A theoretical study of the effect of vitreous hemorrhage on the electroretinogram

Michael J. Doslak and Pei-Chen Hsu

A bioelectric field model of the electroretinogram was utilized to help determine whether the presence of blood in the vitreous could alter its electrical conductivity enough to attenuate what would have been a normal ERG. The electrical conductivities of the structures of the eye and the frequency content of the ERG were incorporated in the model. The result was that the vitreous conductivity would have to be reduced to a value below that of whole blood in order for the ERG to be significantly reduced. A reduced ERG would be due to another cause(s) and might preclude vitrectomy. According to this model, blood in the vitreous has no significant effect on conduction of the ERG to the cornea. Invest Ophthalmol Vis Sci 25:233-235, 1984

A basic postulate of electroretinography is that electric currents are generated in the retina and are transmitted via volume conduction to a recording location. The electric potential at this region, relative to a reference potential, is what is measured. Variations of the properties of the overall volume conductor can have a marked effect on the ERG signal that a normal retina would generate, as demonstrated by a model developed by Doslak et al.1,2 Their work, however, did not consider any abnormal conditions of the vitreous. When vitreous hemorrhage is present, bright-flash electroretinography3,4 is sometimes used to determine the status of the retina and what therapy should be pursued. If the amplitude of the ERG is reduced, it may be because the function of the retina is impaired. However, recent reports5,6 have disclosed a nonrecordable ERG when dense vitreous hemorrhage was present, with good visual function existing after vitrectomy. Possibly, poor light transmission prohibited adequate stimulation of the retina. Or, could the presence of blood in the vitreous have altered the electrical conductivity enough to electrically attenuate what would have been a normal ERG? In the present study, this question was approached theoretically by utilizing a bioelectric field model1,2 but extending it to account for abnormal vitreous. It was assumed that the ERG light stimulus was bright enough to stimulate a functional retina. The model focused only on how the transmission of the resulting retinal electrical activity could be altered by whole blood in the vitreous.

Materials and Methods. The basic model used (Fig. 1) has been described in detail elsewhere,1,2 including both accuracy and physiological validation investigations. The model included representations of both the active source of the ERG, the retina, and the passive volume conductor partitioned into regions corresponding to the main structures of the eye. The retina was modeled as an axially symmetric dipole (double layer) covering a little more than a hemisphere and having a spatially constant strength at an assumed frequency. The strength is arbitrary and represents the magnitude of the time-varying bioelectric source at some particular instant of time in the ERG, e.g., the peak of the b-wave. The spatial locations in the volume conductor and the retinal ERG source were represented numerically with a nodal network incorporating variable spacing between nodes and pointwise variation of the electrical conductivities corresponding to the particular eye regions. The axial symmetry of the eye was used to reduce the three-dimensional geometry effectively to a two-dimensional model. The field at any instant of time was considered to be quasi-static and Laplace's equation \( \nabla^2 \phi = 0 \) was utilized. In this manner, electrical potentials resulting from a dipole layer source of arbitrary strength were calculated for numerous (approximately 1000) locations interior and exterior to the eye.

![Fig. 1. The two-dimensional model depicting the active ERG source (double layer) and the passive volume conductor. The values of the R-membrane resistivity and capacitance parameters (RR and RC) and the conductivities of the other regions are listed in Table 1. The relative dimensions correspond to a viewing adult eye and are all drawn to scale, except the radius of the \( \sigma_7 \) region (4.9).]
Table 1. Ranges of normalized values of the parameters used in the model.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>STRUCTURE REPRESENTED</th>
<th>VALUES IN MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_1$</td>
<td>Aqueous and Vitreous</td>
<td>1-34</td>
</tr>
<tr>
<td>$\sigma_2$</td>
<td>Sclera</td>
<td>0.01-15</td>
</tr>
<tr>
<td>$\sigma_3$</td>
<td>Extraocular region</td>
<td>0.005-0.06</td>
</tr>
<tr>
<td>$\sigma_4$</td>
<td>Lens</td>
<td>0.19</td>
</tr>
<tr>
<td>$\sigma_5$</td>
<td>Cornea</td>
<td>0.44</td>
</tr>
<tr>
<td>$RR$</td>
<td>R-membrane resistivity</td>
<td>1.67-6.25</td>
</tr>
<tr>
<td>$RC$</td>
<td>(2 x R-membrane capacitance)$^{-1}$</td>
<td>43.3</td>
</tr>
<tr>
<td>$RXC$</td>
<td>Capacitive reactance</td>
<td>$RC/f$</td>
</tr>
</tbody>
</table>

Since the ERG is a time-varying signal, it has frequency components that can be described using Fourier analysis methods. In the model, the frequency of the dipole layer source was specified initially and was selected to correspond to a certain part of the ERG, e.g., the fundamental frequency of the a- or b-wave. Due to the phase-shift property of the R-membrane capacitance, complex functions were required in the model to represent the R-membrane impedance and to calculate the potentials at all locations in the model. The result was that the potentials throughout the model were characterized by both a magnitude and a phase.

The ranges of values of the parameters used in the model (Table 1) were based on data given by many investigators. Conductivity $\sigma_1$ was arbitrarily given a value of unity (representing normal vitreous) and was used as a reference to normalize all the other parameters. The use of normalized values causes no loss of generality, since the magnitude of the field is relative and depends on ratios of conductivities (from the boundary conditions) and on the source strength. Whole blood replacing the vitreous is represented by $\sigma_1 = 0.34$. Although the values listed are dimensionless, they are technically equal to $x/57 \ \Omega \cdot \text{cm}^{-1}$ for $\sigma_1$, $RR \ \Omega \cdot \text{cm}^2$, $RC \ \Omega \cdot \text{cm}^2 \cdot \text{Hz}$, and $RXC \ \Omega \cdot \text{cm}^2$.

Results. The effect of vitreous hemorrhage was investigated by varying the normalized conductivity of the vitreous ($\sigma_1$) over a range of values corresponding to different amounts of blood in the vitreous and comparing changes in the potential of the cornea relative with a remote location (Fig. 2). When a sensitivity analysis was done on the effect of other parameters ($RR$, $\sigma_2$, and $\sigma_3$), the effect of decreasing the value of $\sigma_1$ was still approximately the same as shown in Figure 2. A previous investigation showed variations of $\sigma_3$, $\sigma_5$, and $RC$ had negligible effects on the ERG potential when the vitreous was normal.

Figure 3 illustrates the variation of the potential of the cornea due to a dipole layer source of a given frequency when the vitreous is normal and also when it is replaced by whole blood. The model was used to investigate the effect of vitreous blood on fundamental frequency components of the a- and b-waves that were estimated to be approximately 37 Hz and 5 Hz, respectively. Utilizing the values of the corneal potential...
at these frequencies, the normalized amplitude ratio of the b- to a-waves was calculated to be 0.886 when the vitreous was normal and 0.894 when the vitreous was replaced by whole blood. These values were obtained by computing the normalized cornea potentials produced by a-wave and b-wave dipole layer sources of the same strengths but different source frequencies. According to the model, the b- to a-wave ratio increases a very small amount (less than 0.9%) when blood is present in the vitreous.

The accuracy of the model when the conductivity of the vitreous was abnormal was evaluated by comparing the numerical solution with an analytical solution corresponding to a simplified version of the model. The RMS error of all the calculated potentials (at all the locations in the model) ranged from 0.3% to 4.9%, depending on the high and low values of $\sigma_2$ and $\sigma_3$. The accuracy of the potential of the cornea ranged from 0.01% to 2.9%.

**Discussion.** According to the model, blood in the vitreous has no significant electrical attenuating effect on the ERG, even if the vitreous were replaced by whole blood. A significantly reduced ERG would be observed if the electrical conductivity were reduced to approximately $\frac{1}{10}$ of what it is normally. Clotted blood in the vitreous would have a low electric conductivity and, hence, could contribute to a reduced ERG. A quantitative investigation of the amount and location of quantities of clotted blood needed to significantly reduce the ERG is a future goal of the model. Certainly, if the clot is not extensive enough, shunting of current through relatively normal adjacent parts of the vitreous could prohibit reduction of the ERG.

The magnitude of the ERG is a function of the frequency of the components of the ERG source because of the capacitance property of the R-membrane. The electrical attenuation, due to blood in the vitreous, of the higher frequency components of the ERG (5.4% at 50 Hz), is slightly greater than the attenuation of the lower frequency components (4.4% at 3 Hz). It has been observed that an altered b- to a-wave ratio, when vitreous hemorrhage was present, along with other factors, was indicative of poor postoperative vision. According to the model, an altered ratio of the b- to a-waves is not due to frequency-selective electrical attenuation caused by blood in the vitreous. A reduced ERG or b- to a-wave ratio would be due to another cause(s).

The authors speculate that likely causes of a reduced ERG or an altered b- to a-wave ratio are: (1) abnormally functioning retina; (2) inadequate light stimulus reaching the retina; (3) an optical filtering effect of the blood resulting in nonlinear decreases of the a- and b-waves, and hence, an altered b- to a-wave ratio; and (4) toxic effects of blood on the retina, though unlikely.

**Fig. 3.** The effect of the ERG source frequency on the corneal potential.

**Key words:** vitreous hemorrhage, electroretinogram, bioelectric field model, electrical attenuation

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**References**