sets of students were more accurate when viewing the optic nerve images stereoscopically rather than monoscopically. *Conclusions:* Since both the beginning and advanced students were able to judge the CDRs more precisely when viewed in 3-D, it is recommended that stereo photographs be used in some capacity as an instructional tool for training optometry students.

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BACKGROUND

As optometrists and optometry students are well aware, coming to the diagnosis of glaucoma is often difficult and not always clearly defined. Very often patients are labeled as glaucoma suspects simply because they fit certain criteria of the disease but not others. In optometry school, students are taught that there is no single test or single finding that determines whether a patient has glaucoma or does not have glaucoma. Rather, diagnosing a patient with glaucoma requires careful observation and a detailed analysis of several factors. These factors include but are not limited to intraocular pressure, corneal thickness, nerve fiber layer damage and corresponding visual field loss, and optic nerve head appearance. In both primary open angle glaucoma and angle closure glaucoma, morphological changes in the retinal nerve fiber layer and optic nerve head may occur over time.[1] Regardless of the mechanism, thinning of the nerve fiber layer and optic nerve head excavation eventually leads to visual field loss. In order to effectively manage glaucoma patients and those with other forms of optic neuropathy, structural changes in the optic nerve head must be carefully assessed and monitored over time.

Cup-to-disc ratio estimation is a crucial piece of information to include in all patient charts and is especially important in the assessment of glaucoma patients. Clinically, CDRs are estimated stereoscopically with fundus biomicroscopy by determining the diameter of the cup relative to the optic nerve head itself. This measurement, which is routinely assessed at each visit, allows optometrists to not only judge the depth of the cup, but to also assess for structural changes such as rim tissue thinning, sloping, notching, and coloration changes characteristic of progressive optic nerve damage. There have been recent advances in technology which can detect morphological changes in the optic disc and thus track glaucomatous progression. One example is the Heidelberg Retina Tomograph (HRT), a confocal laser-scanning microscope capable of taking multiple measurements of retinal height at certain planes. The instrument then converts these measurements into a topographical map of the optic nerve head extending from the anterior retinal surface to the lamina cribrosa.[2] In addition to the HRT, optical coherence tomography is another instrument capable of providing realistic cup-to-disc ratios. Traditional stereoscopic evaluation of the optic nerve head, however, still remains the clinical gold standard to which all newer methods are to be measured against.[3]

The use of fundus photography can greatly aid the clinician in estimating cup-to-disc ratios as well. Capturing a patient's fundus image allows the clinician to analyze the nerve in detail and to reference it at a later time. Taking fundus photos at successive intervals enables the clinician to monitor for changes in the optic nerve appearance as well as examine for nerve fiber layer defects which may be enhanced with a camera's red free filter. Although there are many advantages to fundus photography, it still requires subjective estimation which is not always reliable and repeatable.[3] Interobserver agreement refers to the degree of consistency among different viewers in assessing the CDR and other optic nerve characteristics. Intraobserver agreement, on the other hand, refers to the degree of consistency among the same viewer in sequential estimations of optic nerve characteristics.[4] Research has shown that CDR estimation may be more accurate and comparable to clinical evaluation with the use of overlapping stereo images.

Intraobserver and interobserver agreement have been assessed in numerous studies, many of which utilized stereo images of the optic nerve head. One such study utilized the digital stereodisc camera and its corresponding software package which enabled the researchers to compute vertical and horizontal cup-to-disc ratios. Following pupillary dilation, retinal photos were taken of 112 new patients using a Discam digital retinal camera with a moving shutter. Disparate images of the optic nerve head region were then collected and viewed by two different observers at separate times. The mean difference between measures for the vertical CDR for the intraobserver category was 0.009. The mean difference between measures for the horizontal CDR was 0.000. Slightly more variability was found in the interobserver category, with a mean difference between vertical CDR equaling 0.002 and horizontal CDR equaling -0.018. Overall the results were in accordance with clinical CDR estimates and interobserver and intraobserver repeatability were found to be positive.[3]

Another recently conducted study sought to compare the CDR values obtained from the Heidelberg Retina Tomograph to those obtained from photographic stereo image pairs. Specifically, a depth value was calculated from the stereo images and then compared to the depth value the HRT provided. At the conclusion of the study, it was found that the calculated depth values were very similar to those produced by the HRT and thus very useful in the management of glaucoma.[5]

The aforementioned study was accomplished by using a computerized technique to estimate the CDR in three dimensions. Two different images of the same optic nerve, a right image and a left image, are taken from different perspectives. This is done with a single lens retinal camera which takes two photos using a parallel shift. The optic nerve head area is then cut from the photos in order to decrease the amount of time needed for the following step. To determine the depth of the cup, corresponding points are identified and the values are then calculated from the disparities between them. Disparity refers to the difference in location of the corresponding points in the stereo photos and is dependent on movement of the camera lens and movement of the participant. By the end of the study, 12 stereo image pairs were collected and the depth values calculated from the stereo pairs were compared to those obtained from the HRT. A strong correlation ($r = 0.91$) was calculated, thus supporting a good relationship between the experimental depth values and the HRT values.[5]

In light of the information obtained from these studies, it is our hope to discover if the use of 3-dimensional optic disc photos alone can increase the accuracy of CDR estimation among both experienced and inexperienced participants. The results of the assessment will be analyzed for interobserver agreement and if they prove to support our theory, then it will lend credibility to the idea of including 3-dimensional stereo images in the teaching of young optometrists.

METHODS:

In order to develop a pool of fundus photos, a total of 10 volunteers and 18 eyes that were free of known or suspected pathology were photographed using the 45 degree setting on a Canon CR6-45NM fundus camera. Sequential photographs of each volunteer's eyes were taken by the same experimenter, with a lateral shift in camera position between photos to obtain a stereo effect when the images are viewed stereoscopically. A ruler was affixed to the non-moving portion of the camera's base to ensure that a lateral movement of approximately 3mm was achieved and thus a similar amount of disparity was obtained between subjects. Two eyes were unable to be photographed due to poor dilation resulting in the inability to achieve the 3mm variance. Images of both left and right eyes were used in the analysis in order to provide approximately equal numbers of left and right discs. Only clear images with a fair to good stereoscopic result were selected for the study. A variety of nerve sizes were also selected in order to prevent observer bias. Images were cropped to a size of 512 x 512 pixels centered on the optic nerve and stereo pairs were merged side-by-side to facilitate stereo viewing (see **Figures 1 and 2, page 6**). The sharper of the two stereo pair photographs was used as the 2-D image for comparison. The nerves were independently graded by a control group of five optometrists, all of whom have been in practice for more than ten years. Any nerves that were not generally agreed upon by the control group (+/- 0.05) were removed from the pool.

The photos were arranged using an online quiz format that allowed observers to input their individual assessment of the C/D ratio as it was presented (see **Appendices A and B, page 15 and 18**). The various optic nerves were randomly presented one at a time and directions were provided for each question to avoid confusion among the observers. To circumvent recognition of the same 2-D and 3-D nerves and thus biases toward grading them the same, the sets were distributed via two separate quizzes. Each quiz contained 12 questions total that included five stereo pairs and five different 2-dimensional optic nerve heads as well as a random dot stereogram to ensure that each participant was actually able to see in stereo. Another question was included requesting the observer's initials in order to match the two quiz results. Observers from two distinct

Figure 1. Original stereo pair with cropped region from left and right images

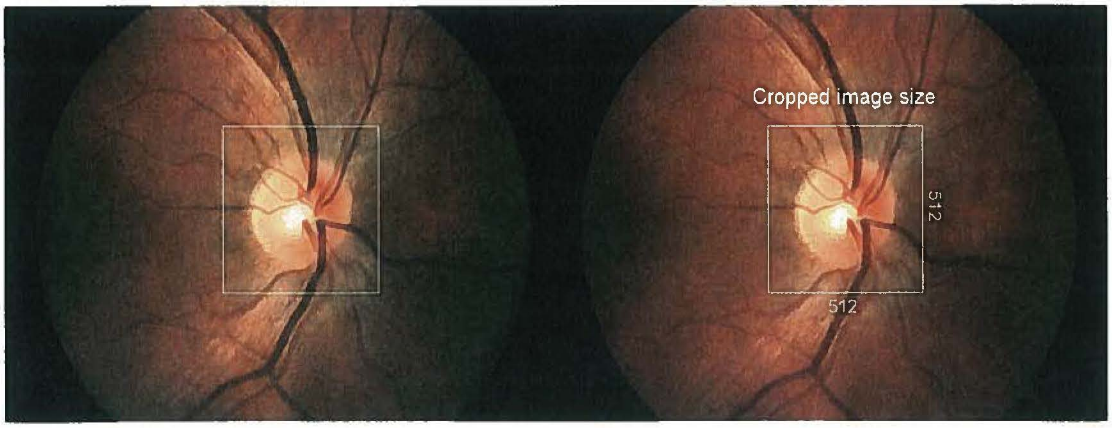
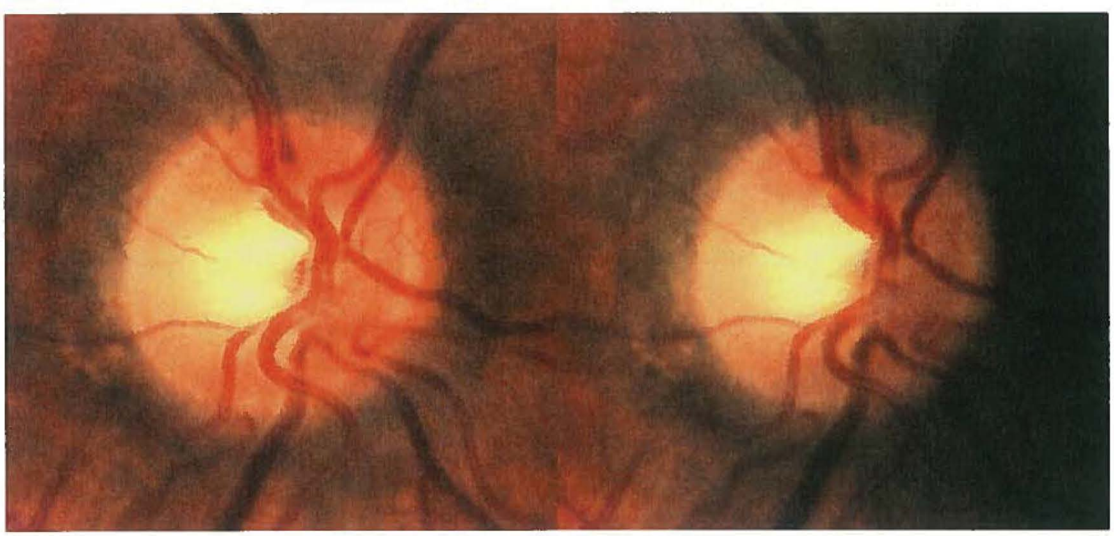


Figure 2. Example of a stereo pair aligned side by side

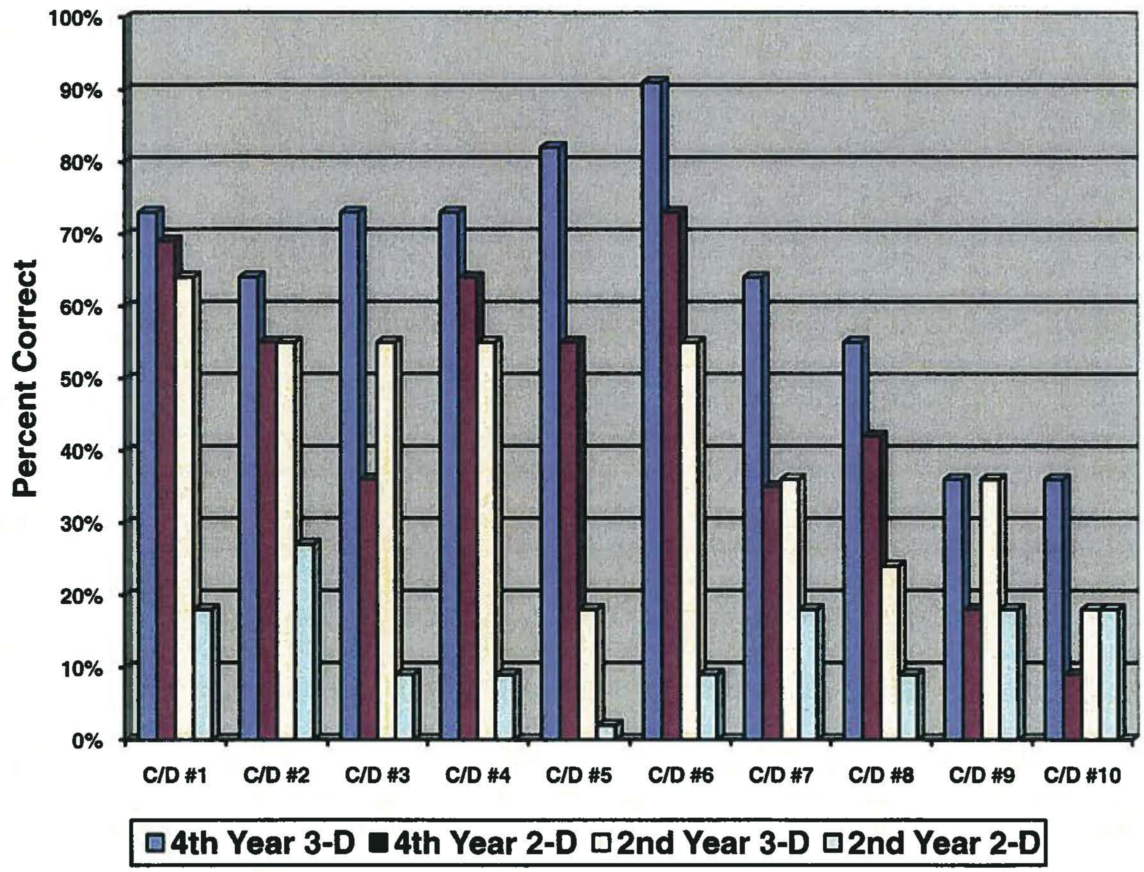


levels of expertise were recruited to take the quizzes: twelve 4th year optometry students who had a minimum of six semesters of clinical experience each and twelve 2nd year students who were currently in their first semester of clinical experience. The observers were randomly given Quiz A or Quiz B first and after a period of at least 24 hours after completing their respective quiz, were given the opposite quiz. In order to facilitate uniform stereo viewing, participants used a Loreo Pixi 3-D Viewer, which are prismatic stereo glasses specially designed for viewing images on a computer screen, when taking the quizzes (see **Appendix C, page 25**). The quizzes were scored with a tolerance of +/- 0.05 in both the vertical and horizontal directions to allow for slight variations between observers. Analysis of the resulting data was performed to look for various correlations among each of the groups of students as well as between the two groups.

RESULTS:

In all, 24 students, 12 from each group, took both quizzes. However, due to two participants' inability to perceive stereo, only 22 scores were used for data purposes. The results of the student observers' C/D estimations were compared to the average of those of the control group. As expected, the 4th year students on average, scored higher than the 2nd year students on all of the optic nerve sets (see **Figure 3, page 8**). The results also showed that among all of the students, the 3-D stereo pairs were more accurately graded than the 2-D images. To aid in analysis purposes only, the optic nerve heads have been labeled in ascending size, ie C/D #1 was the smallest and C/D #10 the largest. The results also show that both experienced and inexperienced observers tended to have greater accuracy when judging smaller CDRs than larger ones. Individual results were

Figure 3. Experienced vs. Inexperienced Observers



also calculated in order to provide a comparison of accuracy between observers (see **Figures 4 and 5, page 10**). It should be noted that the two observers, one from each group, who could not achieve stereo based on the random dot stereogram question not only scored the lowest on the quizzes but also had the most dramatically incorrect responses. Lastly, it was found that on average all students tended to estimate the CDRs larger when viewed in 3-D verses 2-D (see **Figure 6, page 11**).

DISCUSSION

The data collected in this study seeks to compare the CDRs estimated by 2nd year optometry students to that estimated by 4th year optometry students. In addition, the data is simultaneously comparing the CDR estimated from a 2-dimensional photo to that estimated in 3- dimensions. When comparing the estimations made by the optometry students to the control, it was found that the more experienced students estimated the CDR in the 2-D images more accurately than the inexperienced students. This can be attributed to their additional two years of clinical and academic experience. At this stage in their optometric careers, they have simply viewed many more fundus photos than their inexperienced peers and are more sensitive to the subtle cues to depth in the 2-D images. They are more apt to examine the neuroretinal rim, observe the vessel configuration, and follow the subtle contour of the cup rather than rely on color changes alone. For 2nd year students, with limited clinical experience and only basic knowledge of optic nerve morphology, it is difficult to appreciate these intricacies and delicate contours.

When comparing the CDRs reported for the 2-dimensional photos and stereo image pairs, it was discovered that both groups of students estimated the CDRs to be

Figure 4. Overall Quiz Results of 2nd Year Observers

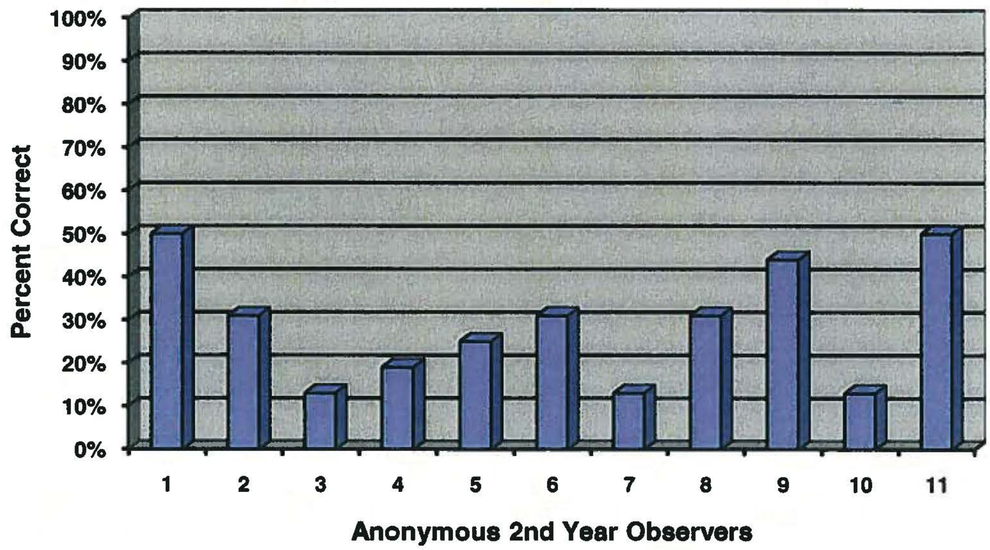


Figure 5. Overall Quiz Results of 4th Year Observers

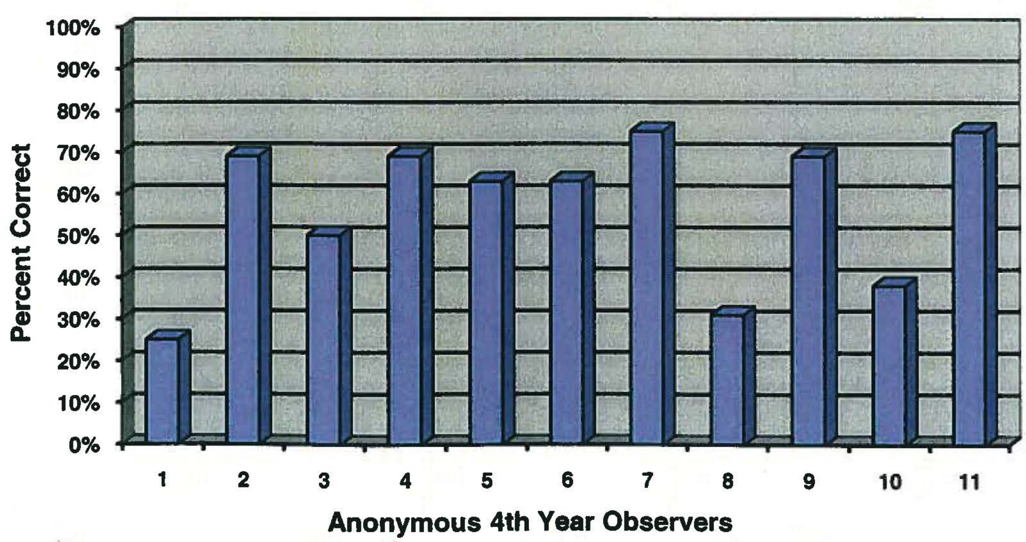
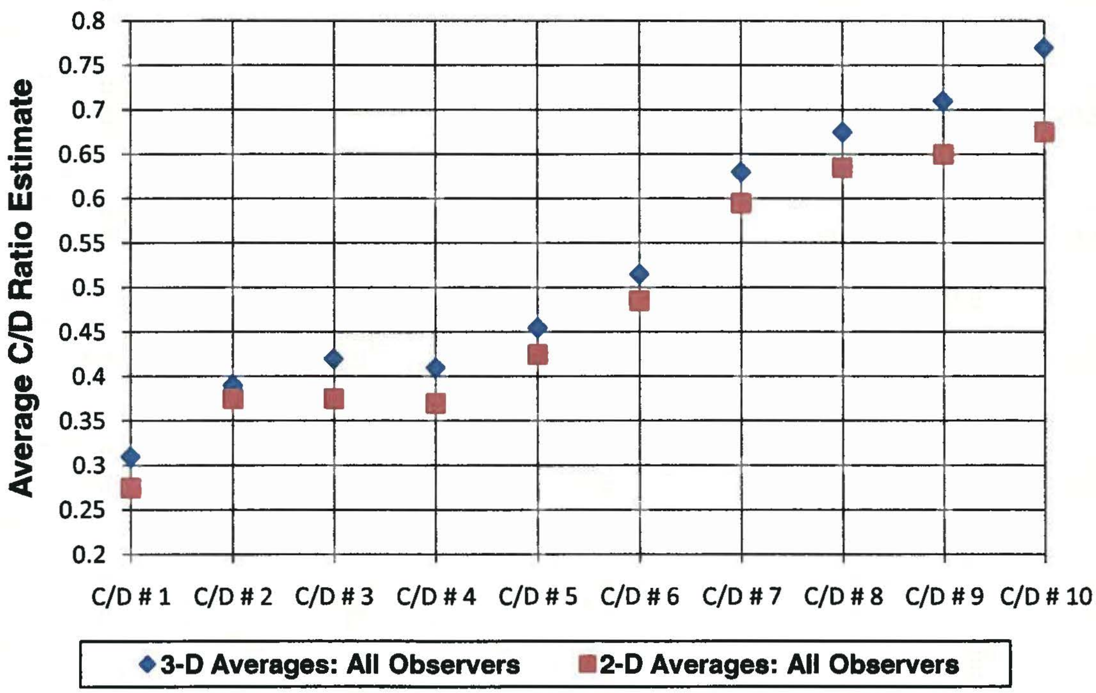


Figure 6. Average C/D Ratio Estimates



larger when viewed stereoscopically. This finding is consistent with previous research comparing monoscopic to stereoscopic CDR evaluation. When judging the size of the optic cup, it is advantageous to err on the side of overestimating rather than underestimating. Underestimating the size of the cup, as was observed in the assessment of the 2-D images, could result in a delay in the detection of glaucoma and other progressive optic neuropathies. Based on our findings and the results reported in previous studies, it is reasonable to say that viewing the CDR stereoscopically can aid in the early detection and proper management of various optic nerve pathologies.

It was found that both the beginning and advanced students judged the CDRs more accurately when the images were presented as a stereo pair. Consequently, there was less of a difference between the 2nd and 4th year students' estimations. In other words, viewing the images stereoscopically enhanced interobserver agreement. Due to the subjective nature of clinical CDR estimation, interobserver agreement is difficult to obtain. In fact, this lack of agreement among clinicians has been a driving force in the development of instruments to objectively measure nerve fiber layer thickness and optic disc parameters.[6] If the use of stereo fundus photography can improve interobserver agreement, it could be of significant benefit as both an instructional tool and clinical asset.

CONCLUSIONS

Learning to describe the appearance of the optic nerve head and to accurately estimate the cup-to-disc ratio is challenging for the beginning optometry student. Without a solid understanding of this vital skill, it is difficult to continue on and develop an appreciation for anatomical subtleties such as optic nerve notching, rim thinning, and pallor. Viewing many 2-dimensional images of the optic nerve head is very important and certainly helpful when first learning to estimate CDRs. It is our recommendation, however, that the use of stereo fundus images be incorporated as an instructional tool for beginning optometry students. This would of course require the use of a retinal camera with stereoscopic capabilities, prismatic stereo glasses or a 3-D viewer, the ability to achieve stereopsis, and increased concentration on the part of the student.[7] In light of the data collected which indicates that CDRs are estimated more accurately when viewed stereoscopically, it would be ideal to prepare the students for this early on in their clinical education. Exposing the students to stereo pairs and stereoscopic viewing prior to examining their own patients will likely enhance their diagnostic skills and help them to become more sophisticated clinicians.

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APPENDIX A

ONLINE QUIZ SPECIFICATIONS

A variety of online test/quiz sites were reviewed prior to the selection of the site used during this study. There were a number of features that were desired by test administrators and only one site matched them all. The site finally picked to host the online quizzes was: www.quizegg.com. The most prominent features that were important to this study included:

1. The quizzes were completely web based. Developing, editing, and distributing each quiz could be done from anywhere, at any time, without any special software or equipment.
2. With the choice of eight different question/answer types, any method of quizzing could be utilized. In this case, fill in the blank questions were used and because the site allowed an unlimited number of correct answer options, even the +/- 0.05 tolerance options could be included.
3. The quizzes in general could be tailored to individual needs. Question order could be randomized, the number of retakes could be adjusted, and even who can take a particular quiz could be specified.
4. Registration for quiz takers is quick, easy, and free. For this study, because we wanted the results to be anonymous, two accounts were set up: one for the advanced students and one for the young students. This way there was no doubt which group each test-taker belonged to and because there were unlimited retakes multiple people could use the same account.
5. Images could be uploaded directly to the quiz with various editing functions. The most important part in this instance, due to the requirements of the stereo viewers, was that the photos could be adjusted to any size necessary.

6. After completion of a quiz, detailed statistical reports are provided, including results viewable in any standard spreadsheet application. Individual scores, as well as group statistics were readily available.
7. Finally, the first three quizzes made and published are free of charge through this website. Following that, a moderate annual charge can be paid to make an unlimited number of quizzes.

APPENDIX B

SAMPLE C/D RATIO QUIZ

Cup-to-disc Ratio Estimation Quiz

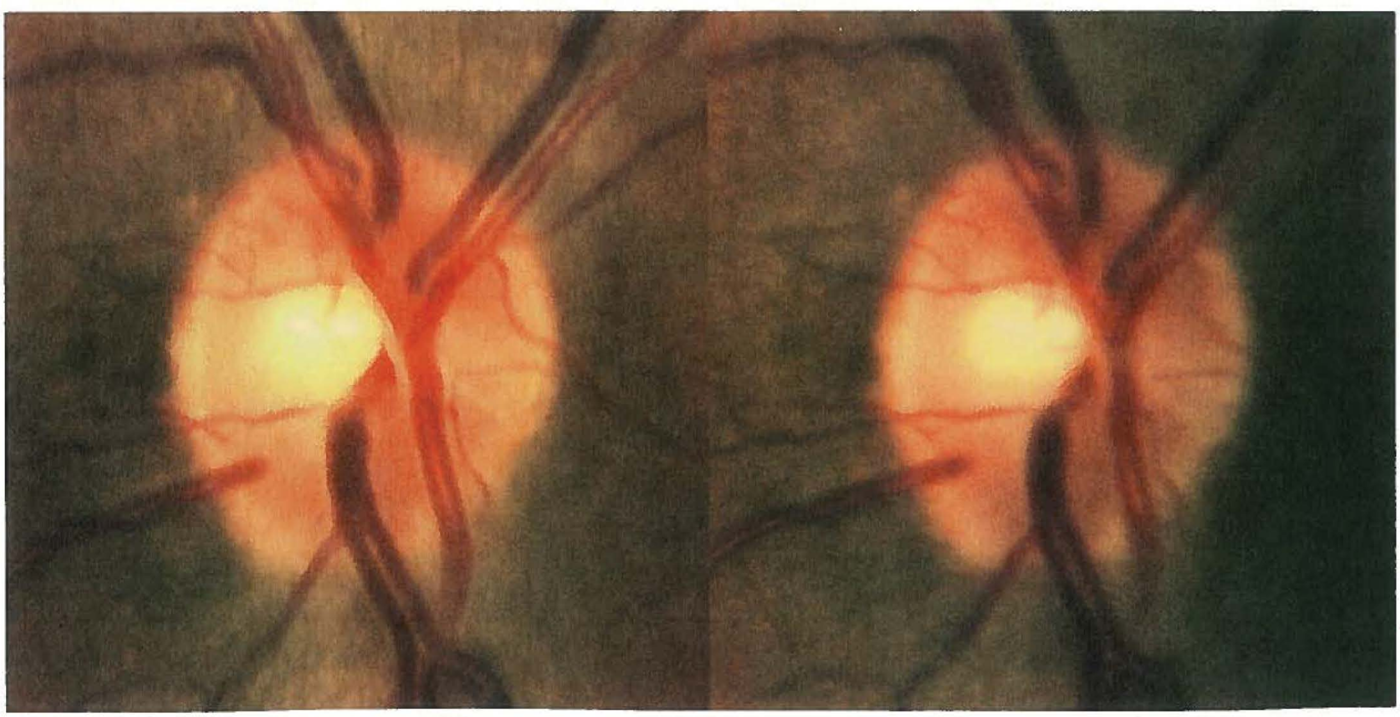
Please look at the following pictures and judge the cup-to-disc ratios for each optic nerve head.

- If there is a pair of photos side by side, please use the provided stereo glasses to view them and make your estimation.
- If there is only one photo, please view it directly and make your estimation.
- Answers should be formatted the same as you would record them in a chart.

  For example: If the cup is half the size of the nerve the C/D ratio would be: .5/.5

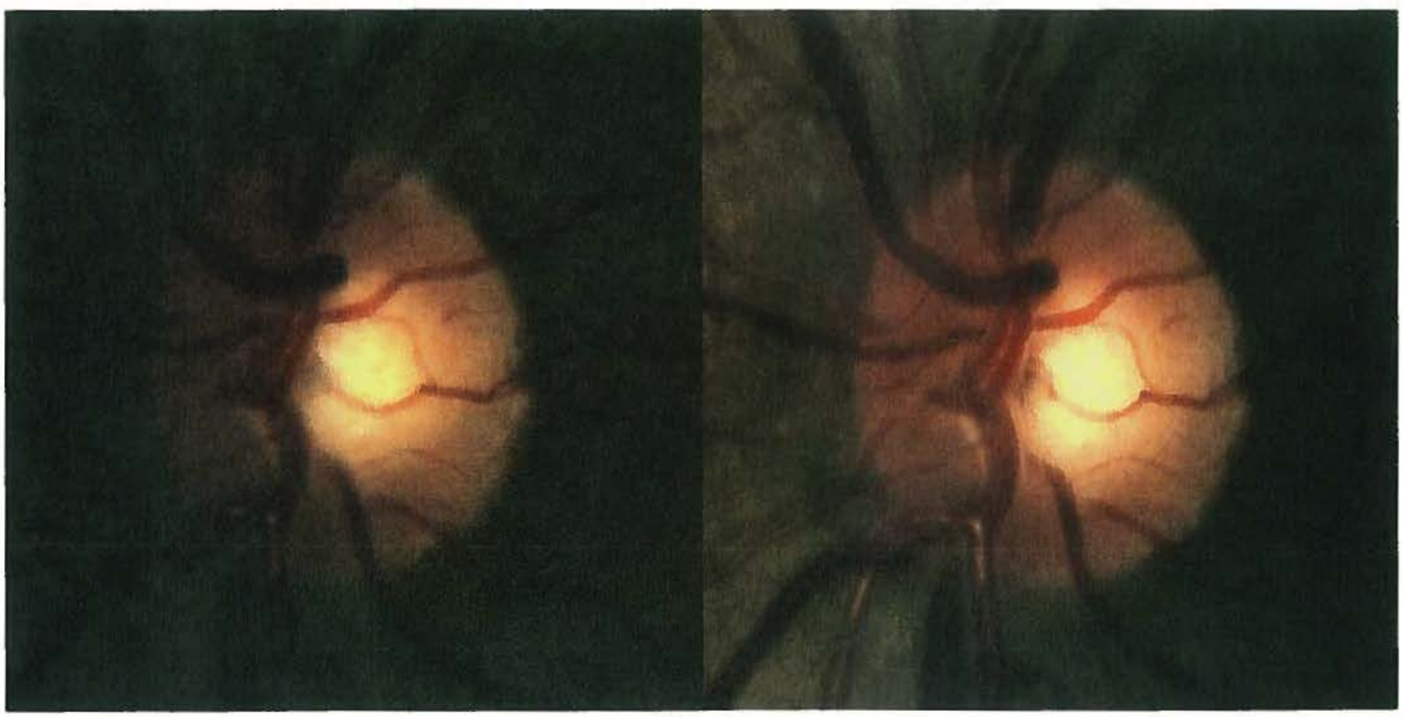
  Also, as a reminder, please record the ratio with the horizontal value first, followed by the veritcal ie: horizontal/ veritcal

1. The cup-to-disc ratio for this optic nerve head is:



2. The cup-to-disc ratio for this optic nerve head is:

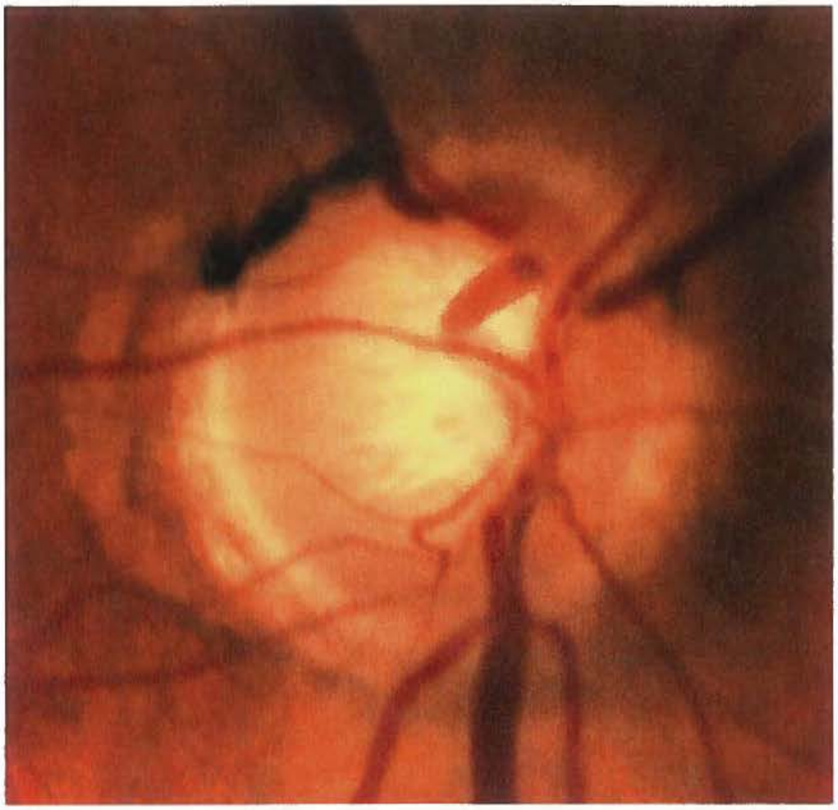
3. The cup-to-disc ratio for this optic nerve head is:



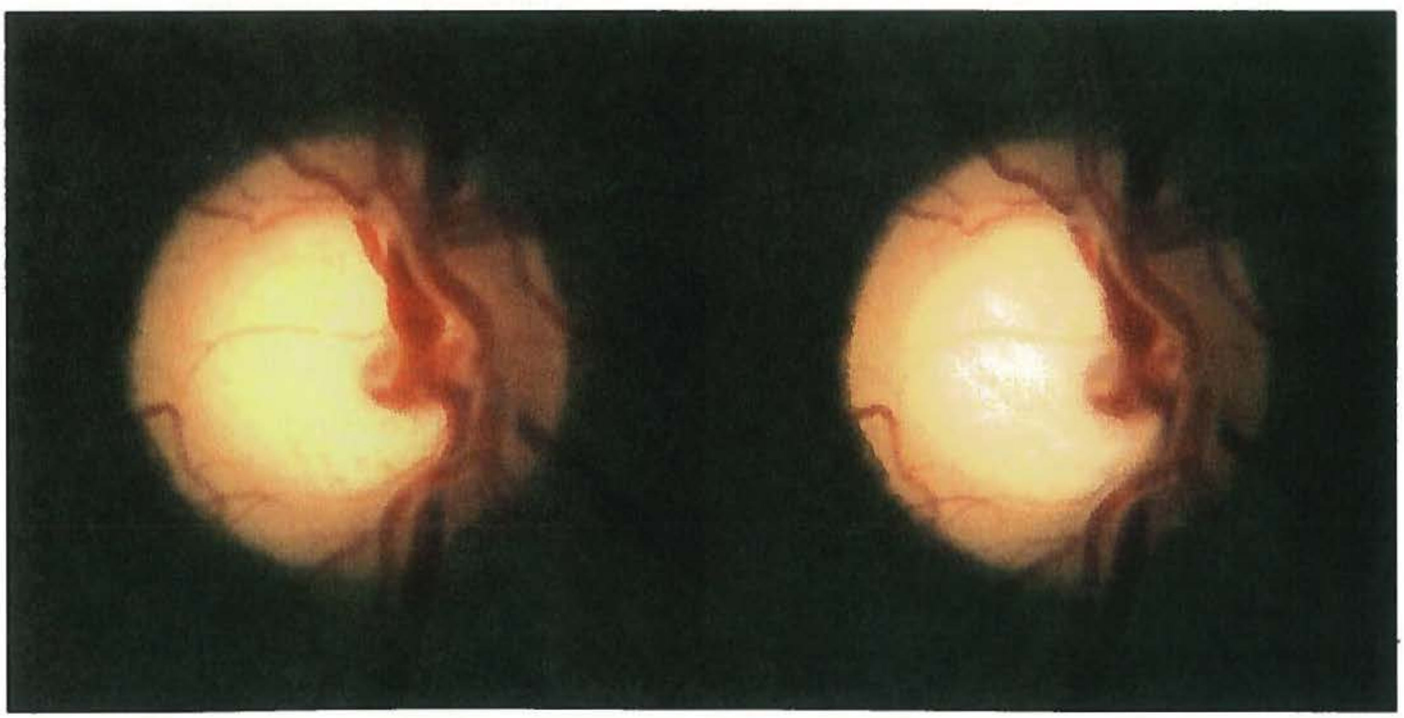
4. The cup-to-disc ratio for this optic nerve head is:

5. The cup-to-disc ratio for this optic nerve head is:

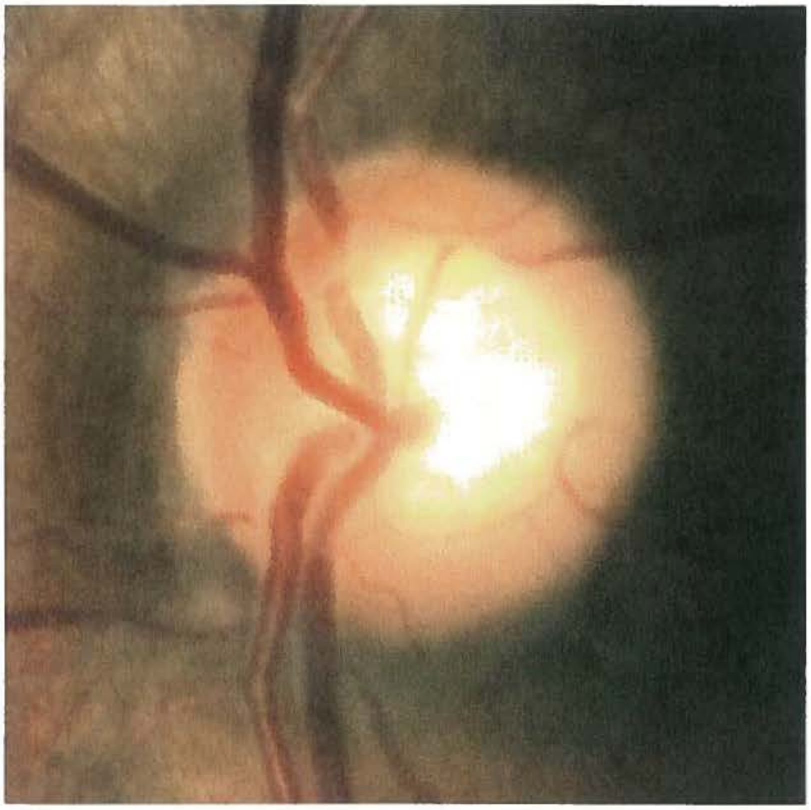
6. The cup-to-disc ratio for this optic nerve head is:



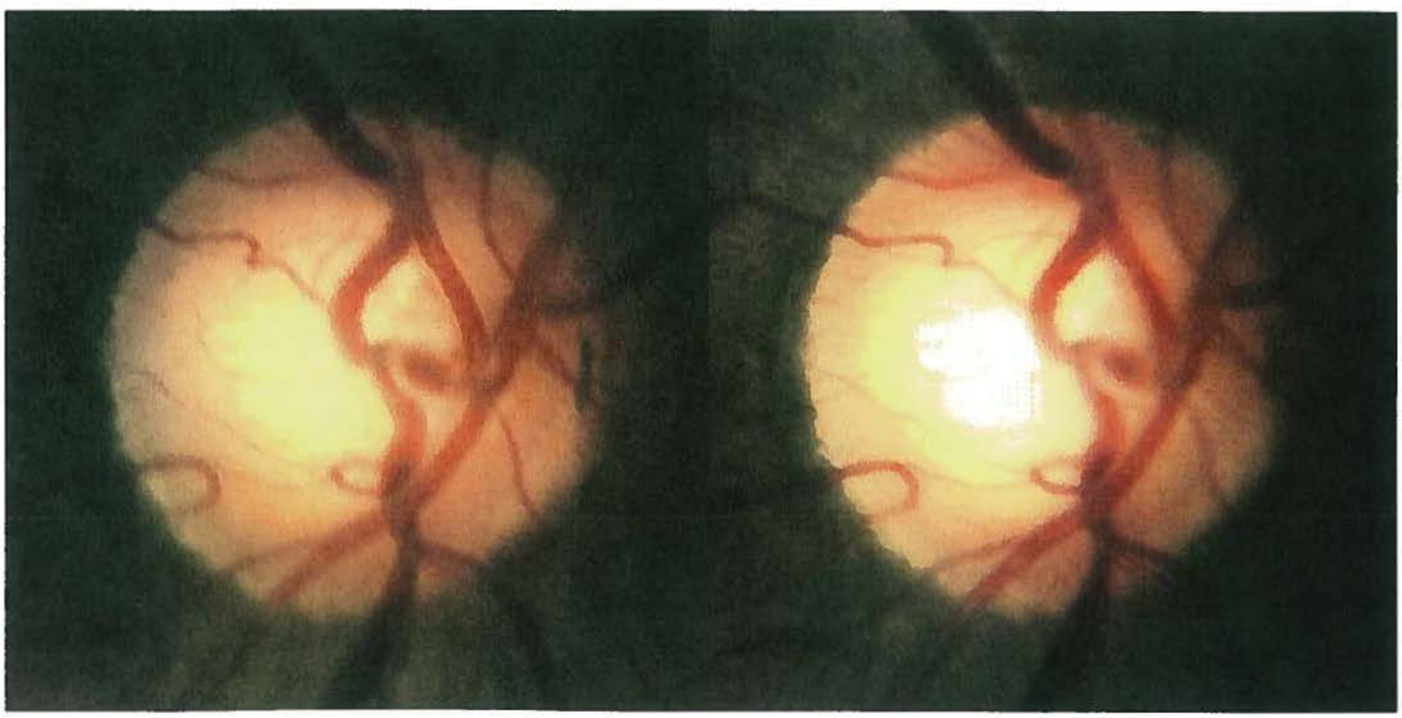
7. The cup-to-disc ratio for this optic nerve head is:



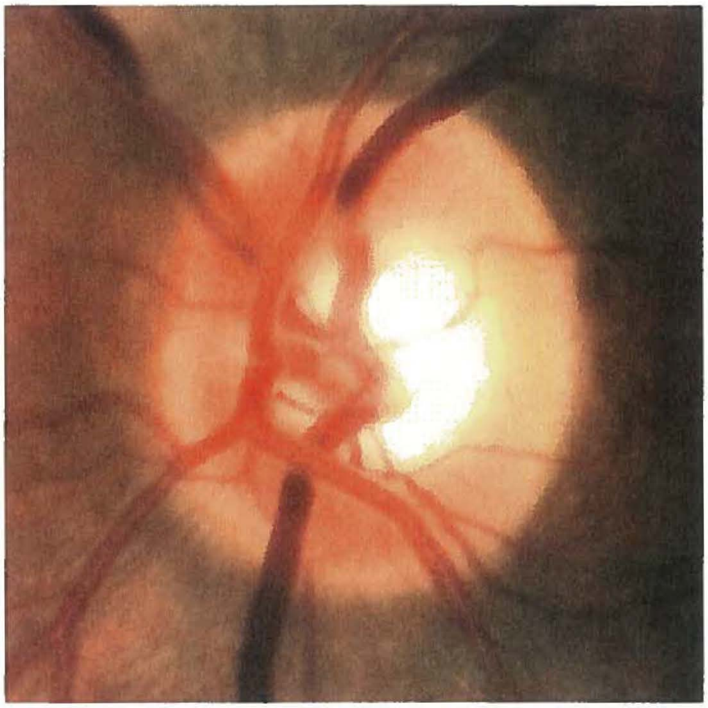
8. The cup-to-disc ratio for this optic nerve head is:



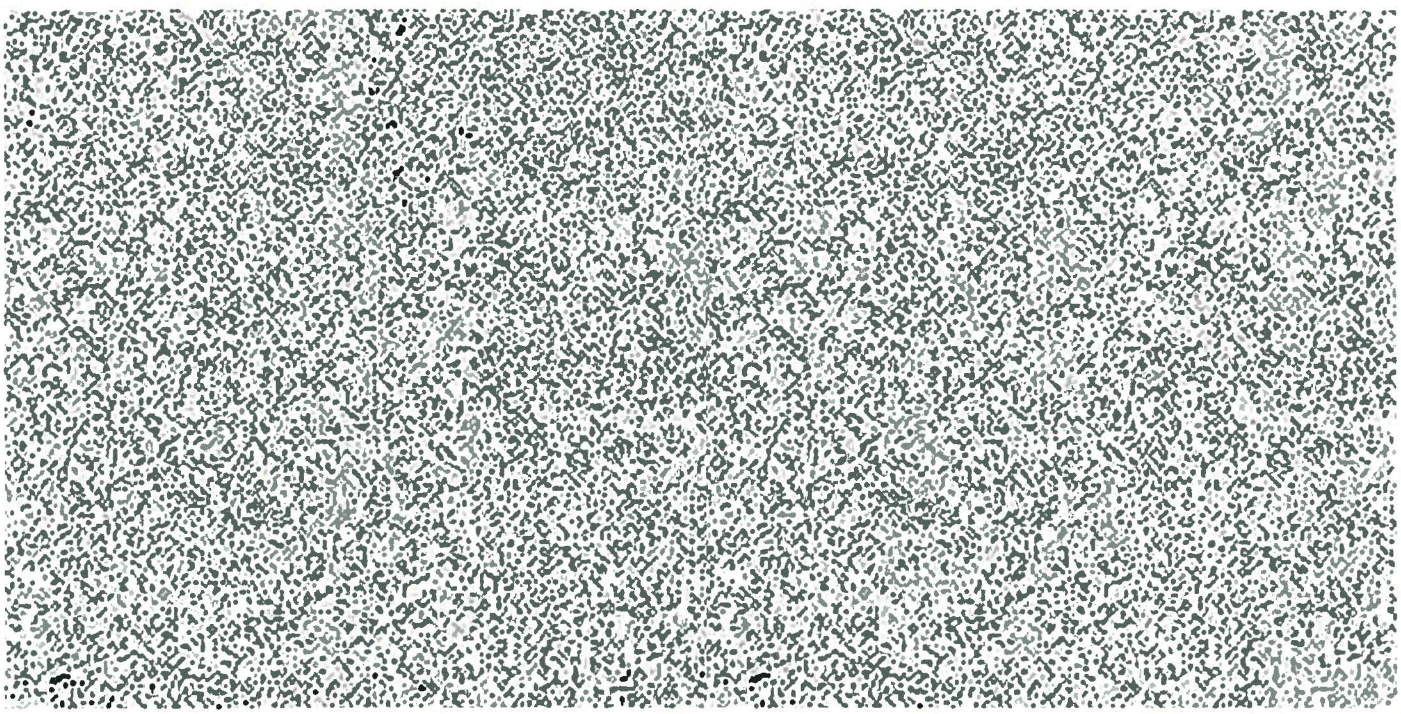
9. The cup-to-disc ratio for this optic nerve head is:



10 The cup-to-disc ratio for this optic nerve head is:



11 Please view this with the provided stereo glasses and record what you see in the space below.



12 Please provide your first, middle, and last initial in the following blank. Thank you!

____

APPENDIX C

LOREO: PIXI 3-D VIEWER

LOREO Pixi 3D Viewer

Front View
(front panel)

Back View
(viewing panel)

Specifications:

Viewing Print Size:	10 - 13 inch (25 - 33 cm) wide prints
Screen Image Size:	Optimized for 10 - 13 inch (25 - 33 cm) wide screen images.
Viewing Format:	Side-by-side (Parallel) format 3D
Viewing Distance:	At least 17 inches (43 cm) from 3D photograph to front panel of viewer
Eyeglasses:	Normal vision required. Wear eysglasses corrected for distance vision.
Lens:	Clear plastic lenses with prisms
Viewer Size:	150 x 96 x 5 mm folded (L x W x D)
Viewer Weight:	25g (with case)
Material:	Plastic coated white card paper with the inside surface printed black
Price:	$2.49ea +S&H
Available:	www.berezin.com