Electroretinogram contact lens electrode with tri-color light-emitting diode

Satoshi Mizunoya[1,2], Kazuki Kuniyoshi[3], Mikki Arai[1], Kyoji Tahara[3] and Tatsuo Hirose[1]

Schepens Eye Research Institute[1], Department of Ophthalmology, Harvard Medical School and Schepens Retina Associates , Boston, Massachusetts, USA, Department of Ophthalmology[2], Chiba University School of Medicine, Chiba, Japan, Department of Ophthalmology[3], Kinki University School of Medicine, Osaka, Japan

ABSTRACT.
Purpose: **This study was performed to evaluate a new electroretinogram (ERG) contact lens electrode containing four light-emitting diodes (LEDs) that are used for both stimulus and background light.**
Methods: **The luminance of each LED could be changed independently and used as stimulus light. Red, blue, bright white, and flickering ERGs were recorded in 12 normal subjects and two patients with progressive cone dystrophy. The long-duration light stimuli separated the on- and off-responses of the ERG. This equipment is not according to the ISCEV standard.**
Results: **The tri-color LED electrode contact lens can efficiently produce and record ERG responses. Off-responses were recordable separately from on-responses by lengthening the stimulus duration.**
Conclusion: **This combined stimulus-electrode system is compact and portable. Combined with the portable amplifier and the recorder, the ERGs can be recorded easily in an operating room, at patients' bedsides, and in remote locations away from clinics and hospitals.**

Key words: electroretinogram – light-emitting diode – off-response – electrode.

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A light-emitting diode (LEDs) is a relatively new light source for use in ERGs (Krakau et al. 1977; Kooijman & Damhof 1981; Spileers et al. 1993). LEDs have numerous advantages over other light sources in that they are small and light, generate virtually no heat when on, have a rapid stimulus onset (0.5 µsec), remain steady without fluctuations in light intensity, are rapidly turned off (0.5 µsec). In addition, the light has a relatively narrow wavelength (monochromatic) and the luminance can be changed relatively easily. Finally, there is no clicking sound when the light is turned on and off, and therefore, no auditory evoked response is provoked when the stimulus is used to record a visual evoked response. Tahara et al. recorded a 30-Hz flicker ERG using a red LED built-in contact lens electrode (LED electrode) (Tahara et al. 1987, 1993). Horiguchi et al. (1995) recorded an ERG produced by the short-wavelength-sensitive cone system using a blue LED built-in contact lens electrode under a yellow background. Miyake et al. (1991) recorded an ERG using a LED electrode during ocular surgery.

Early disadvantages were that the light from the LED was not as bright as a xenon strobe or tungsten bulbs. The maximum intensity from the LED and the color variations provided by the LED were limited. Recent advances in technology have overcome those disadvantages of the LED. The luminance of the LED now is brighter than that previously available. In 1994, a new high-emitting blue LED became available in addition to red, orange, and green-yellow. In 1996, a high-emitting pure green LED was also developed. These LEDs are sufficiently strong to record oscillatory potentials from the normal human eye.

The present report describes a modification of the LED electrodes of Tahara that incorporates red, blue, and green LEDs into one contact lens electrode (tri-color LED electrode), and records ERGs using red, blue, bright white light with or without background light, 30-Hz flickering white light, and relatively long-duration white light stimulus to record off-responses (Seiple & Holopigian 1994; Sieving et al. 1994).

Material and Methods

A schema of the contact-lens electrode with four LEDs is shown in Fig. 1A. The LEDs incorporated in the contact lens electrode were used as a light source for both stimulus and background light. A power supply designed and built for the LED electrode controls the duration and intensity of each LED. Fig. 1B shows the contact-lens electrode.

The electrode (EL-3102, Mayo, Nagoya, Japan) is made of white acrylic resin (polymethylmethacrylate) and contains four LEDs: a blue LED (NLPB500, Nichia Chemical Industries, Tokushima, Japan), two green LEDs (NSPG500,

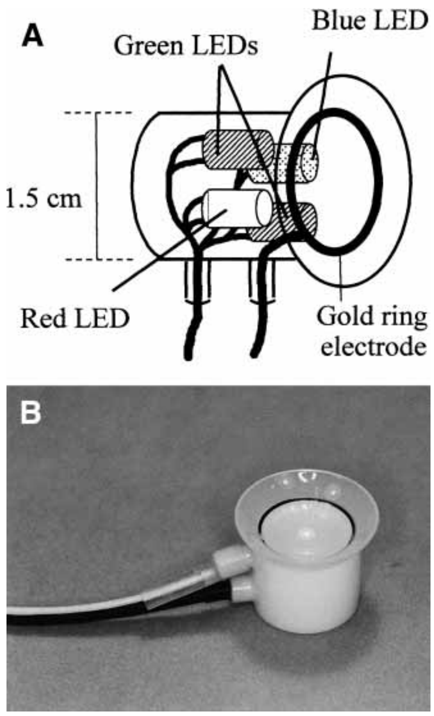

Fig. 1. (Mizunoya and associates). A, Schema of the contact-lens stimulus-recording electrode with four light-emitting diodes (LEDs). B, The contact lens electrode.

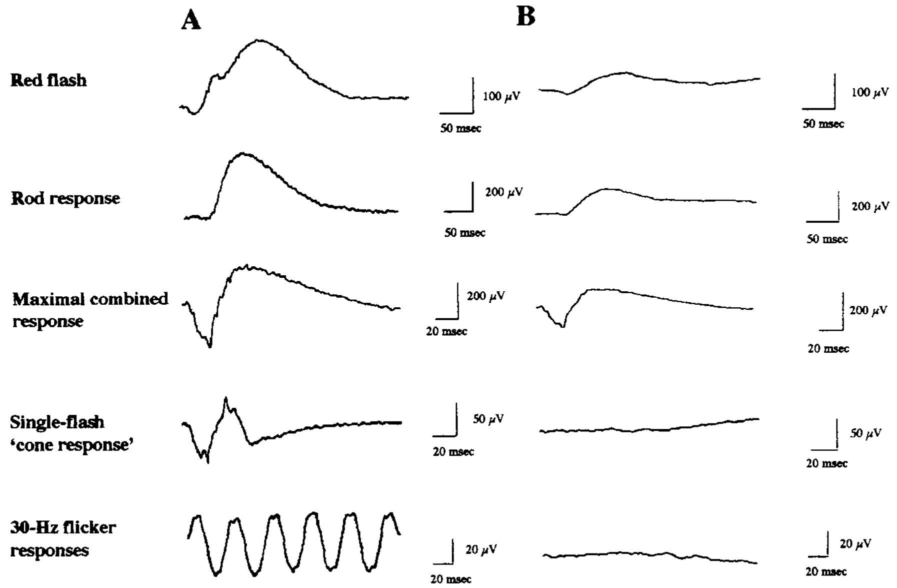

Fig. 2. (Mizunoya and associates). Electroretinograms (ERGs) recorded using a tri-color light-emitting diode electrode. A, ERG from a normal 33-year-old man. B, ERG from a 39-year-old man with progressive cone dystrophy. The ERGs were recorded using red flash, blue flash (rod response), scotopic single bright flash (maximal combined response), photopic single flash (cone response), and photopic 30-Hz flicker.

Nichia Chemical Industries), and a red LED (H-2000, Stanley, Tokyo, Japan). The peak wavelengths and half widths of each LED were, respectively, 450 and 70 nm for the blue LED, 530 and 40 nm for the green LEDs, and 660 and 25 nm for the red LED. The luminance of each LED could be changed independently, and each could be used individually as a monochromatic stimulus light or to produce white light by combining all colors. Two green LEDs are needed to provide the same luminance as a blue LED and a red LED for making white light, because a green LED is darker than a blue LED or a red LED.

The LEDs are activated by an electric power supply (LS-30H, Mayo) and an electric stimulator (Grass S-11 stimulator, Grass Instruments, Quincy, Massachusetts, U.S.A.) that controls the light intensity and duration. The luminance of each LED could be altered independently within the range of 4 log units. The LEDs could be turned on as a light source with the capability of changing the luminance continuously and alternatively using the electric power supply and an electric stimulator. Thus, it was possible to use the tri-color LED electrode not only as a stimulation light source but also as a background light source. The duration and intervals of photo-stimulation were controlled by the electric stimulator. The opalescent acrylic resin of which the contact lens was made worked as a light diffusing lens and created the diffuse full-field illumination for both stimulus and background.

The luminance of the electrode was measured on the surface of the electrode with a photometer (Minolta luminance meter 1/3-degree, Minolta Camera, Osaka, Japan) and was almost equal to the luminance measured on the corneal surface. The luminance was set at 0.17 $cd \cdot s/m^2$ in red, 0.01 $cd \cdot s/m^2$ in blue, and 3.0 $cd \cdot s/m^2$ in white on the corneal surface to record photopic b- and scotopic b-waves with red, rod response with blue, maximal combined response, single-flash 'cone response', and 30-Hz flicker responses with white light. Four LEDs were used (30 cd/m^2) for white background illumination.

The subjects' and patients' pupils were maximally dilated with 0.5% tropicamide and 2.5% phenylephrine hydrochloride for all ERG recordings. After inducing anesthesia with one drop of 0.4% oxybuprocaine hydrochloride, the tri-color LED electrode was placed on the cornea. A reference electrode was placed on the cheek and a ground electrode was placed on the earlobe. ERGs were recorded from 12 normal subjects (age range, 23 to 61 years) and two patients with cone dysfunction syndrome. We recorded ERGs with red flash, blue flash (rod response), and white flash light (maximal combined response) after 30 min of dark adaptation. All participants then underwent 10 min of light adaptation. The ERG then was recorded for single-flash 'cone response', 30-Hz flicker responses, and off-responses with white light. The luminance of the stimulus and background light provided by the tri-color LED electrode was determined to be compared with the standards of the ISCEV for ERG recordings (Marmor & Zrenner 1999). Stimulus durations were 5 msec for red, blue flash (rod response), single bright and white flash (maximal combined response, single-flash 'cone response'), and 30-Hz flicker responses. A long-duration light stimulus then separated the on- and off-responses of the ERG using longer stimulation. The ERG with a long-duration light stimulus from 10 to 200 msec was recorded using a 750 cd/m^2 stimulus light with a 30 cd/m^2 background light. ERG responses were amplified by an evoked potential measuring system (Neuropack Sigma MEB-5508, Nihon Kohden, Tokyo, Japan) with a band-pass filter of 0.2 to 500 Hz. In dim red and rod response ERG recordings, three to five responses were averaged. When recording the 30-Hz flicker responses and off-responses, 10 responses were averaged. Recordings of the maxi-

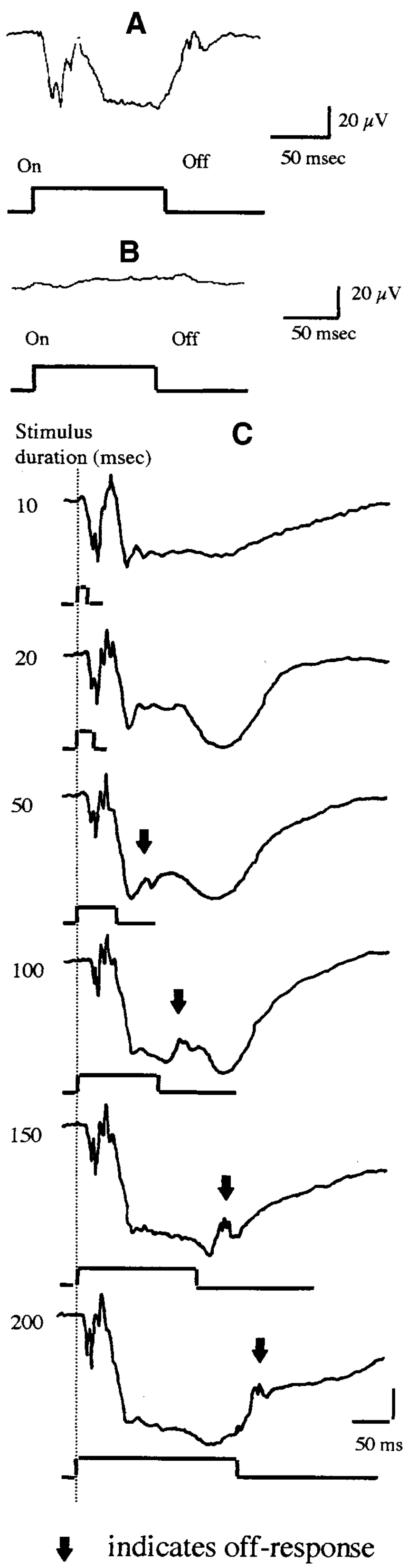

Fig. 3. (Mizunoya and associates). A, On- and off-responses from a normal 34-year-old man. B, On- and off-responses from a 39-year-old man with progressive cone dystrophy. The electroretinograms were recorded using a 100-msec stimulus duration. Both off-responses and on-responses from the patient with progressive cone dystrophy were recordable but much smaller. C, Off-responses from a normal subject (35-year-old male) recorded with stimuli ranging from 10 to 200 msec. The off-responses were recordable with an increase in stimulus duration. The off-responses were recorded separately from the on-responses (b-wave) with a stimulus duration of more than 50 msec. All responses were recorded with 750 cd/m^2 stimulus light and a 30 cd/m^2 background light.

Table 1. Electroretinogram range of amplitudes and peak times from normal subjects

	Amplitude (μV) range (mean±SD)	Peak time (msec) range (mean±SD)
Photopic b-wave	75–133 (111±20)	53.6–59.2 (56.6±2.2)
Scotopic b-wave	230–485 (350±103)	103.2–123.6 (110.0±6.7)
Scotopic single bright flash ERG (maximal combined response)		
a-wave	250–348 (304±39)	21.0–23.6 (22.8±0.8)
b-wave	423–715 (550±108)	48.4–65.6 (57.5±7.5)
Photopic single flash ERG (cone response)		
a-wave	55–80 (62±8)	21.0–22.4 (21.6±0.5)
b-wave	104–238 (155±48)	29.0–31.8 (30.6±0.8)
30-Hz flicker responses	31–70 (54±14)	29.2–32.0 (30.9±0.9)

ERG, electroretinogram.
SD, standard deviation.

mal combined response and single-flash 'cone response' were not averaged.

Before the ERGs were recorded, informed consent was obtained from all participants. The research was conducted in accordance with institutional guidelines and the tenets of the Declaration of Helsinki.

Results

Fig. 2A shows the ERGs of a normal subject recorded using red, blue, and bright white stimuli. The range of amplitudes and peak times of the a- and b-waves of each ERG from normal subjects are shown in Table 1. Obvious variations in values were observed, particularly amplitudes, partly because of the different ages of each subject. Fig. 2B shows the ERG of a patient with progressive cone dystrophy. No photopic b-wave was recordable, but the scotopic b-wave was well preserved. The maximal combined response showed reduced a- and b-waves with no oscillatory potentials. The single-flash 'cone response' under light adaptation and 30-Hz flicker responses were non-recordable.

The ERGs recorded with long-duration white light stimuli produced detectable off-responses. Fig. 3 shows the typical on- and off-responses from a normal subject and a patient with progressive cone dystrophy. The off-response was recorded using a 100-msec stimulus duration with 750 cd/m^2 stimulus light and a 30 cd/m^2 background light. Off-responses from the patient were at noise level responses as well as on-responses.

Fig. 3C shows the off-responses from a normal subject recorded with stimuli ranging from 10 to 200 msec, using 750 cd/m^2 stimulus light and a 30 cd/m^2 background light. The off-responses were recognized as a separate response with an increase in stimulus duration longer than 50 msec.

Discussion

The tri-color LED electrode can provide various colors as both stimulus and background light. The stimulus color was easily changed using a switch on the electric power supply for LEDs. The white acrylic resin of which the electrode was made mixed the light from four LEDs and provided diffuse and homogeneous illumination. The luminance of the stimulus and background light provided by this electrode resemble some components of the standard ERG recommended by ISCEV (Marmor & Zrenner 1999). But this equipment is not according to the ISCEV standard (Marmor & Zrenner 1999) where the red stimulus is not included for rod responses, and the white light from four LEDs may not be sufficient with the standard flash of ISCEV. Though we would emphasize the advantage of LED electrode. We think the red stimulus is very important because cone mediated responses are isolated from rod mediated response as a double hump (Adrian 1945, 1946). We recognize these responses are very important.

One advantage of the LED over more conventional and more commonly used xenon strobe light is its long-duration light stimuli. Because of the short duration, the stroboscopic flash does not isolate the off-response. The light from the LEDs has a perfect rectangular-shaped stimulation, so that the LED is ideal as a light source for recording the off-response. Although the clinical importance of the off-response has not been established, except for rare and unusual retinal diseases (Miyake et al. 1987), further study of the off-response in human ERGs may widen its application.

One disadvantage of this system is the lack of a fixation point for patient use during the recordings. The subjects and patients were instructed to look straight at a visually empty space with the contact lens electrode in place on the cornea. The subjects' eyes occasionally wandered, which resulted in base-line fluctuate in the recording. This drawback was partly corrected by increased concentration of the subjects during the recording. And one more disadvantage of this method is its lack of ability to carry out hemi-field or more localized stimulations. This is a drawback from the conventional stimulation techniques.

Finally, the electrode requires less storage space. Combined with the portable amplifier and the recorder, the ERG can be recorded in an operating room, at patients' bedsides, and in remote locations away from clinics and hospitals.

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Correspondence:
Satoshi Mizunoya, M.D.
Department of Ophthalmology
Chiba University School of Medicine
Inohana 1–8–1, Chuo-ku
Chiba 260–8670
Japan
Phone: +81 43 222 7171
fax: +81 43 224 4162
e-mail: s-miz@jg7.so-net.ne.jp