Reports

Videographic Quantification of Optic Disc Pallor

Joseph M. Miller and Joseph Caprioli

Digitized images of the optic disc, acquired videographically (Rodenstock Analyzer) under green (540 nm) and red (640 nm) illumination, were used to quantify optic disc pallor. The pallor density of each pixel was defined as twice the reflectance under green illumination divided by the sum of the reflectance under red and green illumination. Pallor densities can range from 0 (red) to 1 (white); typical median values were 0.25 for vessels, 0.40 for healthy disc rim, and 0.70 for the lamina cribrosa. The variability of pallor measurements using this technique was determined. Two uniform color fields (Farnsworth-Munsell 100-Hue Test color chips 1 and 18) were imaged five times each using a model eye. Significant ($P < 0.0001$) drift of mean pallor densities occurred between images of both sets. The optic discs of seven normal eyes and of seven glaucomatous eyes were imaged nine times each. The non-normal frequency distribution of pallor densities for each image was described by trimmed means and a measure of distribution width. Variability was defined as the standard deviation of the measurements divided by the full scale pallor density. The variability of the trimmed means increased with pallor density ($r = 0.99, P < 0.0001$). The variability of distribution width was smaller than that of the mean values, and averaged 3.4% in normal and glaucomatous eyes. Videographic reflectometry may provide useful, quantitative measurements of optic disc pallor. Invest Ophthalmol Vis Sci 29:320–323, 1988

Measurements of optic disc color and pallor may provide important quantitative information about the condition of the optic nerve. Retrospective measurements of the optic disc in ocular hypertensive patients have shown increases in pallor before visual field defects could be detected.¹ We determined the variability of videographic reflectometric pallor measurements using a computerized image analysis system (Rodenstock Analyzer; Rodenstock Instruments GMBH, Munich, West Germany).

Materials and Methods. A computerized optic disc imaging system (Rodenstock Analyzer) was used to acquire, digitize and analyze videographic images of the optic nerve head.² To perform pallor measurements, images are separately recorded under red (540 nm) and green (640 nm) illumination. A reference light is used to calibrate camera sensitivity. After image acquisition, the operator interactively super-

imposes the two images and marks the edge of the optic disc. The pallor density of each pixel is calculated from the brightness of corresponding pixels under red and green illumination:

$$\text{pallor density} = \frac{2 \times \text{(green reflectance)}}{\text{(red reflectance)} + \text{(green reflectance)}} \quad (1)$$

The selection of the formula for pallor density and illumination wavelength is derived from the following model. A grey-white nerve head, equally reflective to red and green illumination, is overlaid by a thin layer of blood. Relative blood layer thickness (RBLT) is proportional to the difference of the log of the reflectances at green and red wavelengths.³

$$\text{RBLT} = \log \left( \text{green reflectance} \right) - \log \left( \text{red reflectance} \right) + 1.0 \quad (2)$$

A constant (1.0) is added to provide a convenient range of pallor densities from 0 (thick blood layer) to 1.0 (no blood layer present).

The pallor density equation (1) approximates the RBLT formula (2) to within 3.3% for values > 0.3 and does not require computation of logarithms. As the formula is evaluated for each pixel, calculation time is thereby significantly decreased.

Measurement reproducibility was estimated for different pallor densities, both within a single image and between sequential images. Farnsworth-Munsell color chips #1 (red) and #18 (yellow) were imaged five times each in a model eye. The yellow chip, with equal red and green reflectances, has a known pallor density and provided an estimate of accuracy.

For measurements of the optic disc, seven eyes of seven normal subjects and seven eyes of seven patients with primary open angle glaucoma were imaged nine times each. The procedure had been fully explained and informed consent obtained. Subjects were randomly chosen and were not preselected for ability to fixate or for the appearance of the disc. Normal subjects had a normal fundoscopic examination, and no history of eye disease. Glaucomatous
subjects had typical visual field defects. The two groups were combined to provide a wide range of pallor in the data set. Approximately 15 min were required to record and process the required images of each eye.

Optic disc reflectance distributions are typically bimodal and can be described by nonparametric statistics. Location estimates may be described by percentiles or trimmed means; the latter technique averages segments of the distribution. Trimmed means are more robust location estimators than are percentile measures. We used mean values trimmed from the largest 5% (designated as h1), next 15% (h2), next 30% (h3), next 30% (h4), next 15% (h5), and the smallest 5% (h6) of the distribution. The difference between means h2 and h5 was used to estimate distribution width. Variability was defined as the standard deviation of the repeated measure divided by the

<table>
<thead>
<tr>
<th>Sample</th>
<th>CHIP #1 (red)</th>
<th>CHIP #18 (yellow)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>0.649</td>
<td>0.012</td>
</tr>
<tr>
<td>2</td>
<td>0.686</td>
<td>0.014</td>
</tr>
<tr>
<td>3</td>
<td>0.661</td>
<td>0.013</td>
</tr>
<tr>
<td>4</td>
<td>0.706</td>
<td>0.012</td>
</tr>
<tr>
<td>5</td>
<td>0.693</td>
<td>0.014</td>
</tr>
<tr>
<td>F Ratio*</td>
<td>327.6*</td>
<td>293.3*</td>
</tr>
<tr>
<td>95% C.I.</td>
<td>0.679 ± 0.029</td>
<td>1.002 ± 0.037</td>
</tr>
</tbody>
</table>

* P < 0.0001.

full scale pallor density (1.0) and expressed as a percentage.

**Results.** Pallor measurements of the Farnsworth-Munsell color chips are summarized in Table 1.

**Pallor Density Distribution**

**Fig. 1.** An example of the contribution of regions of the optic disc image to the pallor distribution (top). Three windows for pallor densities were selected to correspond to the areas indicated in the histogram: <0.3, 0.3–0.5, and >0.5, and are shown graphically (bottom left). The window corresponding to the smallest pallor densities comprised 20% of the image and was primarily contributed by the major vessels. The window corresponding to the greatest pallor densities comprised 37% of the image and was largely contributed by the lamina cribrosa. The remaining 43% of the pixels had pallor densities corresponding to the intermediate window, and were contributed by the disc rim. The standard disc photograph is shown for comparison (bottom right).
Pallor Density Distribution

Grouped Normal and Glaucomatous Eyes

Fig. 2. The pooled distributions of optic disc pallor densities for normal (n = 7) and glaucomatous (n = 7) eyes imaged nine times each. The distribution for glaucomatous eyes (dotted line) is skewed toward the right (pale) end of the pallor scale, and has a larger distribution width than the normal (solid line) group.

Within a single image, a normal distribution of pallor density values was observed and had a standard deviation averaging 1.5% of full scale. Variability of the mean pallor densities between successive images averaged 2.7%, though one-way analysis of variance revealed statistically significant differences (P < 0.0001). Chip #18 (yellow) has a theoretical pallor density of 1.0 which compared favorably with the measured value.

A representative optic disc pallor density distribution is shown in Figure 1 with the corresponding pallor image and disc photograph. Three "windows" for pallor are shown in the coded pallor image and pallor density distribution (dark grey indicates pallor densities < 0.3, light grey 0.3 to 0.5, and white > 0.5). The windows were chosen to differentiate vessels, disc rim and lamina cribrosa, and were approximate. For example, the threshold for distinguishing disc rim from pale disc is not exactly 0.5, so boundary differences between the pallor image and disc photograph are evident. Analysis of typical pallor images revealed approximate median pallor densities of 0.25 for large blood vessels, 0.40 for normal disc rim, and 0.70 for areas of the disc identified as lamina cribrosa on corresponding color photographs.

The distribution of the combined optic disc pallor densities for normals and glaucomas is shown in Figure 2. Inclusion of glaucomatous optic discs provided a wider range of pallor densities to evaluate. The variability of optic disc pallor measurements ranged from 1.7% to 10.8% and is summarized in Table 2. A trend of increasing variability with increasing pallor density is apparent (r = 0.99, P < 0.0001).

Discussion. Attempts to quantify the color of the optic disc date to Boch\(^7\) who compared the appearance of the optic disc with various shades of pink oil paints. Davies\(^4\) in 1970 used color optic disc photographs analyzed under red and green illumination to develop a model of the blood content of tissue overlying the optic nerve head. The method was further refined by Sebag et al\(^8\) to estimate both blood layer thickness and nerve head reflectance. Microdensitometric, monochromatic measurements of the optic disc have also been made.\(^5\) Boundary techniques were subsequently developed to identify an area of greatest pallor within the optic disc.\(^2,9\)

Videographic image analysis was used here to obtain reflectometric measurements of optic disc pallor. This method offers advantages over photography, including a calibrated, linear response to light intensity, and immediate display of images for quality control.

We analyzed the distribution of pallor density values obtained from uniform color fields and the optic disc. The method of trimmed means was employed to describe the skewed distributions of pallor densities.\(^6\) Trimmed means h1 and h6 were chosen to cluster outliers. H2 is sensitive to the pale region of the distribution and h5 is sensitive to red. The distribution width (h2–h5) is a measure of image contrast.

<table>
<thead>
<tr>
<th>Trimmed mean</th>
<th>Percentiles</th>
<th>Pallor density (mean)</th>
<th>Variability*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>h1</td>
<td>96–100</td>
<td>0.604</td>
<td>7.03%</td>
</tr>
<tr>
<td>h2</td>
<td>81–95</td>
<td>0.557</td>
<td>6.77%</td>
</tr>
<tr>
<td>h3</td>
<td>51–80</td>
<td>0.479</td>
<td>6.10%</td>
</tr>
<tr>
<td>h4</td>
<td>31–50</td>
<td>0.369</td>
<td>5.15%</td>
</tr>
<tr>
<td>h5</td>
<td>6–30</td>
<td>0.257</td>
<td>4.13%</td>
</tr>
<tr>
<td>h6</td>
<td>1–5</td>
<td>0.185</td>
<td>3.38%</td>
</tr>
<tr>
<td>h2–5</td>
<td></td>
<td>0.300</td>
<td>3.36%</td>
</tr>
</tbody>
</table>

* Variability is defined as the standard deviation of nine repeated measurements divided by the full scale pallor density of 1 and expressed as a percentage.
between red vessels and portions of the disc with greatest pallor.

Measurement variability is contributed by a number of sources, including camera positioning, camera temperature and ambient illumination. The red and green images are not recorded simultaneously; variations in image registration and fluctuations of the specular reflections from the ocular media and blood vessels may alter computed pallor densities. It is not yet known what effect aging changes of the ocular media will have on sequential pallor measurements. We expect the aging lens to shift the entire distribution toward smaller (less pale) pallor densities, but measures of distribution width may be less affected.

The present study demonstrates the feasibility of videographic methods to provide rapid, quantitative measurements of optic disc pallor. Work is underway to investigate the utility of this method in the early diagnosis of glaucoma.

Key words: optic disc pallor, computerized image analysis, glaucoma, videogrammetry, trimmed means

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Reprint requests: Joseph Caprioli, MD, Yale University School of Medicine, Department of Ophthalmology and Visual Science, Box 3333 Cedar Street, New Haven, CT 06510.

References