achieve a greater deturgescence, when rewarmed to 35°C, by approximately 50 to 60 μm. This appears to contrast with the present studies where little difference is found in the net flux between solutions X and XI which have widely different HCO₃⁻ concentrations. As mentioned above, it seems that the presence of dextran exerts a larger influence on the maintenance of thickness in this storage regimen.

We thank Mrs. I. Prior for her secretarial assistance and Mrs. Frances T. O’Connor for her generous assistance in performing the gas analysis of the samples.

From the Departments of Ophthalmology and Physiology, Medical College of Georgia, Augusta. Supported in part by Research Grants EY 01413 (K. G.) and EY 02386 (D. S. H.) from the National Eye Institute, in part by a Research Grant from the Georgia Lions Lighthouse Foundation, Inc., and in part by the Lions Clubs of Augusta, Georgia. A Wang 2200 Computer, used for statistical data evaluation, was provided through a Research to Prevent Blindness Inc., grant. Submitted for publication May 1, 1978. Reprint requests: Keith Green, Ph.D., Department of Ophthalmology, Medical College of Georgia, 1120 15th St., Augusta, Ga. 30901.

Key words: cornea, endothelium, bicarbonate pump, M-K medium, tissue preservation, electrolytes

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Monochromatic (red-free) photography and ophthalmoscopy of the peripapillary retinal nerve fiber layer. Neil R. Miller and Terry W. George

The appearance of the peripapillary retinal nerve fiber layer (PRNFL) is crucial in the evaluation of patients with presumed optic neuropathies as well as in the differentiation of true optic disc edema from pseudopapilledema. Monochromatic (red-free) photography performed at 2x magnification with a Zeiss fundus camera, a filter with maximum transmission at 540 nm, and Kodak Plus-X black-and-white film provides excellent PRNFL detail. Since direct ophthalmoscopy depends upon maximum illumination, which in turn depends upon increased color temperature of the light source, use of a direct ophthalmoscope with a gas-surrounded tungsten filament light source driven at 4.5 V raises color temperature sufficiently to allow practical use of monochromatic, red-free filters for optimum PRNFL evaluation.

The use of monochromatic light for ophthalmoscopic examination of the ocular fundus was first suggested by Ginestous in 1911, and a practical means to accomplish it was demonstrated by Vogt several years later. Although other investigators also advocated the use of various filters and light sources for observation of the fundus, their results were inconsistent and seemed impractical for clinical application. Subsequently, Behrendt and Wilson found that the spectral reflectance (the amount of light reflected vs. the amount of light absorbed) of specific fundus components differed, depending on the wavelength of light used to illuminate them. Their results suggested that different wavelengths of light could be used to optimally illuminate specific fundus elements. Nevertheless, the practical advantage of such an approach was ignored until Hoyt and co-workers published a series of articles stressing the clinical usefulness of red-free illumination of the peripapillary retinal nerve fiber layer (PRNFL) in the evaluation of patients with suspected optic neuropathies. We have attempted to evaluate the efficacy of monochromatic filter sys-
Fig. 1. Relative luminance of various light sources with different color temperatures. Note marked increase in relative luminance in the lower (blue-green) end of the visible spectrum with light sources having higher color temperatures. Asterisk, Similar curves apply to krypton-and xenon-filled tungsten bulbs.

Methods and materials

Fundus photography. A Zeiss fundus camera with a high-intensity xenon arc bulb was modified to permit placement of narrow bandpass and neutral density filters, 10 nm wide at 50% transmission, in the pathway of light from the camera's lamp. Fundus photographs of individuals with varying skin and intraocular pigmentation were made at 10 nm intervals from 400 to 900 nm using Kodak Plus-X black-and-white film developed in Kodak D-11 (diluted 1:1 with water) for 6 min at 70° C. On the basis of data from these experiments, commercial filters with maximum transmission from 450 to 600 nm were used in an unmodified Zeiss fundus camera with the same film and developing technique.

Direct ophthalmoscopy. A variety of commercial filters with maximum transmissions ranging from 450 to 600 nm were used in several direct ophthalmoscopes with various light and power sources. Independent observers compared their abilities to evaluate the PRNFL in individuals with varying skin and intraocular pigmentation.

Results

Fundus photography. Optimum visualization of the PRNFL was obtained with a 540 nm filter (Spectrotech Corp., Lincoln, Mass.). We found that this filter, when used in an unmodified Zeiss fundus camera, highlights the fine, radially-oriented striations, superficial light reflexes, and capillaries of the normal PRNFL. The filter system also enhances the distortion or loss of these features in patients with various optic neuropathies.

Direct ophthalmoscopy. In individuals with heavy pigment epithelial and choroidal pigmentation, a number of filters that transmit maximally in the range of 520 to 560 nm permit excellent observation of the PRNFL when combined with the increased illumination provided by a 4.5 V oph-
Fig. 2. Effect of monochromatic (red-free) filter on relative luminance of various light sources with different color temperatures. Note marked increase in luminance when gas-filled, tungsten-filament light source is combined with increased power source. Asterisk, Similar curves apply to krypton- and xenon-filled tungsten bulbs.

Thalamoscope with a light source consisting of a tungsten filament surrounded by either an inert (krypton, xenon) or halogen (iodine) gas. Ophthalmoscopes with weaker power sources provided inadequate illumination, as did tungsten-filament vacuum-type bulbs.

In patients with lightly pigmented choroid and pigment epithelium, Kodak Wratten filters Nos. 57 and 60 provided excellent contrast and detail in observation of the PRNFL. Both filters have a dominant wavelength at 525 nm and a maximum transmittance of 60%.

**Discussion.** Using narrow bandpass filters to examine the ocular fundus, Behrendt and Wilson\(^5\) and, later, Delori and co-workers,\(^6,7\) concluded that monochromatic photography and ophthalmoscopy require a multiple-filter system to optimally view each fundus component in any given individual. In addition, these authors found that the PRNFL was optimally visualized at wavelengths between 470 and 530 nm. However, Flower et al.\(^11\) have recently found that for wavelengths from 400 to 900 nm, at each wavelength, all structures in the fundus have spectral reflectances in a relatively narrow region. Differences in spectral reflectance therefore occur among different individuals, not among different fundus components in a single individual. Moreover, they found that in individuals with varying skin and intraocular pigmentation, the "envelopes" of spectral reflectance were quite close in the 520 to 560 nm range. We agree with Flower et al. that the use of filters transmitting in this range facilitates observation not only of the PRNFL but also of the macula, arteries, veins, and capillaries.

Hoyt and Knight\(^7\) originally produced red-free photographs by using color transparencies from which black-and-white negatives were made using a Kodak Wratten No. 65 filter. These in turn were printed on Kodak Ektomatic SC-F paper. We believe that sharper photographs can be produced using our filter system in an unmodified Zeiss fun-
dus camera with Kodak black-and-white Plus-X film. All photographs are made at 2X magnification, thereby eliminating the need for secondary magnification techniques. Finally, all observations are made from the black-and-white transparencies rather than from black-and-white prints.

Optimum observation of the ocular fundus depends on the contrast that is produced when maximum illumination is combined with an optimum filter. The tungsten-filament vacuum lamps used in most older, less powerful direct ophthalmoscopes produce uneven illumination across the visible spectrum, with significantly reduced luminance in the lower end of the spectrum (400 to 550 nm) than in the higher end (Fig. 1). For this reason, light produced by these lamps appears more yellow than true white light (sunlight), and filters that absorb light in the red spectral region cause a marked reduction in total fundus illumination, making observation of critical fundus details impossible. Since the luminance of any bulb is dependent on its color temperature, raising the color temperature of the bulb will increase its total luminance, particularly across the lower end of the visible spectrum.

Color temperature, defined as the absolute temperature of a blackbody that has the same chromaticity as that of the light source under consideration, can be raised by either increasing the voltage used to power the light source or changing the nature of the light source itself. Recently, halogen (iodine) and inert gases (krypton, xenon) have been used in the tungsten-filament ophthalmoscope bulbs, replacing the previous vacuum-type bulb. The color temperatures of these bulbs are significantly higher than that of the vacuum bulb, resulting in an increased luminance across the entire visible spectrum, particularly in the lower end (Fig. 1). Increasing the power source of the ophthalmoscope to 4.5 V raises the color temperature of the gas-filled bulbs even higher, providing increased illumination and permitting optimum use of a monochromatic filter (Fig. 2). At present, we prefer a gas-filled (halogen or krypton) tungsten bulb in a direct ophthalmoscope with a 4.5 V power source; however, a different light source with an intrinsically higher color temperature, rather than a power boost, may ultimately provide optimum observation of the PRNFL in the future.

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Key words: peripapillary retinal nerve fiber layer, red-free, filter, photography, ophthalmoscopy

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Electroretinography with noncorneal and corneal electrodes. JULIAN FREDERICK GIL-TROW-TYLER, SYDNEY JAMES CREWS, AND NEVILLE DRAIDO.

The noncorneal ERG is essential for certain patients in which corneal recording is contraindicated. A prelimi-