Retinal function in high refractive error assessed electroretinographically

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SUMMARY The retinal function of patients with high refractive error was studied electroretinographically. Thirty-one hypermetropic patients, 7 myopic patients, and 7 patients with either unilateral or bilateral aphakia participated in the study. The ERG responses were measured in the light- and dark-adapted states. It was found that myopic eyes were characterised by subnormal amplitude but normal pattern, expressed by normal relationship between the b-wave amplitude and the a-wave amplitude. In aphakia the ERG responses were of normal amplitude and pattern. However, the hypermetropic patients could be divided into 3 groups. One group included subjects with a subnormal b-wave to a-wave relationship. The second group was characterised by a normal b- to a-wave relationship, while patients belonging to the third group exhibited supernormal b-wave to a-wave relationship. This classification of hypermetropic subjects did not correlate with the axial length of the eye or the refraction of the ocular media.

The electrical response of the eye (ERG) to a flash of light is commonly used to evaluate the functional integrity of the retina.^{1,2} The a wave of the electroretinogram reflects light absorption by the photoreceptors and their functional integrity.²⁻⁵ The b wave is generated in the proximal retina,²⁻⁵ and therefore its amplitude depends on that of the a wave and on signal transmission in the retina.⁶ Thus the relationship between the b-wave amplitude and that of the a wave depends on the functional integrity of the retina. Any extraretinal parameter, such as opacities in the ocular media, resistance of ocular and extraocular tissues, or resistance between the recording electrodes, may affect the size of the electroretinogram but not the b-wave to a-wave relationship. Therefore the b-wave to a-wave relationship may serve as a useful index for the assessment of retinal function.⁶

It has been previously reported that the amplitude of the b wave was proportional to the refraction of the eye, being smallest for high myopia and largest for hypermetropia.⁷ An inverse relationship was found between the b wave and the axial length of the eye, which was attributed to the increase in the ocular

resistance to electric current due to larger eyeball.⁷ Thus the low values of b potential recorded from myopic eyes were attributed to higher ocular resistance⁷ and not to degeneration due to stretching and thinning of the retina, which was implicated in other studies.⁸ In a preliminary study the electroretinogram was measured in patients with high hypermetropia.⁹ The patients were divided into 3 groups according to the relationship between the b-wave amplitude and that of the a wave.⁹

In this report retinal function was assessed electroretinographically in patients with high hypermetropia, high myopia, and aphakia. All myopic eyes had subnormal ERG response, but normal pattern indicating normal signal transmission in the retina. Aphakic eyes had ERG of normal amplitude and pattern, while hypermetropic eyes could be classified as having either normal or abnormal signal transmission from the photoreceptors to the proximal retina.

Materials and methods

Subjects. Forty-five patients with high refractive error served in this study. They were divided into 3 groups: one group consisted of 31 patients with hypermetropia (larger than +5 D); the second group consisted of 7 patients with high myopia (larger than -6

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D), while the third group included 7 patients with at least one aphakic eye due to cataract extraction. Most of the hypermetropic patients were youngsters age 7 to 25 years. The myopic and aphakic patients were older (15 to 50 years). Some of the subjects ($n=30$) had corrected visual acuity 6/12 or better, while others ($n=15$) had corrected visual acuity worse than 6/12, as measured by a Snellen chart. None of the hypermetropic and aphakic patients complained of poor night vision, while some of the myopic patients did complain of difficulties in the dark. They all had normal visual fields, and ophthalmoscopic examination revealed no retinal abnormalities except myopic crescents in eyes with high myopia.

Twenty-six volunteers with normal or normally corrected vision and normal night vision served as controls.

Electroretinography. The apparatus and procedure for recording the ERG responses have been previously described in detail.^{6,10} Light stimuli originated from an electronic camera flash. The intensity of the test flash was controlled by 'neutral'-density filters interposed in the light path. The ERG was recorded between a contact-lens electrode (Henkes type, Medical Workshop) placed on the cornea and an indifferent electrode made of silver cup attached to the forehead above the eye. The ground electrode

was attached to the right earlobe. The contact-lens electrode used had an additional -100 D lens to disperse the light reaching it, and thus full-field illumination was achieved. The ERG signal was amplified (Grass, P511 AC preamplifier), displayed on an oscilloscope (Tektronix 5103N), and photographed for later analysis. The subject's eyes were maximally dilated by 0.5% cyclopentolate hydrochloride and 2.5% phenylephrine hydrochloride. The ERG responses were first recorded in the light-adapted state. The patient was then allowed to dark-adapt for 25 minutes. Finally, the ERG responses evoked by stimuli of different intensities were recorded in the dark-adapted state.

Data analysis included: (1) measurements of amplitude and implicit time of the b wave recorded in the light-adapted state to determine the integrity of the cone system; (2) measurements of amplitude and implicit time of the b wave evoked by dim white stimulus in the dark-adapted state for the assessment of the rod system; (3) plotting the b-wave amplitude as a function of the a-wave amplitude obtained from dark-adapted ERG responses evoked by white stimuli of different intensities. This plot described signal transmission from photoreceptors to the proximal retina.⁶

Ultrasound. The axial length of the eye globe was

Fig. 1 ERG responses from a normal subject (1st column), 3 representative patients with high hypermetropia (2nd–4th columns), a myopic patient (5th column), and an aphakic one (6th column). The responses were recorded in the light- (1st row) and dark-adapted states. The stimulus intensity is given as the density of the 'neutral' filter interposed in the light path and is denoted to the left of each row of responses. The ERG was recorded from the left eye (upper frame) and right eye (lower frame) of each subject. The calibration mark has a length of 50 ms and a height of 100 μ v.

Fig. 2 The relationship between the b-wave amplitude and the a-wave amplitude for hypermetropic patients belonging to group 1 (A), group 2 (B), and group 3 (C). The data points were obtained from dark-adapted ERG responses evoked by stimuli of different intensities. Different symbols describe different patients. The 2 continuous curves represent the normal range from mean -2 SD to mean $+1$ SD.

measured with a Kretz 7200 echograph in the contact-A mode technique. Oxybuprocaine (Novesine) 0.4% was used for corneal anaesthesia and methylcellulose 1.5% for lubrication. The subject was asked to fixate a little light source in front of him while measurements of axial length were taken.

Results

Electroretinographical responses of 5 patients and one normal subject are illustrated in Fig. 1. The ERGs were evoked in the light-adapted state (1st row) and in the dark-adapted state. The intensity of

the light stimulus is given to the left of each row as the density of the 'neutral' filter interposed in the light path. All hypermetropic and aphakic patients showed a normal b-wave amplitude and implicit time in the light-adapted state, while the myopic patients were characterised by a photopic b wave of subnormal amplitude but normal implicit time. This finding indicated against a progressive retinal defect in our patients.¹¹

In the dark-adapted state the hypermetropic patients could be divided into 3 groups according to their ERG pattern. Group 1 (Fig. 1, 2nd column) was characterised by relatively large a wave and sub-

Fig. 3 The relationship between the size of the b-wave amplitude and the a-wave amplitude for myopic (A) and aphakic (B) patients. The data points show the ERG characteristics in the dark-adapted state. The 2 continuous curves describe the normal range (mean ± 2 SD).

Fig. 4 The relationship between the b-wave ratio and the axial length of the eye globe for hypermetropic patients belonging to group 1 (solid circles), group 2 (open circles), and group 3 (solid squares).

normal b wave. Group 2 (Fig. 1, 3rd column) consisted of patients with normal ERG responses, while patients in group 3 (Fig. 1, 4th column) had abnormally large b wave. All the myopic patients had dark-adapted ERG responses of subnormal amplitude, but the relationship between the b wave and the a wave was normal (Fig. 1, 5th column). Aphakic eyes gave ERG responses of normal amplitude and normal pattern (Fig. 1, 6th column). The dark-adapted ERG data of all hypermetropic patients are illustrated in Fig. 2.

Fig. 3, A and B, illustrates data obtained from the myopic and aphakic eyes respectively. Each data point in these figures describes the relationship between the b-wave amplitude and the a-wave amplitude measured from a single ERG response. The 2 continuous lines represent the normal range of the b-wave to a-wave relationship. Eleven hypermetropic patients belonging to group 1 (Fig. 2A) were characterised by a subnormal b-wave amplitude for a given a-wave amplitude. Most of the data points representing the ERG of these patients lie below the normal range. Group 2 of hypermetropic patients ($n=14$) gave a normal ERG response with regard to amplitude and pattern (Fig. 2B), while patients in group 3 ($n=6$) were characterised by a supernormal b wave for a given a wave (Fig. 2C). The dark-adapted ERG responses measured in patients with high myopia were usually subnormal in amplitude, but displayed a normal relationship between the b-wave and a-wave amplitude (Fig. 3A). Aphakic eyes showed a normal ERG (Fig. 3B).

Fig. 5 The relationship between the rod response and the axial length of the eye globe for hypermetropic patients belonging to group 1 (solid circles), group 2 (open circles), and group 3 (solid squares). The rod response was defined by the amplitude of the b wave evoked by very dim stimulus in the dark-adapted state.

Most hypermetropic patients ($n=23$) underwent ultrasound examination to determine the axial length of the eye globe. For each of these patients the b-wave ratio was computed to describe the functional integrity of the retina.⁶ The b-wave ratio was calculated as follows: the a-wave amplitude was measured and used to obtain the expected b-wave amplitude from the mean normal b-wave to a-wave relationship. The ratio between the measured b wave and the expected value described the deviation from normality. The mean of all the ratios obtained from the dark-adapted ERG responses from each eye of each patient was defined as the b-wave ratio. The mean b-wave ratio for our normal population is 1.00 ± 0.18 (2 SD).

The relationship between the b-wave ratio and the axial length of the eye globe for 46 eyes of 23 hypermetropic patients is illustrated in Fig. 4. The solid circles, open circles, and solid squares describe respectively the data from group 1, 2, and 3 hypermetropic patients. As in Fig. 4 shows no definite relationship could be found between the 2 parameters. However, the amplitude of the rod response obtained from the dark-adapted ERG response evoked by dim stimulus was inversely proportional to the axial length of the eyeball, as illustrated in Fig. 5 for group 1 (solid circles), group 2 (open circles), and group 3 (solid squares) hypermetropic patients. A similar dependency was previously observed for patients with high refractive error.⁷

Fig. 6 The relationship between the b-wave ratio and the refractive error for hypermetropic patients belonging to group 1 (solid circles), group 2 (open circles), and group 3 (solid squares), and for myopic patients (open squares).

Fig. 6 illustrates the relationship between the b-wave ratio and refractive error for group 1 (solid circles), group 2 (open circles), and group 3 (solid squares) hypermetropic patients and for myopic subjects (open squares). All myopic eyes could be described by a b-wave ratio within the normal range but close to the lower limit of the normal range. There is also a tendency in myopic eye to be characterised by a larger b-wave ratio in smaller refractive error. No definite relationship could be found between the b-wave ratio and the refractive error in hypermetropia.

Discussion

The data presented here show that in a large proportion of patients with high hypermetropia the dark-adapted ERG responses had an abnormal pattern. The amplitude of the rod response defined by the ERG evoked by very dim stimulus was inversely related to the axial length of the eye globe (Fig. 5), in agreement with previous report.⁷ This finding was attributed to the effect of the size of the eye globe on the resistance of the ocular tissue, which in turn affected the size of the ERG.⁷ A similar relationship between ERG amplitude and resistance has been recently reported for a normal population with relatively small refractive error.¹² Analysis of the dark-adapted ERG responses evoked by stimuli of different intensities revealed that hypermetropic patients could be divided into 3 distinct groups according to the b-wave to a-wave relationship. Eleven patients belonged to group 1, which was characterised by a subnormal b-wave ratio (Fig. 2A), indicating subnormal signal transmission from the photoreceptors to the proximal retina.⁶ Such ERG

pattern is reminiscent of the one found in stationary night blindness, where abnormal signal transmission was implicated as the cause of the defect.^{13 14} However, none of these patients complained of difficulties in the dark, and their rod response was slightly subnormal in contrast to the extinct rod response found in stationary night blindness.^{12 10 13} The ERG responses obtained from patients in group 2 ($n=14$) were of normal amplitude and pattern (Fig. 2C). In group 3 patients ($n=6$) the amplitudes of the b waves were larger than expected from the measured a wave (Fig. 2C), indicating stronger amplification of photoreceptor signals transmitted to the proximal retina.

The abnormal b-wave ratio found in hypermetropic patients could not be caused solely by the abnormal refraction of their ocular media. Aphakia may be regarded as high hypermetropia due solely to ocular media (lentectomy). Yet all aphakic eyes gave ERG responses of normal amplitude and pattern (Fig. 3B). The mean b-wave ratio of all aphakic eyes ($n=9$) was 1.005 ± 0.101 (SD). Therefore abnormal refraction of the ocular media could not affect, by itself, the retinal function.

High hypermetropia can result either from smaller-than-normal size of the eye globe with normal refraction of the cornea and lens or from a smaller-than-normal refractive power of the ocular media in an eye of normal size. We therefore tried to correlate the b-wave ratio with either the axial length of the eye globe (Fig. 4) or the refraction (Fig. 6). No definite correlation could be obtained; that is, the 3 groups of hypermetropic patients classified electroretinographically could not be further characterised by the refraction and/or related parameters. The mean b-

wave ratio obtained from patients with aphakia indicated that refractive error due to ocular media occurring in mature individuals did not affect retinal function. On the other hand hypermetropic patients with eye globe of normal size did have an abnormal b-wave ratio, suggesting that changes in retinal function might have occurred during the process of maturation.

In high myopia the ERG was of subnormal amplitude, in agreement with previous reports,^{7,8} but was characterised by a normal b-wave to a-wave relationship (Fig. 3A). It should be noted that the mean b-wave ratio of all myopic eyes ($n=14$) was 0.891 ± 0.057 (SD), which was close to the lower limit of the normal range. Moreover, it is evident from Fig. 6 that the b-wave ratio is inversely related to the absolute value of the refraction in myopic patients (open squares)—that is, the stronger the myopia, the smaller the b-wave ratio. These findings suggest that signal transmission in the retina of an eye with high myopia, although within the normal range, tends to be somewhat reduced, so that in high myopia the reduction in the ERG amplitude is caused by 2 separate sources. Changes in the resistance of the ocular tissue due to the larger-than-normal size of the eye globe reduce the ERG.⁷ However, there is also a reduction in the functional integrity of the retina due to retinal abnormality.

This work was supported by the Technion VPR Fund-M and the D. Starr Research Fund for Ophthalmology.

References

- 1 Armington JC. *The electroretinogram*. London: Academic Press, 1980.
- 2 Berson EL. Electrical phenomena in the retina. In: Moses RA, ed. *Adler's physiology of the eye*. St Louis: Mosby, 1981: 466–520.
- 3 Brown KT, Wisel TN. Analysis of the intraretinal electroretinogram in the intact cat eye. *J Physiol (Lond)* 1961; **153**: 257–80.
- 4 Brown KT. The electroretinogram: its components and their origin. *Vision Res* 1968; **8**: 633–77.
- 5 Rodiek RW. Components of the electroretinogram: a reappraisal. *Vision Res* 1972; **12**: 773–80.
- 6 Perlman I. The relationship between the amplitudes of the b wave and the a wave as a useful index for evaluating the electroretinogram. *Br J Ophthalmol* 1983; **67**: 443–8.
- 7 Pallin E. The influence of the axial size of the eye on the size of the recorded b-potential in the clinical single-flash electroretinogram. *Acta Ophthalmol (Kbh)* 1969; **101** (suppl): 1–57.
- 8 Prijot E, Coleman I, Marechal-Courtouns C. Electroretinography and myopia. In: François J, ed. *Fifth Symposium of the International Society for Clinical Electroneurography (ISCERG)*, Ghent, Belgium, 1966. Basel, New York: Karger, 1968: 440–3.
- 9 Meyer E, Perlman I. The electroretinogram in high hypermetropia. In: Henkind P, ed. *Strabismus II*.
- 10 Perlman I, Haim T. Visual function in a new type of night blindness. *Invest Ophthalmol Visual Sci* in press.
- 11 Hill DA, Arbel KF, Berson EL. Cone electroretinogram in congenital nyctalopia with myopia. *Am J Ophthalmol* 1974; **78**: 127–36.
- 12 Lemaigne J-M, Gagne S, Cortin P. Resistance in clinical electroretinography: its role in amplitude variability. *Can J Ophthalmol* 1982; **17**: 67–9.
- 13 Carr RE, Ripps H, Siegel IM, Weale RA. Rhodopsin and the electrical activity of the retina in congenital night blindness. *Invest Ophthalmol Visual Sci* 1966; **5**: 497–507.
- 14 Carr RE, Ripps H, Siegel IM, Weale RA. Visual function in congenital night blindness. *Invest Ophthalmol Visual Sci* 1966; **5**: 508–14.