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Comparisons of contact lens, foil, fiber and skin electrodes for patterns electroretinograms

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Abstract. Pattern electroretinograms are small physiologic signals that require good patient cooperation and long recording times, particularly when conditions are not optimal. Six electrodes were compared to evaluate their efficacy. Pattern electroretinograms were recorded in eight healthy volunteers to high-contrast, pattern-reversal checks (40′ width) with Burian-Allen, DTL fiber, C-glide, gold foil, HK loop and skin electrodes. Raw data for 320 reversals were analyzed off-line to evaluate signal amplitude, quality, P50 and N95 peak times, artifact rate and electrical noise. Insertion time, impedance and subjective comfort were also assessed. The Burian-Allen contact lens electrode gave the largest signal and lowest impedance but was the least comfortable and had the highest artifact rate ($p < 0.01$). A skin electrode on the lower eyelid produced the smallest pattern electroretinogram with the poorest quality ($p < 0.05$). The four other electrodes were foil or fiber electrodes in contact with the tear film, conjunctiva and/or the inferior cornea. The signal from these showed only minor differences. When electrodes are compared for pattern electroretinograms recording, the foil and fiber electrodes do not differ substantially but contact lens and skin electrodes show substantial disadvantages.

Key words: contact lens electrode, electrode, fiber electrode, foil electrode, pattern electroretinogram, skin electrode

Abbreviations: ANOVA – analysis of variance; PLSD – protected least significant difference

Introduction

The pattern electroretinogram (PERG) is a small signal that provides a direct measure of the physiologic function of the inner layers of the retina [1, 2]. This signal is useful to assess and monitor a variety of conditions affecting the inner retina, including common disorders such as diabetes, optic neuritis and glaucoma [3-7]. PERG recording requires good electrical contact near the anterior part of the eye and a clear retinal image. In addition, the patient must be comfortable enough to maintain good fixation on the patterned stimulus for up to 1 min per recording. Thus, the PERG is more difficult to record than other visual electrophysiologic signals, and success is limited in young children and uncooperative adults. Good reliability and repeatability require consistent and careful recording technique [8].

The expanded use of PERGs in clinical practice has led to the development of guidelines for basic pattern electroretinography [9]. These recommend recording from non–contact lens electrodes (thin conductive fibers and foils) in contact with the tear film, conjunctiva and/or the inferior cornea. These foil and fiber electrodes, when placed in the lower cul-de-sac, are relatively comfortable and do not interfere with the optical image. A good signal to noise ratio for PERG recording can be achieved in most patients by averaging 150 stimulus presentations.

Although foil and fiber electrodes can reliably record PERGs, the signal is quite small. Studies of the flash ERG have shown that contact lens electrodes record larger amplitudes than those recorded from other types of electrode, provided that a similar reference site is used [10-15]. Thus, some advantage might be expected if contact lens electrodes were used for PERG recording.

A second problem with PERG recording is artifact. To minimize eyelid and blink artifact, the electrode must be comfortable. Young children may not tolerate any electrode in contact with the ocular surface. Good-quality flash ERGs can be recorded from skin electrodes placed on the lower eyelid [16], but amplitudes are smaller than those from all other [12, 13, 15, 17, 18]. PERGs recorded from skin electrodes are smaller in amplitude than those recorded from other electrodes [19]. Thus, it is not clear whether acceptable PERGs can be consistently recorded in this way.

For a clinician, the electrode chosen for PERG recording should be the most efficient—specifically, the electrode that gives the best-quality signal in the shortest recording time. An electrode that records a larger amplitude does not necessarily give a better signal to noise ratio. Prager et al. [20] found significantly larger PERG amplitudes with gold foil electrodes compared with DTL fiber electrodes, but signal to noise ratios were not significantly different.

PERGs from six different commercially available electrodes were compared to identify those with the greatest efficiency. These included a contact lens electrode, a carbon fiber, a silver impregnated fiber, a gold-coated Mylar foil, a silver wire loop and an electroencephatography-type skin electrode. Electrodes were compared on the basis of comfort and efficiency, signal amplitude, peak latencies and signal quality after a fixed recording time.

Subjects and methods

PERGs were recorded from eight adults (aged 31 to 51 years) who were recruited from among the staff and family members of the Eye Department of Childrens Hospital Los Angeles. Subjects were free of ocular disorders and had corrected visual acuity ranging from 6/7.5 to 6/4.8 at the testing distance of 75 cm. This study was approved by the hospital's human subjects conimittee, and each subject gave informed consent.

PERGs were recorded under identical conditions from each of six electrodes. The eye tested and order of testing were assigned randomly. The stimulus, a high-contrast checkerboard reversing 2.03 times per second, was presented on a large high-resolution screen. Checks subtended 40′ at the test distance of 75 cm, and the field size was 28.1° × 21.8°. Signals were amplified 50,000 times. Raw data for 320 pattern reversals was digitized and stored for off-line processing on a Neuroscan evoked potential system (Neuroscientific, Herondon, PA, USA).

The electrodes used were as follows: (1) a contact lens electrode, the Burian-Allen bipolar [21, 22]. (2) a carbon fiber, the C-glide electrode [23], (3) a silver impregnated fiber electrode, the DTL fiber [24], (4) a gold-coated Mylar foil, the gold foil electrode [25], (5) a silver wire loop electrode, HK-loop [12] and (6) a silver/silver chloride skin electrode attached to the lower eyelid with conductive paste and tape [26]. Figure 1 illustrates the six electrodes used. Foil and fiber electrodes were referenced to a skin electrode near the ipsilateral outer canthus. The bipolar Burian-Allen electrode was referenced to its lid speculum, and the skin electrode was referenced to the ipsilateral mastoid. A skin electrode on the forehead served as the ground. All electrodes were sterilized with 70% isopropyl alcohol and air dried except the single-use, disposable C-glide electrode.

The visual evoked potential (VEP) was recorded simultaneously from a scalp electrode at O_z to confirm good fixation and to compare VEP signal quality with the PERGs. Subjects wore their habitual refractive correction, if necessary, for recordings with foil, fiber and skin electrodes. With the Burian-Allen contact lens electrode in place, refraction was checked by retinoscopy and a suitable trial lens was used to obtain visual acuity of 6/7.5 or better at the testing distance.

Electrodes were tested in random order and randomly assigned to the left or right eyes. To limit the recording time, two different electrodes were generally tested simultaneously in the left and right eyes. Some contamination from the contra lateral eye is possible when PERGs are recorded binocularly, but this is minor when both eyes are normal [27, 28]. In any case, the effect of the contralateral eye would be similar for all electrodes. The Burian-Allen

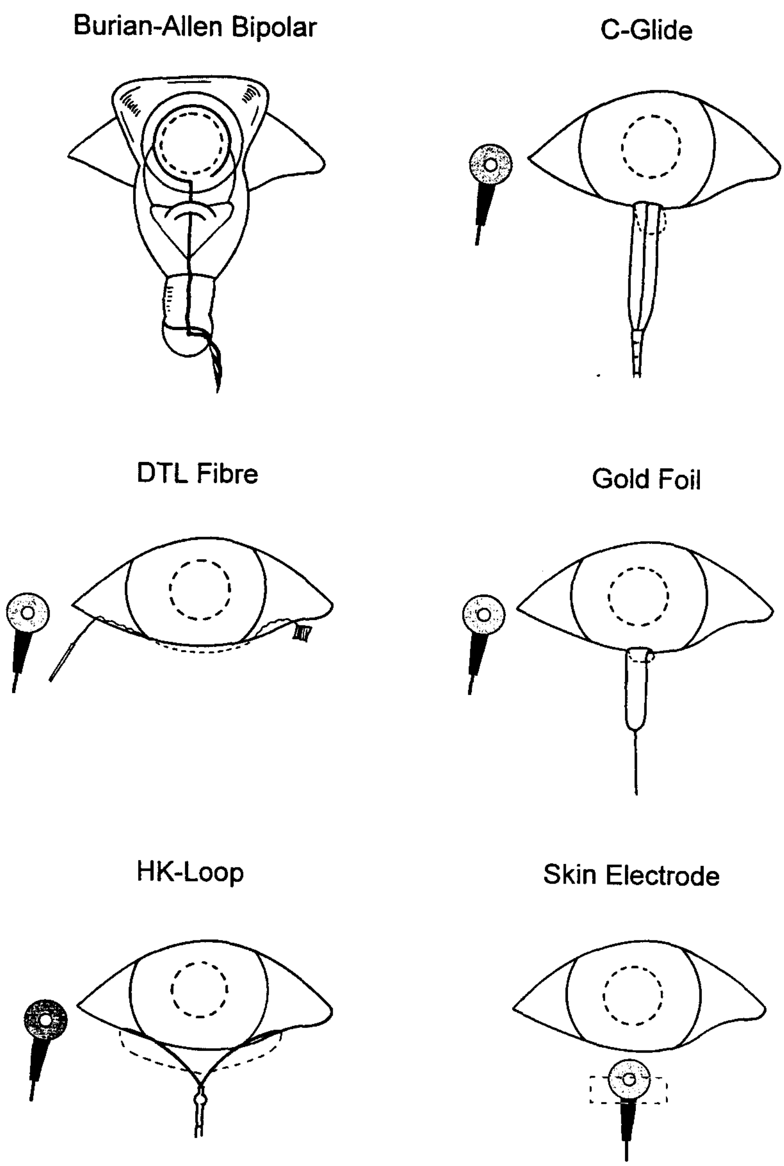

Figure 1. The six types of electrode used to record PERGs, with the reference electrode at the ipsilateral outer canthus shown for the foil and fiber electrodes. Note that the DTL fiber is placed in the lower palpebral sac [15, 20, 35]. Gold foil and C-glide electrodes were placed slightly higher than illustrated to clear the eye lashes with the upper curve at approximately the lower margin of the pupil.

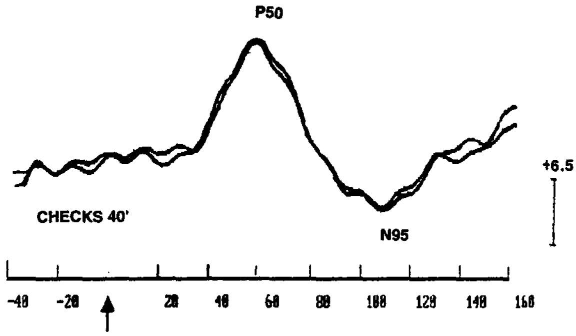

Figure 2. A PERG to reversing checkerboards is shown after signal processing (check width, 40′). The two averages produced from the raw data are overlaid to show reproducibility. The reversal occurred at time zero, indicated by the arrow, and the P50 and N95 peaks are labeled. These averages, recorded with the C-Glide electrode, are made up of 135 epochs each (acceptance rate, 84.7%).

electrode (with lid speculum) was used alone, without another electrode in the opposite eye, as it was felt that the speculum may affect the blink rate and contaminate results for any other electrode tested simultaneously. Similarly, other electrodes were tested singly whenever a subject reported discomfort. Subjects were given one drop of topical anesthetic (proparacaine 0.5%) before insertion of the first electrode. The drops were reinstalled once during the recording session to avoid recovery of corneal sensitivity. After recording from all six electrodes, each subject was asked to rank the electrodes from most comfortable to least comfortable.

The electrodes were inserted by one of us (D.L.M. or G.B.V.B.) Each of these authors had at least 10 years of experience in handling ERG electrodes in clinical and research settings and had routinely used Burian-Allen and skin electrodes. Both had previous experience using gold foil and DTL electrodes but had limited or no exposure to the C-Glide and HK loop electrodes. After some practice, both examiners were thought competent to place all electrodes correctly. The time taken to insert each electrode was recorded. If electrodes became displaced, requiring reinsertion, this was also noted. Electrode impedance was measured with a Grass PS2 impedance meter.

For each subject, the raw data for each electrode consisted of 320 epochs of 200 ms after each pattern reversal. Noise, blink artifacts and shifts in the baseline associated with eye movements were retained in the raw data. Before other signal processing, the amplitude of the 60-Hz electrical noise component was measured from the fast Fourier transform of the raw data. To make optimal use of the data, the raw signals were then digitally filtered with a bandpass of 1 to 50 Hz. Next, each epoch was adjusted so that the mean value was zero (baseline correction routine, Neurosoft Inc.) and so that the mean slope was also zero (linear detrend, Neurosoft Inc.). After this processing, epochs still containing artifacts greater than $\pm 100\ \mu V$ were rejected and the acceptance rate was noted. For a within session comparison of the PERG quality, two separate average PERGs were produced, using half of the retained epochs for each average. A typical PERG is illustrated in Figure 2. The intraclass correlation statistic (Neurosoft Inc.) was used to objectively measure the related variability of the two PERG averages, his statistic ranges from 0 for dissimilar signals to 1 for identical signals.[1] Quality was also rated subjectively as excellent, good, fair or poor by observation of the superimposed averages. Finally, a grand average of the PERG was produced from the two averages. The amplitude and peak times for the P50 and N95 were recorded from the grand average. The six electrodes were compared by means of a separate one-way repeated measures analysis of variance (ANOVA) (subject versus electrode as repeated measure) for each measure of the efficiency, quality, amplitude and peak time.

Results

Efficiency and comfort

An important measure of recording efficiency is the proportion of sweeps that do not contain artifact (acceptance rate). In clinical situations, a test would continue until sufficient sweeps are accepted so that recordings with more artifacts would take longer. To test efficiency, we recorded a fixed number of sweeps of raw data. Mean acceptance rates for all subjects ranged from 36.4% (±19.5%) for the Burian-Allen electrode to 83.4% (±15.3%) for the skin electrode (Table 1). Differences among electrodes were found to be highly significant (repeated measures ANOVA, $F = 10.3$, $p < 0.0001$). Subjects did not differ significantly ($F = 1.2$, $p < 0.3$). Post hoc testing demonstrated that the Burian-Allen electrode had a significantly poorer acceptance rate than all other electrodes ($p < 0.01$), Fisher's protected least significant difference [PLSD] [29]) and that differences among the other electrodes were not significant.

Comfort was ranked from best to worst by all eight subjects. There was considerable variation in individual comfort ratings, but seven of eight subjects reported that the Burian-Allen electrode was the least comfortable. The DTL fiber and skin electrodes were chosen most frequently as most the comfortable. Differences in comfort ranking are highly significant (Friedman χ

[1] The intraclass statistic is similar to the omega-squared statistic found in analysis of variance and is sensitive to both wave shape and absolute voltage.

Table 1. Comparison of electrodes for PERGs

	Burian-Allen	C-glide	DTL fiber	Gold foil	HK loop	Skin
P50 (ms)	52.7 (±4.6)	52.8 (±4.5)	54.9 (±2.7)	55.1 (±4.5)	53.6 (±2.5)	54.7 (±4.3)
N95 (ms)	100.8 (±10.1)	100.2 (±5.5)	100.0 (±9.7)	98.2 (±10.9)	98.3 (±7.6)	100.0 (±7.9)
Amplitude (μV)	10.2 (±5.9)	8.7 (±5.9)	7.0 (±3.1)	8.1 (±3.6)	7.2 (±4.6)	5.1 (±3.2)
Quality rating (range)	good to poor	excellent to fair	excellent to fair	good to fair	excellent to fair	good to poor
Quality (intraclass)	0.648 (±0.30)	0.895 (±0.11)	0.816 (±0.29)	0.863 (±0.15)	0.781 (±0.19)	0.767 (±0.31)
Comfort ranking	4-6	2-6	1-5	1-4	1-5	1-4
Insertion time (s)	63 (±25)	82 (±50)	50 (±12)	51 (±8.3)	23 (±10)	53 (±14)
Impedance (mΩ)	3.3 (±1.4)	6.7 (±3.1)	6.6 (±2.5)	11.1 (±7.0)	9.7 (±4.1)	11.3 (±7.6)
Acceptance rate (%)	36 (±20)	77 (±15)	66 (±17)	75 (±17)	75 (±18)	83 (±15)

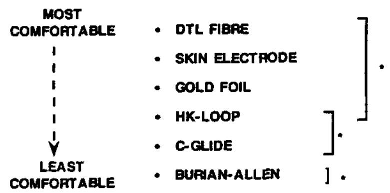

Figure 3. The six electrodes listed in order of the comfort rankings by the subjects. Brackets to the left (asterisks) indicate the electrodes with comfort rankings, which do not differ significantly (p > 0.05, Fisher's PLSD).

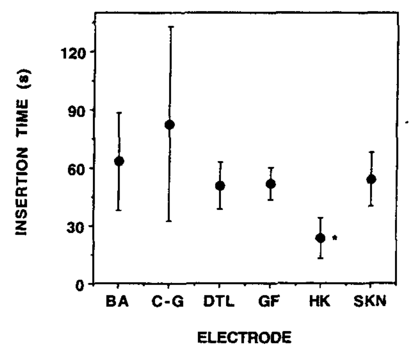

Figure 4. Insertion time for each ERG electrode is illustrated (mean±standard deviation) including the time taken for the initial insertion and securing of the electrode. The time required to measure the overrefraction for the Burian-Allen (BA) electrode after insertion is not included. HK loop was significantly faster than all other insertion times (asterisk) (p < 0.05). The C-glide (C-G) required longer than all other electrodes except the Burian-Allen electrode. GF indicates gold foil; SKN, skin.

= 21.3, p < 0.001). Figure 3 shows the electrodes listed in order of average comfort ranking for the six electrodes and indicates differences in comfort that are significant (p < 0.05, Fisher's PLSD).

All electrodes could be inserted efficiently enough for routine clinical use. Insertion, including securing the lens with tape, ranged from a mean of 23 to 83 seconds and differences were significant (repeated measures ANOVA, F = 4.6, p = 0.004). Post hoc testing demonstrated that insertion of the HK loop electrode was faster than for all other electrodes (p < 0.05, Fisher's PLSD). The C-glide electrode required longer than the other electrodes and was more variable because we had some difficulty placing it at the proper height. This might have resulted from relative lack of experience with this electrode. Other differences in insertion time were not significant. Figure 4 summarizes the mean and standard deviation for initial insertion times. Reinsertion of dislodged electrodes was necessary eight times, once each for the DTL, gold foil and HK loop, twice for the C-glide and three times for the Burian-Allen

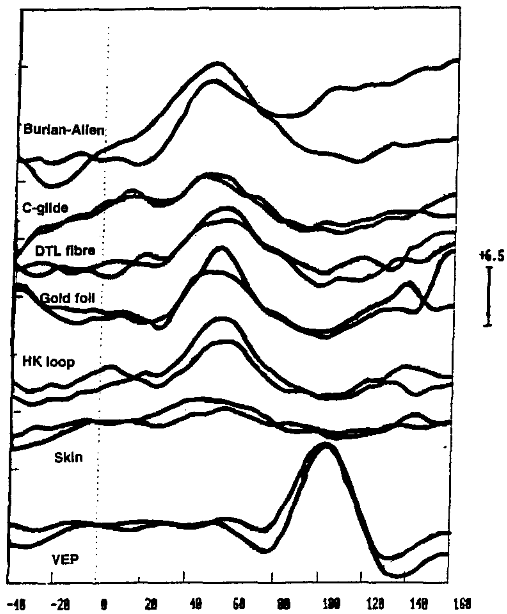

Figure 5. Typical PERGs for one subject with the use of all six electrodes. The VEP recorded simultaneously from O_z is also shown for comparison. Two averages produced after processing of the raw data are overlaid to show reproducibility. The stimulus was high-contrast pattern-reversal checks (40′ check width).

electrode. Differences in the number of reinsertions were not significant (chi squared with Yates correction, $p > 0.25$).

Impedance values (Table 1) differed significantly among electrodes (repeated measures ANOVA, $F = 6.0$, $p < 0.002$). The Burian-Allen electrode gave the lowest impedance, with a mean of 3.3 (±1.4), which was significantly lower than the impedance for gold foil, HK loop and skin electrodes ($p < 0.05$, Fisher's PLSD). Impedance for the C-glide and DTL fiber was significantly lower than for the skin and gold foil electrodes ($p < 0.05$, Fisher's PLSD). Other electrode impedances did not differ significantly from each other on post hoc testing.

Peak times, amplitudes and signal quality

For all electrodes, peak times for the P50 and N95 peaks averaged 54.0 (±3.8) ms and 99.4 (±8.3) ms, respectively. There were no significant differences among electrodes for either peak time (repeated measures ANOVA, $p > 0.05$). However, there were significant differences among subjects for both P50 and N95 (repeated measures ANOVA, $F = 3.7$, $p < 0.005$, and $F = 2.5$, $p < 0.05$

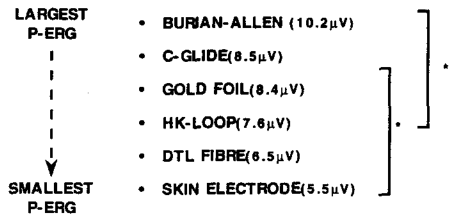

Figure 6. The six electrodes listed in order of the mean amplitude from P50 to N95 of the PERG. Brackets to the left (asterisks) indicate amplitudes, which do not differ significantly ($p > 0.05$, Fisher's PLSD).

respectively). Mean values for each electrode are summarized in Table 1, and representative PERGs for each of the six electrodes are shown for one subject in Figure 5.

The amplitude of the PERG measured from P50 to N95 was largest for the Burian-Allen electrode and smallest for the skin electrode. Figure 6 illustrates the significant differences in amplitude (main effect: repeated measures ANOVA, $F = 7.1$, $p < 0.0001$; post hoc: $p < 0.05$, Fisher's PLSD). Specifically, the Burian Allen electrode recorded larger amplitudes than the DTL fiber or skin electrodes and the C-glide recorded amplitudes significantly larger than the skin electrode only. Amplitude differences among the four foil or fiber electrodes were not significant. The 60-Hz electrical noise component did not differ in amplitude or signal to noise ratio among any of the electrodes tested (repeated measures ANOVA, $p > 0.1$).

Within-session quality, as measured by the intraclass statistic, was generally good for most PERG electrodes, with the majority (68.8%) of recordings giving intraclass values higher than 0.8, indicating good agreement between the first and second averages. However, there were significant differences among electrodes (repeated measures ANOVA, $F = 2.1$, $p < 0.05$). Post hoc testing demonstrated that the C-glide and gold foil electrodes gave significantly better intraclass values than the Burian-Allen value of 0.65 ± 0.3 ($p < 0.05$, Fisher's PLSD).

The quality of the PERG (rated as excellent, good, fair or poor) was completely unacceptable (poor) in only two recordings. One failure was caused by too much movement artifact (acceptance rate of 13.8%) when the Burian-Allen electrode was used. The other resulted from a very small signal amplitude with the skin electrode. Quality rating for the C-glide electrode was better than for either the Burian-Allen or the skin electrode but other PERG electrodes did not differ significantly (main effect: repeated-measures ANOVA, $F = 4.7$, $p < 0.001$; post hoc: Fisher's PLSD, $p < 0.05$). Individual subjects showed significant differences in PERG quality by both the rating and the intraclass statistic (repeated-measures ANOVA, $p < 0.01$). The VEP recorded simultaneously from O_z was larger and had better overall quality ratings (excellent or good for all eight subjects) and consistently higher intraclass scores (0.97±0.2) than the PERG recorded from any electrode.

Discussion

This study supports the use of foil and fiber electrodes for recording PERGs in clinical settings. Disadvantage were demonstrated for both contact lens and skin electrodes.

Contact lens electrodes are expected to record the larger signals. In fact, the bipolar Burian-Allen contact lens electrode recorded PERGs that were 1.31 times larger, on average, than those recorded from foil and fiber electrodes. This advantage was, however, greatly outweighed by the disadvantages of patient discomfort, increased artifact and the need to measure refraction through the contact lens electrode before recording the PERG. In contrast to these PERG recordings, contact lens electrodes have distinct advantages for recording flash ERGs and are recommended by the International Society for Clinical Electrophysiology of Vision as the standard [30]. For flash ERG recording, the relative advantage of contact lens electrodes increases with flash luminance and dark adaptation. Monopolar contact lens electrodes (referenced to a skin electrode rather than to the lid speculum) produce flash ERGs that are between 1.8 and 8.3 times larger those recorded from skin electrodes on the lower eyelid [11, 13, 15, 18]. Bipolar contact lens electrodes (referenced to the lid speculum), such as the Burian-Allen used in the present study, record flash ERGs that are slightly smaller than those recorded by monopolar contact lens electrodes [11, 15].

Although a skin electrode on the lower eyelid routinely gives a robust signal for flash ERG recording [16, 31], one of our eight cooperative adults produced an unrecordable signal for the PERG. Overall, the skin electrode recorded smaller signals with poorer quality than that of all other electrodes. This result is supported by Hawlina [19], who reported that PERGs from a skin electrode were about half the amplitude of those recorded with the HK loop electrode. He did not report any unsuccessful recordings with the skin electrode when he continued recording until 256 uncontaminated sweeps were collected. In the present study, recordings were stopped after 320 sweeps of raw data regardless of the artifact rate. With longer recording times, the quality of the PERG recorded from skin electrodes may be acceptable for screening or for cases where other electrodes are not tolerated. However, skin electrodes on the lower eyelid may not be reliable for PERGs in patients with attenuated responses, those with elevated noise levels or those who cannot tolerate long testing sequences.

Prager and colleagues [20] reported that the gold foil electrode recorded larger-amplitude PERG than did the DTL fiber [20]. However, the gold foil had no significant advantage in signal reproducibility. We also found larger mean amplitudes for the gold foil compared with the DTL fiber but this difference was not statistically significant in the present study. The report by Hawlina [19] that PERGs from the HK loop and from the gold foil electrodes are similar in amplitude also agrees with the present results. It is interesting that the rank order for PERG amplitude is similar to reports of electrode comparisons for flash ERGs, although absolute amplitude differences are greater for flash [11–13, 15, 17, 18].

From the present study, we find no compelling reason to recommend a particular type of foil or fiber electrode for PERGs. Some electrodes have advantages in some of the criteria assessed but, on balance, there were advantages and disadvantages of each electrode type. The C-glide electrode gave the largest amplitude, the HK loop electrode had the fastest insertion time and the DTL fiber was rated the most comfortable of this type of electrode. On important criteria including peak, latencies, electrode impedance, signal quality, amplitude of electrical noise and artifact rate, the four electrodes did not differ significantly.

Cost and convenience may be important factors in selecting PERG electrodes. Foil and fiber electrodes are either disposable, single-use or sterilizable for reuse. Reuse is limited for thin foils or fibers, so a comprehensive cost comparison would require a measurement of durability. The following comments may provide general guideline for clinicians, who are encouraged to investigate their local suppliers and assess convenience in their own laboratories. For single use, the C-glide electrode is the least expensive, followed by DTL fiber (which requires assembly in the laboratory) (Unimed Electrode Supplies, Farnham, UK). The gold foil (Unimed Electrode Supplies), HK loop (Avantia, Ljubljana, Slovinia) and DTL Plus (Retina Technologies, Scranton, PA, USA) electrodes are more expensive. However, if these are reused six to 10 times, their cost per use would be similar to the cost of the C-glide electrode. Only the gold foil an HK loop are marketed as 'sterilizable' but DTL fiber electrodes may also be sterilized [32] (Prof. W.W. Dawson, University of Florida, personal communication). Alcohol solutions or gas (ethylene chloride) are recommended for sterilization. Amplitude reduction with repeated use of gold foil electrodes has been reported [33] but this was not replicated. Arden et al. [34] found no deterioration of the PERG signal with gold foil electrodes used at least 10 times. The HK loop is more robust than the gold foil, but this electrode also requires ultrasonic cleaning to maintain clean apertures.

PERG recording can be challenging, particularly in children or in patients with diminished signals. Whenever possible, a foil or fiber electrode should be selected. The clinician's personal preference, skill and experience should guide the choice of electrode as the PERGs from these electrodes is quite similar. It may be useful to have a range of electrodes available as preferences based on comfort differ among individual patients.

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