A gold foil electrode: extending the horizons for clinical electroretinography


A gold foil ERG electrode is described. The device is inexpensive and simple to fabricate. Since it is hooked over the lower lid and makes minimal touch contact with the inferior limbal area, it can be used in circumstances which require prolonged testing of retinal function or in eyes with corneal pathology. Because the optics of the eye are not compromised, it is possible, with the use of appropriate stimuli and response-averaging techniques, to record local ERGs from relatively small retinal areas.

There are many varieties of electrodes for recording the clinical electroretinogram (ERG). Most are derivatives of the original design of Riggs1 or Karpe.2 These devices consisted of modified full scleral contact lenses containing an eccentrically located wire, often a silver–silver chloride electrode, which provided electrical continuity with the cornea through tears or a saline solution. A later modification by Burian and Allen3 consisted of a spring-loaded corneal contact lens mounted on a speculum. Electrical contact was maintained by a stainless steel wire girdling the circumference of the contact lens. Although these lenses and others similar to them are adequate for most clinical purposes, there are many circumstances in which their usefulness can be limited, and occasionally their application to the eye is contraindicated. We wish to report on the use of a radically different type of ERG electrode made of gold foil and Mylar film, which greatly extends the range and possibilities of clinical electroretinography. Electrical contact is made only with the inferior area of the cornea, and the electrode is so light, flexible, and smooth that it scarcely stimulates nerve endings in the cornea. Therefore it can be worn comfortably for long periods of time.

Anyone with experience of clinical ERG examinations performed with conventional lenses cannot fail to be impressed by the favorable patient reaction. Indeed, it is now routinely possible to make ERG studies of dark adaptation and increment thresholds, which may take up to 2 hr. Since the optics of the eye are unaffected by the electrode, it is also an ideal way to obtain local ERGs (from the fovea, for example) which require sharp imagery and a minimum of scattered light.

Since corneal or haptic contact lenses may cause abrasions to the cornea, skin electrodes have been used to record the ERG (Tepas and Armington4). However “skin ERGs” are small and quite variable in amplitude because the eye-to-skin current pathway contains high and varying resistances. In addition, skin electrodes record artefacts due to muscular activity in the lids. This is not the case for the foil electrode, which provides ERGs very similar to those obtained by more conventional contact lens electrodes. It is possible to use the gold foil electrode on young children whose palpebral fissures are very narrow or congenitally malformed. We have, for example, used them successfully in cases of craniofacial dysostosis, where neither skin or contact lenses can be employed. Finally, it is possible, with the foil electrode, to obtain ERGs immediately following cataract or corneal surgery.

Description and development. In 1977 our attention was drawn to a Mylar foil electrode, commercially available, which, it was claimed, could be inserted in the lower fornix without anesthesia. This claim we completely confirmed, but the ERGs obtained with the electrode were unsatisfactory. In practice, we found that the records obtained were very noisy, especially at low frequencies, so that it was impossible to obtain a stable baseline. The electrode behaved, in fact, as though it had a very high resistance and a variable current source. This property persisted when the electrode was placed in saline and was present even when the indifferent and ground electrodes were placed in contact with the foil. While conducting these tests, we noticed that the aluminum coating of the Mylar was being rapidly removed from the electrode, which took on an irregular fissured appearance. The instructions for use included the warning that the resistance of the electrode should never be measured with conventional equipment. But the amplifier head stages we used were FET types, with leakage currents in the picoamp range, making it unlikely that our equipment was electrolyzing away the metal. One plausible explanation of the behavior of the electrodes was that the oxide layer on the aluminum surface was being continuously and locally damaged by the voltage gradients across it and that the exposed metal was reacting chemically with the saline. An obvious cure was to replace the aluminum by an inert metal, such as gold. When this
Fig. 1. Gold foil electrode inserted into patient's eye. The junction wire has been bent and formed so that much of the foil is in the lower fornix. The pupil is unobscured by the foil.

Table I. Comparison of results with Karpe lens and gold foil electrode

<table>
<thead>
<tr>
<th>Condition</th>
<th>a-wave amplitude (µV ± 1 S.D.)</th>
<th>b-wave amplitude (µV ± 1 S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photopic:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karpe</td>
<td>37.5 ± 6.1</td>
<td>87.5 ± 27.1</td>
</tr>
<tr>
<td>Foil</td>
<td>33.5 ± 6.4</td>
<td>72.8 ± 7.8</td>
</tr>
<tr>
<td>1 min dark-adapted:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karpe</td>
<td>67.5 ± 23.2</td>
<td>333.2 ± 83.6</td>
</tr>
<tr>
<td>Foil</td>
<td>62.8 ± 13.8</td>
<td>272.8 ± 66.5</td>
</tr>
<tr>
<td>5 min dark-adapted:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karpe</td>
<td>62.5 ± 24.9</td>
<td>356.2 ± 54.5</td>
</tr>
<tr>
<td>Foil</td>
<td>63.3 ± 18.0</td>
<td>267.7 ± 41.7</td>
</tr>
</tbody>
</table>

Results from 10 subjects, with strobe light equivalent to Grass PS 22 at intensity 2, no filters, with direct viewing.

Table II. ERG amplitudes and times to peak with foil electrode

<table>
<thead>
<tr>
<th></th>
<th>Amplitude (µV)</th>
<th>Range</th>
<th>Time to peak (msec)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-wave</td>
<td>144</td>
<td>51-237</td>
<td>19.6</td>
<td>12-27</td>
</tr>
<tr>
<td>b-wave</td>
<td>311</td>
<td>181-441</td>
<td>40.0</td>
<td>32-48</td>
</tr>
</tbody>
</table>

Results from 40 eyes; light intensity, equivalent to Grass PS 22 at position 2, in dark-adapted eye. Range is ±2 S.D.

was done, the problems described above vanished, and the electrodes performed satisfactorily.

Construction. The most recent foil electrodes are constructed with 12 µm Mylar sheet, onto which a layer of chromium and then gold has been implanted by ion bombardment. This works very well and facilitates electrode construction, but the materials may be difficult to obtain. Therefore we describe the construction of the electrodes we made first, which provided the ERGs shown in this paper. Two types of base material have been used: 1¼ inch "tape stops" (3M Corp.) and 3 inch cassette tape splices (Radio Shack). The tape stops are sold on a precut continuous roll and consist of 22.5 µm Mylar onto which a layer of aluminum coated with adhesive has been bonded. The tape stop is very similar to the aluminum foil electrode mentioned above. The cassette tape splices consist of the same thin Mylar, coated with adhesive. To make the electrode, we attach a piece of light flexible wire to one end of the adhesive-coated side of the Mylar, either 40-gauge lacquered wire or a single strand cut from a 7-strand flexible insulated cable. This wire will form the junction between the gold foil, which is stuck to the adhesive, and the input lead to the amplifier, so we usually enlarge the end with a small solder drop or by coiling it. This also helps the wire stick to the Mylar. The assembly is then touched, adhesive side down, onto a piece of goldbeater's leaf, which is very thin, pure gold sheet, obtainable from scientific sources or art suppliers. It has no mechanical strength. As the Mylar approaches the gold leaf, the charge on the plastic attracts the gold, which then adheres as a uniform smooth film to the adhesive and makes an electrical junction with the fine wire. Gold leaf may be bought in the form of booklets, each containing 20 squares, 2 by 2 inches, so that one booklet makes many electrodes. Gold may also be bought already applied to Mylar, for use in bookbinding. This material has not proved suitable for electrodes because the gold is electrically discontinuous.

The electrode now has to be shaped to fit the eye. The tip of the foil must be bent into a hook, with the gold surface convex. This can be done with pressure, using the edge of a card, or by gentle warming of the under (Mylar) surface, e.g., by holding a miniature soldering iron under the foil.

The junction wire is soldered onto any suitable lead. To place the electrode in position in the subject or patient's eye, the lead is taped to the patient's face, and the junction wire bent in any suitable curve so that the Mylar will seat in the lower fornix. The lower lid is pulled down, and the Mylar thrust as far as possible into the fornix, gold side up. The bend at the electrode tip helps to keep the electrode in position and ensure that it will not be "blinked out." The same function is fulfilled by the bent junction wire. Shaping this bend and placing
Fig. 2. A, Single-flash ERGs obtained from 9 "normal" patients, illustrating low intersubject variability. The stimulus was a 25° white flash (intensity setting × 2, Grass PS-22). Records obtained from dark-adapted eyes. B, Variation of ERG waveform with increase in stimulus intensity on Grass. Each response is the computer-summated average of four repetitions.

Fig. 3. ERG dark-adaptation curve obtained on patient with fundus albipunctata, a rare form of congenital stationary nightblindness. The stimulus was attenuated by neutral filters, and voltage-intensity curves were constructed at many intervals during adaptation. From these curves ERG thresholds with a 20 µV criterion were determined (solid dots). Inset traces show development of ERG waveforms (photopic and scotopic) elicited during the lengthy return to sensitivity following exposure to an intense bleaching light.

the electrode so that it does not touch the lower lashes is a skill that has to be learnt. The exact bend depends upon the depth and shape of the lower fornix and the shape of the subject’s cheekbone. The junction wire should be in the air and thus does not require insulation. Fig. 1 shows the electrode in place in a patient’s eye.

The patient can initially feel the electrode, but the sensation should not be one of pain, and tearing or excess blinking should not occur. In practice, we usually use a drop of corneal anesthetic before inserting the electrode into patients’ eyes. This is not absolutely necessary, but it avoids waiting while the patient becomes accustomed to the
Although the acuity recorded for the right eye is similar for both patients, the mother's ERG amplitudes are much smaller (note the difference in voltage calibration). The large vitelliform lesion in the left eye of the young propositus is intact and does not markedly reduce acuity or ERG amplitude. The mother's left macula shows typical postvitelliruptive changes responsible for the acuity loss and localized decrease of electrical activity.

Bacteriological tests show that the electrodes can be cleaned and sterilized in 70% alcohol and then stored dry. Before use, they are washed in saline.

**Results.** We have used foil electrodes routinely on about 700 patients over 1 year. With only two exceptions, every patient has been able to tolerate the foil. Many patients have worn the electrodes for periods over 1 hr. The youngest child tested was 6 years of age, and we have been able to obtain local ERGs from the fovea of an 8-year-old with Best's disease (see Fig. 4). In experimental work, the authors have worn the electrodes for several hours at a time on consecutive days without any irritation or reddening of the eye. We present the data below to substantiate our claims and also to give normative values. We believe that this will provide to other clinics who wish to use the new technique, some guidelines for establishing their own limits of normal.

Table 1 shows the results of a series of 10 patients in whom the ERGs were normal and were recorded consecutively with the foil electrode and a standard Karpe lens. It can be seen that the amplitudes and times to peak of the ERG components were nearly the same for the two lenses under photopic and scotopic conditions. We believe that the Karpe lens gives slightly larger b-waves, probably because of greater light scatter.
Fig. 5. Local ERGs produced by a reversing checkerboard of about 60% contrast. The stimulus was a TV display subtending about 12° by 12° at the eye with the patterns as indicated. Subject is required to fixate the center of the TV screen. A, Half-screen black and white alternation; pattern reverses every 200 msec. Vertical or horizontal pattern alternation produced the same ERG. The deflection at the end of the trace is the response to the next stimulus and is omitted in remaining records. B, Two consecutive records obtained in response to 46 min squares. C, Response absent or greatly reduced when 6 min squares used. D, Small or absent responses when a large central portion (10°) of the field is occluded or blanked out. E, Responses are approximately half size when a smaller area (5°) of the checkerboard pattern is removed. F, Reduction of stimulus contrast to 20% results in reduced ERG amplitude. G, Repeat of B, 1 hr later, to show consistency of response.

The gold foil electrode records a b-wave (to a standard flash of light) with more pronounced high-frequency components than has usually been described (Fig. 2, A). This may be due to the fact that the "local ERG" components are more prominent. Table I also shows that the variability of response was rather less with the foil than with the Karpe lens. It is our impression that the voltages recorded for either the foil or Karpe electrode in Table I are smaller than obtainable with a Burian-Allen lens. Table II gives the result of an extended series and includes limits of the normal. Fig. 2 shows the variation in response waveform obtained as the stimulus intensity is changed (using a photic stimulator (Grass FS 22), commonly employed in most clinics). It will be noted that we did not obtain the smoothly rising "rod" ERGs which are often illustrated. This was probably due to the presence of large "local" ERGs on the records, which can be avoided if the stimulus is delivered to a large retinal area in a homogeneous manner (Ganzfeld stimulation).

We have taken the opportunity afforded us by the foil electrode to do prolonged ERG investigations on selected patients.

ERG dark adaptometry. A patient with fundus...
albipunctata was found to have very slow recovery of sensitivity in the dark, and the ERG b-wave was recorded with the use of flashes of blue light of different intensity for almost 3 hr. Single-flash responses were measured, and amplitude vs. intensity functions, with single flashes constructed at various times after the end of the light adaptation. With a b-wave criterion amplitude of 20 μV, the dark adaptation curve of Fig. 3 was developed. Apart from the fact that in this condition the b-wave accurately reflects psychophysical dark adaptometry, the result is of interest in showing the stability of recording possible with the foil electrode. If the amplitude of the response had changed with small motions of the foil, the result shown in the figure could not have been obtained.

**Local ERGs.** Because the foil does not interfere with the optics of the eye, it is possible, with appropriate stimulus conditions, to obtain local ERGs. Fig. 4 shows records from mother and propositus daughter (8 years of age) with unilateral Best's disease. In the left eye, the mother had a large scar, with vision 20/200; in the right eye, the cyst was in the process of breaking down, with vision reduced to 20/50. The focal ERG was elicited with a 6° red target. It was absent in the eye with the scar and reduced in the eye where the macula was undergoing degenerative changes. The daughter had an intact cyst in the left eye; the local ERG of that eye was slightly reduced but not significantly different from the right eye which showed less macular change. Note that the ERG, conventionally obtained, is normal in Best's disease.

Fig. 5 shows the ERGs obtained by pattern-reversing checkerboards of various configurations. The patterns were generated on a TV set and were similar to the ones used in the visual evoked response (VER) for testing visual cortical function. It can be seen that when the screen was divided into two halves, the ERG was easily elicited, even though the total flux entering the eye remained constant when the pattern reversed. A pattern of 46 min squares elicited the same response (Fig. 5 B), but small (6 min) squares were ineffective (Fig. 5, C). High contrast (about 90%) is required to obtain such responses. Note that in Fig. 5, D and E, the response decrement was associated with central loss of the ERG as well as a decrease in the total retinal area stimulated. It seems likely from the result that the central 4° of retina gives proportionately larger ERGs than do comparable areas of peripheral retina (see Armington), but no quantitative experiments were performed to confirm this point.

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**REFERENCES**


**Vision threshold profiles in X-linked retinitis pigmentosa.** Robert W. Massof and Daniel Finkelstein.

Absolute thresholds for blue-green and red stimuli were measured along the horizontal and vertical meridians in two patients with X-linked retinitis pigmentosa. From these data, we deduced that cones mediate detection of both stimuli in the central 10°, there is a ring scotoma in the mid-periphery, and in the far periphery rods mediate...